HONORABLE GEORGE J. JORDAN
ADMINISTRATIVE LAW JUDGE

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

In re: **Proposed Waiver and Regulations Governing the Taking of Eastern North Pacific Gray Whales by the Makah Indian Tribe**	Docket No. 19-NMFS-0001 RIN: 0648-BI58 and RIN: 0648-XG584

SECOND DECLARATION OF DR. JEFFREY MOORE

I, Dr. Jeffrey Moore, declare as follows:

1. I am a research biologist with the Marine Mammal and Turtle Division (Division) of the National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC), within the National Oceanic and Atmospheric Administration (NOAA). This is the second declaration I have submitted for the above-referenced matter. I incorporate by reference paragraphs one through seven of my first declaration, filed April 5, 2019, which explain my qualifications and expertise to testify in this matter.

2. I have reviewed all of the direct testimony submitted to date through declarations by other parties to this proceeding. I have also reviewed the list of "Issues to be Addressed at the Hearing" as stated in the "Announcement of Hearing and Final Agenda Regarding Proposed Waiver and Regulations Governing the Taking of Marine Mammals," 84 Fed. Reg. 30088 (June 26, 2019), with particular focus on those issues related to the information provided in my first declaration or otherwise within my areas of expertise. I submit this declaration to respond to

certain information provided in the other parties' declarations noted above and in support of NMFS's proposed waiver and regulations. My testimony focuses on those issues related to my initial direct testimony. In addition, I provide an overview of the updated analysis Dr. Weller and I conducted based on the recently finalized 2018 Stock Assessment Report (SAR) for the Western North Pacific (WNP) gray whale stock as introduced by Dr. Bettridge. Third Bettridge Decl. ¶¶ 4, 7.

3. Mr. Schubert alleges that NMFS failed to determine whether the Pacific Coast Feeding Group (PCFG) is within OSP, and thus cannot issue an MMPA waiver. Schubert Decl. ¶¶ 40–41. But as explained by Mr. Yates, NMFS does not need to calculate OSP for the PCFG before issuing this waiver. Third Yates Decl. ¶ 8. Nevertheless, as stated in NMFS's Proposed Rule, because the PCFG appears to be a feeding aggregation and may one day warrant consideration as a stock, NMFS Ex. 2-12 at 3 (Caretta et al. 2019), NMFS did previously attempt to determine theoretical carrying capacity and optimum sustainable population (OSP) levels for the PCFG based on modifications to an existing model used by the International Whaling Commission. 84 Fed. Reg. 13604, 13607 (April 5, 2019); NMFS Ex. 4-13 (Punt and Moore 2013[1]). However, due to uncertainties in population parameters such as emigration and immigration rates, bycatch mortality, and recruitment, we were unable to do so.

4. In response to the testimony submitted, the Final Hearing Agenda asks what effect the removal of a WNP whale would have on the OSP of WNP whales. Agenda at I.B.2.c. But we do not have the data required to assess the WNP stock's status with respect to OSP. This is not unusual. We lack sufficient data to calculate OSP values for most marine mammal

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[1] Punt, A. E., and J. E. Moore. 2013. Seasonal gray whales in the Pacific Northwest: An assessment of optimum sustainable population level for the Pacific Coast feeding Group. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-518. July 2013.

stocks. OSP assessments are best informed when we have data showing that a population starts in a highly depleted state, grows at its maximum potential rate for some time, and then displays slowing growth due to density dependence (competition for resources). For a scientifically reasonable calculation, anthropogenic mortality should be negligible or quantified. Under these conditions, it can be possible to estimate the environmental carrying capacity (and thus the population size relative to this) or whether the population is above the level at which population growth is slowing down (which would indicate it is within OSP). But, rarely are these data conditions met for marine mammal stocks. For example, of the 34 stocks of large cetaceans identified to date, only the ENP gray whale stock has had a formal OSP assessment completed and referenced in its SAR. S*ee* NMFS Ex. 2-3 (Taylor et al. 2000) (for a historical review of this issue); *see also* Initial Testimony of Dr. John R. Brandon, Report, filed by the Makah Indian Tribe on May 17, 2019 at 19–21 (explaining OSP limitations).

5. Mr. Schubert also alleges that NMFS failed to disclose any information about the forecasting model used to generate PCFG abundance estimates, such as who created it, its parameters, its inherent assumptions, who will run the model, and how and where the results will be published. Schubert Decl. ¶ 90. This is incorrect. I included much of this information as part of my direct testimony. Moore Decl. ¶¶ 19–24. In addition, NMFS made much of this information available as part of Appendix 2 to its Biological Report. NMFS Ex. 1-7 at 50–52. Further, our proposed rule explained that NMFS will run the model: “These estimates allow us to employ the population forecast model . . . to assist in making more timely decisions for managing PCFG mortality.” 84 Fed. Red. 13604, 13609 (Apr. 5, 2019). Finally, the proposed regulations at § 113(a)(4)(vi) describes that the NMFS Regional Administrator will notify the tribe if the low abundance thresholds are triggered.

6. Mr. Schubert also mischaracterizes Nmin. Schubert Decl. ¶ 66. The Nmin is not simply "calculated from" the point estimate. Rather, it can vary based on the degree of confidence in the point estimate. The lower the confidence in the point estimate, the wider the error bands and the lower the Nmin will be relative to the point estimate.

7. Mr. Schubert alleges various uncertainties in the data regarding WNP whales' migration along the west coast of North America, including the number or proportion of WNP whales that make the migration annually, or their migration timing and travel speeds. Schubert Decl. ¶¶ 31–36, 92. We took the uncertainty in these values into account through the model I described in my first Declaration that estimates the likelihood that a WNP whale might be subjected to a strike, unsuccessful strike attempt, or approach. Moore Decl. ¶¶ 11–18. Because there have not been any actual sightings of WNP gray whales in the proposed hunt area and there is limited data on the likely amount of time it takes for whales to transit the proposed hunt area, we also made certain assumptions. For example, we assume that WNP whales migrating with ENP whales have the same migration characteristics (e.g., corridor, timing, travel speeds), so that a WNP whale that might travel through the Makah U&A area would have the same exposure to the hunt or hunt training as an ENP animal. *See* NMFS Ex. 1-7 at 84–89. If migrating WNP whales spend more time in the Makah U&A, then this would increase their risk of being approached, struck, or subjected to an unsuccessful strike attempt, but there is no scientific basis for believing they might do so. Because we do not know with certainty how many WNP gray whales migrate through the proposed hunt area, our analysis of the chances of Makah tribal members interacting with a WNP gray whale during hunting or training uses a range of assumptions about that number. Also, we assumed that all approaches (hunting and training) in both even and odd years occur during the winter/spring period when WNP whales may be

present. Realistically we would expect a substantial number of approaches to occur outside this period, i.e., during the summer when ocean conditions are more favorable and, in odd years, when hunting approaches are restricted to July–October. *See* first Moore Decl. ¶ 15. In these ways, we have properly considered the uncertainty regarding data on WNP whales traversing the hunt area.

8. Finally, as described by Dr. Bettridge, the Final 2018 SAR identifies the best available abundance estimate for the WNP stock of gray whales as 290 whales. Second Bettridge Decl. ¶ 7. Because this number differs from the numbers we used in our 2018 analysis, *see* Moore Decl. ¶ 14, NMFS Ex. 4-8, we updated our analysis. The updated analysis used the same methods as Moore and Weller (2018), but it uses the newer, higher abundance estimate and also a revised estimate of the mixing proportion of WNP (animals that migrate with the ENP), based on the best available scientific evidence. The new mixing estimate is approximately 60%, with a 95% confidence interval ranging from 45% to 80%. NMFS Ex. 4-14 at 6 (Cook et al. 2019[2]). This mixing estimate is more precise, and lower than the median value of the plausible range used by Moore and Weller (2018), which assumed up to 100% of WNP whales migrated with the ENP population. *See* NMFS Ex 4-15 at 3–4 (Moore and Weller 2019[3]). Results from the revised analysis are as follows. For an individual strike on a gray whale, the expected probability of it being a WNP whale is 0.005, or one half of one percent (95% Bayesian CRI:

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[2] Cooke, J.G., O. Sychenko, A.M. Burdin, D.W. Weller, A.L. Bradford, A.R. Lang, and R.L. Brownell, Jr. 2019. Population assessment update for Sakhalin gray whales. Paper SC/68A/CMP/WP/07 presented to the International Whaling Commission Scientific Committee.

[3] Moore, J.E. and D.W. Weller. 2019. Memorandum from Jeff Moore (NMFS- SWFSC) to Chris Yates (NMFS-WCR/PRD) dated July 3, 2019, with attached draft NOAA Technical Memorandum titled “Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2019.”

0.003–0.007), up slightly from 0.004 in the 2018 analysis. For a single even-year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.015, or 1.5 percent (0.009–0.022), up slightly from 0.012. Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.074, or 7.4 percent (0.045–0.104), up slightly from 0.058. I provide further details of the revised analysis and results in the attached memo and draft report. *Id*. Stated another way, the most likely point estimates indicate that 1 in 13.5 ten-year hunt periods (i.e., 1 year out of 135) would result in an individual WNP gray whale being struck by Makah hunaters, if the tribe made the maximum number of strike attempts and if ENP and WNP populations sizes and migration patterns remained constant. *Id*.

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

MOORE.JEFFREY.E.1392968578
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Date: 2019.08.05 08:02:44 -07'00'

Dr. Jeffrey Moore

Dated: 8/5/19

SECOND DECLARATION OF DR. JEFFREY MOORE
EXHIBIT LIST

4-13	Punt and Moore 2013	Punt, A. E., and J. E. Moore. 2013. Seasonal gray whales in the Pacific Northwest: An assessment of optimum sustainable population level for the Pacific Coast feeding Group. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-518. July 2013.
4-14	Cooke et al. 2019	Cooke, J.G., O. Sychenko, A.M. Burdin, D.W. Weller, A.L. Bradford, A.R. Lang, and R.L. Brownell, Jr. 2019. Population assessment update for Sakhalin gray whales. Paper SC/68A/CMP/WP/07 presented to the International Whaling Commission Scientific Committee.
4-15	Moore and Weller 2019	Moore, J.E. and D.W. Weller. 2019. Memorandum from Jeff Moore (NMFS- SWFSC) to Chris Yates (NMFS-WCR/PRD) dated July 3, 2019, with attached draft NOAA Technical Memorandum titled "Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2019."

NOAA Technical Memorandum NMFS

JULY 2013

SEASONAL GRAY WHALES IN THE PACIFIC NORTHWEST: AN ASSESSMENT OF OPTIMUM SUSTAINABLE POPULATION LEVEL FOR THE PACIFIC COAST FEEDING GROUP

André E. Punt[1]
and
Jeffrey E. Moore[2]

[1]School of Aquatic and Fishery Sciences
Box 355020
University of Washington
Seattle, WA 98195-5020

[2]Marine Mammal and Turtle Division
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
8901 La Jolla Shores Dr.
La Jolla, CA 92037, USA

NOAA-TM-NMFS-SWFSC-518

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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JULY 2013

SEASONAL GRAY WHALES IN THE PACIFIC NORTHWEST: AN ASSESSMENT OF OPTIMUM SUSTAINABLE POPULATION LEVEL FOR THE PACIFIC COAST FEEDING GROUP

André E. Punt[1]
and
Jeffrey E. Moore[2]

[1]School of Aquatic and Fishery Sciences
Box 355020
University of Washington
Seattle, WA 98195-5020

[2]Marine Mammal and Turtle Division
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
8901 La Jolla Shores Dr.
La Jolla, CA 92037, USA

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U. S. DEPARTMENT OF COMMERCE
Penny Pritzker, Secretary of Commerce
National Oceanic and Atmospheric Administration
Dr. Kathryn D. Sullivan, Acting Administrator
National Marine Fisheries Service
Samuel D. Rauch III, Assistant Administrator for Fisheries

Seasonal gray whales in the Pacific Northwest: An assessment of optimum sustainable population level for the Pacific Coast Feeding Group

Punt, André E.[1] and Moore, Jeffrey E.[2]

1 – School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA 98195-5020
2 – Marine Mammal and Turtle Division, Southwest Fisheries Science Center, NOAA, 8901 La Jolla Shores Drive, La Jolla, CA 92037

Summary

A single population stock of gray whales referred to as the eastern North Pacific (ENP) stock is presently recognized in U.S. waters (Carretta *et al.* 2013). A small group of gray whales, known as the Pacific Coast Feeding Group, or PCFG spends the summer and autumn along the Pacific coast of North America, where they overlap with the Makah Tribe's Usual and Accustomed (U&A) fishing grounds off the coast of Washington. In 2005, the Makah requested that NOAA/NMFS waive the MMPA take moratorium and adopt regulations that would authorize the tribe to hunt ENP gray whales within their U&A. As part of its review of this proposed hunt, NMFS continues to evaluate information relevant to ENP stock structure and status, including the population dynamics of the PCFG. Assessing whether the PCFG is currently at Optimum Sustainable Population (OSP) (i.e., not depleted) was the objective of the analysis described in this report[1]. The assessment is based on modifications to an existing population dynamics model used by the International Whaling Commission (IWC) to conduct projections of gray whale abundance. The model is deterministic, age- and sex-structured, and consists of two groups (the 'north' group and the PCFG), which are assumed to be separate for purposes of the analysis, but with possible immigration between them. Parameter estimation is based on Bayesian methods. Thirteen variants of the model were run (models A – M); these differed with respect to how priors were specified and the number of parameters estimated. Ultimately it was not possible to draw a definitive conclusion as to whether the PCFG is within OSP. Across all 13 model variants, the estimated probability of the PCFG being above its Maximum Net Productivity Level (*MNPL*) and hence within OSP ranged from ≈ 0.35 on the low end (models F and G) to 0.83 (model M) and 0.88 (model K) on the high end. In the latter two models (K and M), bycatch mortality[2] was fixed at zero, which is not realistic. For the remaining 11 models, the probability was ≤ 0.70, which is fairly equivocal. This stems from the PCFG abundance time series being largely uninformative regarding population rate parameters since it is relatively flat (no information about growth rate or density-dependence), apart from the short period of growth explained by an atypical pulse immigration event. Given the limited available information, the apparent stability of the PCFG population size for the past decade has several possible explanations. One explanation is that the population is at or near its carrying capacity and thus above *MNPL* and within OSP. However, it is also possible, given different potential rates of intrinsic population growth, that the PCFG area could support more whales and that current numbers are regulated by a combination of bycatch mortality and emigration that offsets immigration and internal production (recruitment of calves born to known PCFG females). Obtaining better empirical estimates of bycatch mortality, net annual immigration rates, and reducing prior uncertainty in Maximum Sustainable Yield Rate (*MSYR)* and *MNPL* could potentially improve inference about the likelihood of the PCFG being within OSP.

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[1] This is a continuation of work first considered during the gray whale stock identification workshop described in Weller *et al*. (2013).

[2] "Bycatch mortality" refers to human-caused fisheries-related mortality (e.g., from entanglement in gear) as summarized in U.S. marine mammal stock assessment reports (e.g., Carretta *et al*. 2013).

Introduction

The National Marine Fisheries Service (NMFS) recognizes a single population stock of gray whales (*Eschrichtius robustus*) within U.S. waters, termed the Eastern North Pacific (ENP) stock (Carretta *et al.* 2013). This stock ranges from wintering areas in Baja California, Mexico, to summer/autumn feeding areas in the Bering, Beaufort, and Chukchi Seas. A relatively small number (100s) of these whales, referred to as the Pacific Coast Feeding Group (PCFG), spend the summer/autumn along the Pacific coast of North America, between Kodiak Island, Alaska, and northern California (Calambokidis *et al*. 2012). In 2010, the International Whaling Commission (IWC) Standing Working Group on Aboriginal Whaling Management Procedure noted that different names had been used to refer to gray whales feeding along the Pacific coast, and agreed to standardize the terminology referring to animals that spend the summer and autumn feeding in coastal waters of the Pacific coast of North America from California to southeast Alaska as the PCFG (IWC 2011). This definition was further refined for purposes of abundance estimation, limiting the geographic range to the area from northern California to northern British Columbia (from 41°N to 52°N), limiting the temporal range to the period from June 1 to November 30, and counting only those whales seen in more than one year within this geographic and temporal range (IWC 2012) for abundance estimation purposes. The IWC adopted this definition, but noted that "not all whales seen within the PCFG area at this time will be PCFG whales and some PCFG whales will be found outside of the PCFG area at various times during the year." (IWC 2012).

The range of the PCFG overlaps with the Makah Tribe's Usual and Accustomed (U&A) fishing grounds off the coast of Washington. In 2005, the Makah requested that NOAA/NMFS waive the U.S. Marine Mammal Protection Act (MMPA) take moratorium and adopt regulations that would authorize the tribe to hunt ENP gray whales within their U&A. As part of its review of this proposed hunt, NMFS continues to evaluate information relevant to ENP stock structure and status, including the population dynamics of the PCFG. This paper evaluates whether the PCFG is likely to be within its Optimum Sustainable Population level, or OSP. Under the MMPA, OSP means, "with respect to any population stock, the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element." Federal regulations implementing the MMPA describe OSP as a population size within a range that is at or above the level where the population's maximum net productivity occurs (termed the Maximum Net Productivity Level, or MNPL).[3] Populations below OSP are considered 'depleted' under the MMPA. Assessing whether the PCFG is currently within OSP (not depleted) was the objective of the analysis described in this report.

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[3] Regulations implementing the MMPA at 50 CFR 216.3 state that "Optimum sustainable population is a population size which falls within a range from the population level of a given species or stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity. Maximum net productivity is the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality."

Methods

Population Model

The assessment of ENP gray whales is based on a population dynamics model with two groups, a 'north' group and the PCFG. These two groups are assumed to be separate for purposes of the analysis, but with possible immigration between them. The model considers four strata (north of 52^0N, south of 41^0N, PCFG area December – May, and PCFG area June – November) because the relative vulnerability of the two groups to whaling and bycatch mortality differs among these strata.

The parameters of the model are estimated using Bayesian methods. Unlike IWC (2013), the analysis allows for uncertainty in the amount of 'pulse' immigration from the north group to the PCFG in 1999 and 2000, uncertainty in the annual level of immigration from the north group to the PCFG, and in $MSYL_{1+}$[4] and $MSYR_{1+}$[5] (the subscript 1+ refers to animals 1-year old and older). In contrast, IWC (2013) conducted analyses for pre-specified values for the level of 'pulse' immigration, the annual level of immigration, and $MSYL_{1+}$ and $MSYR_{1+}$. Note that the terms *MSYL* and *MSYR* reflect IWC terminology; within an MMPA context MSYL is the same as MNPL.

The underlying population dynamics model is deterministic, age- and sex-structured, and based on a two-stock version of the Baleen II model (Punt, 1999). Reference to 'stock' or 'population' below means either the north group or the PCFG, noting that usage of the term 'stock' with the model descriptions refers generically to a population unit and does not imply a formally recognized stock as defined under the MMPA.

Basic dynamics

Equation 1 provides the underlying 1+ dynamics.

$$\begin{aligned}
R^{s,m/f}_{t+1,a+1} &= (R^{s,m/f}_{t,a} + I^{s,m/f}_{t,a} - C^{s,m/f}_{t,a})\,\tilde{S}^s_t\,S^s_a + U^{s,m/f}_{t,a}\,\tilde{S}^s_t\,S^s_a\,\delta_{a+1} && 0 \le a \le x-2 \\
R^{s,m/f}_{t+1,x} &= (R^{s,m/f}_{t,x} + I^{s,m/f}_{t,x} - C^{s,m/f}_{t,x})\,\tilde{S}^s_t\,S^s_x + (R^{s,m/f}_{t,x-1} + I^{s,m/f}_{t,x-1} - C^{s,m/f}_{t,x-1})\,\tilde{S}^s_t S^s_{x-1} && (1) \\
U^{s,m/f}_{t+1,a+1} &= U^{s,m/f}_{t,a}\,\tilde{S}^s_t\,S^s_a\,(1-\delta_{a+1}) && 0 \le a \le x-2
\end{aligned}$$

where $R^{s,m/f}_{t,a}$ is the number of recruited males/females of age *a* in stock *s* at the start of year *t*; $U^{s,m/f}_{t,a}$ is the number of unrecruited males/females of age *a* in stock *s* at the start of year *t*; $C^{s,m/f}_{t,a}$ is the catch of males/females of age *a* from stock *s* during year *t* (whaling and bycatch mortality is assumed to take place in a pulse at the start of each year); δ_a is the fraction of unrecruited animals of age *a*-1 which recruit at age *a* (assumed to be independent of sex, time, and stock); S^s_a is the annual survival rate of animals of stock *s* and age *a* in the absence of catastrophic mortality events (assumed to be the same for males and females):

$$S^s_a = \begin{cases} S^s_0 & \text{if } a = 0 \\ S^s_{1+} & \text{if } 1 < a \end{cases} \qquad (2)$$

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[4] MSYL (Maximum Sustainable Yield Level) is the population size relative to carrying capacity at which surplus production is maximized; this is the same as MNPL under the MMPA.

[5] MSYR is the ratio of MSY to the population size at which MSY is achieved.

S_0^s is the calf survival rate for animals of stock *s*; S_{1+}^s is the survival rate for animals aged 1 and older for animals of stock *s*; $\tilde{S}_t^s$ is the amount of catastrophic mortality (represented in the form of a survival rate) for stock *s* during year *t* (catastrophic events are assumed to occur at the start of the year before mortality due to whaling, bycatch and natural causes; in general $\tilde{S}_t^s = 1$, i.e. there is no catastrophic mortality); $I_{t,a}^{s,m/f}$ is the net migration of female/male animals of age *a* into stock *s* during year *t*; and *x* is the maximum (lumped) age-class (all animals in this and the *x*-1 class are assumed to be recruited and to have reached the age of first parturition). *x* is taken to be 15 for these trials.

Catastrophic mortality is assumed to be zero (i.e., $\tilde{S}_t^s = 1$) except for the north group in 1999 and 2000 when it is assumed to be equal to the parameter $\tilde{S}$ (Punt and Wade, 2012). This assumption reflects the large number of dead ENP gray whales observed stranded along the coasts of Oregon and Washington during 1999 and 2000 relative to annual numbers stranding there historically (Gulland *et al*. 2005; Brownell *et al*. 2007). The mortality event is assumed to have only impacted the north group because the abundance estimates for the PCFG increased when the mortality event occurred, in contrast to those for the north group which declined substantially.

Immigration only occurs from the north group to the PCFG, and only animals aged 1+ immigrate. The annual number of animals immigrating is $I_t = \bar{I}\, N_t^{\text{north},1+} / 20000$ where $\bar{I}$ is the hypothesized recent average number of individuals recruiting into the PCFG and 20000 is the approximate 1+ population size for the north group during those years (i.e., recent $N_t^{\text{north},1+}/20000 \approx 1$ (Laake *et al*. 2012) and thus recent $I_t = \bar{I}$). The annual number of immigrants by age and sex is given by:

$$I_{t,a}^{s,m/f} = I_t \frac{(R_{t,a}^{\text{north},\text{m/f}} + U_{t,a}^{\text{north},\text{m/f}})}{N_t^{\text{north},1+}} \tag{3}$$

Emigration from the PCFG is modelled by implementing an extra survival rate, $\tilde{\tilde{S}}$ after 1930 (immigration or emigration are ignored when carrying capacity and the parameters which determine the productivity of the population are calculated). Owing to the different sizes of the two groups, emigrants from the PCFG are assumed to die rather than join the north group. The value of $\tilde{\tilde{S}}$ is set so that at carrying capacity immigration and emigration are balanced, i.e.:

$$\frac{\bar{I}\, K_{1+}^{\text{north}}}{20000} = K_{0+}^{\text{PCFG}} (1 - \tilde{\tilde{S}}) \tag{4}$$

Births

The number of births to stock *s* at the start of year *t*+1, B_{t+1}^s, is given by:

$$B_{t+1}^s = b_{t+1}^s N_{t+1}^{s,f} \tag{5}$$

where $N_t^{s,f}$ is the number of mature females in stock *s* at the start of year *t*:

$$N_t^{s,f} = \sum_{a=a_m}^{x} (R_{t,a}^{s,f} + U_{t,a}^{s,f}) \tag{6}$$

a_m is the age-at-maturity (the convention of referring to the mature population is used here, although this actually refers to animals that have reached the age of first parturition); b_{t+1}^s is the probability of birth/calf survival for mature females:

$$b_{t+1}^s = b_{-\infty}^s \{1 + A^s (1 - (N_{t+1}^{s,1+} / K^{s,1+})^{z^s})\} \tag{6}$$

$b_{-\infty}^s$ is the average number of live births per year per mature female in the pristine (pre-exploitation) population for stock *s*; A^s is the resilience parameter for stock *s* (A^s determines how much birth rate can increase from $b_{-\infty}^s$ when resources are not limiting); z^s is the degree of compensation for stock *s* (determines the population size – relative to carrying capacity – at which MNPL occurs); and $N_t^{s,1+}$ and $K^{s,1+}$ are defined according to the equations:

$$N_t^{s,1+} = \sum_{a=1}^{x} (R_{t,a}^{s,\mathrm{f}} + U_{t,a}^{s,\mathrm{f}} + R_{t,a}^{s,\mathrm{m}} + U_{t,a}^{s,\mathrm{m}}) \qquad K^{s,1+} = \sum_{a=1}^{x} (R_{-\infty,a}^{s,\mathrm{f}} + U_{-\infty,a}^{s,\mathrm{f}} + R_{-\infty,a}^{s,\mathrm{m}} + U_{-\infty,a}^{s,\mathrm{m}}) \tag{7}$$

The number of female births, $B_t^{s,f}$, is computed from the total number of the births during year *t* according to the equation:

$$B_t^{s,f} = 0.5 B_t^s \tag{8}$$

The numbers of recruited/unrecruited calves is given by:

$$\begin{aligned} R_t^{s,f} &= \pi_0 B_t^{s,f} & R_t^{s,m} &= \pi_0 (B_t^s - B_t^{s,f}) \\ U_t^{s,f} &= (1-\pi_0) B_t^{s,f} & U_t^{s,m} &= (1-\pi_0)(B_t^s - B_t^{s,f}) \end{aligned} \tag{9}$$

π_0 is the proportion of animals of age 0 which are recruited ($\pi_0 = 0$ for the analyses of this report).

Catches

The historical ($t < 2010$) catches by stratum (north, south, PCFG December – May, and PCFG June – November) are taken to be equal to the reported catches (IWC 2011; Table 1). The historical catches are allocated to the north group or PCFG in fixed proportions as follows:

(1) North area catches: all north animals;

(2) PCFG area catches in December – May: PCFG animals with probability ϕ_{PCFG} (base-case value 0.3, as determined by the photo-ID data; Calambokidis *et al.* 2012);

(3) PCFG area catches in June – November: all PCFG animals; and

(4) South area catches: PCFG animals with probability ϕ_{south} (base-case value 0.01, as determined by relative abundance).

The bycatch estimates by stratum for the historical period are computed using the equation (IWC 2013):

$$C_y^{\mathrm{I}/s} = 0.5 \begin{cases} \left\{1 - \frac{0.5}{69}[1999 - y]\right\} \bar{C}^I & \text{if } y \le 1999 \\ \bar{C}^I N_y^{1+} / \bar{N}^{1+} & \text{otherwise} \end{cases} \tag{10}$$

where $C_y^{\mathrm{I}/s}$ is the bycatch of animals of sex *s* during year *y*; $\bar{C}^I$ is the mean catch in the stratum (see Table 2); and $\bar{N}^{1+}$ is the mean 1+ abundance (in the stratum concerned from 2000-2009). The catches from the PCFG and the north group are then allocated to age and size using the formula:

$$C_{t,a}^{s,m} = C_t^{s,m} R_{y,a}^{s,m} / \sum_{a''} R_{y,a''}^{s,m}; \qquad C_{t,a}^{s,\mathrm{f}} = C_t^{s,\mathrm{f}} R_{y,a}^{s,\mathrm{f}} / \sum_{a''} R_{y,a''}^{s,\mathrm{f}}; \tag{11}$$

Recruitment

The proportion of animals of age *a* that would be recruited if the population was pristine is a knife-edged function of age at age 0, i.e.:

$$\pi_a = \begin{cases} 0 & \text{if } \quad a = 0 \\ 1 & \text{otherwise} \end{cases} \tag{12}$$

The (expected) number of unrecruited animals of age *a* that survive to age *a*+1 is $U_{t,a}^{s,m/f}\, S_a$. The fraction of these that then recruit is:

$$\delta_{a+1} = \begin{cases} [\pi_{a+1} - \pi_a]/[1 - \pi_a] & \text{if } 0 \le \alpha_a < 1 \\ 1 & \text{otherwise} \end{cases} \tag{13}$$

Maturity

Maturity is assumed to be a knife-edged function of age at age a_{m}.

Initialising the population vector

The numbers at age in the pristine population are given by:

$$\begin{aligned} R_{-\infty,a}^{s,\mathrm{m/f}} &= 0.5 \;\; N_{-\infty,0}^{s} \;\; \pi_a \prod_{a'=0}^{a-1} S_{a'}^{s} && \text{if} \quad 0 \le a < x \\ U_{-\infty,a}^{s,\mathrm{m/f}} &= 0.5 \;\; N_{-\infty,0}^{s} \;\; (1 - \pi_a) \prod_{a'=0}^{a-1} S_{a'}^{s} && \text{if} \quad 0 \le a < x \\ R_{-\infty,x}^{s,\mathrm{m/f}} &= 0.5 \;\; N_{-\infty,0}^{s} \prod_{a'=0}^{x-1} \frac{S_{a'}^{s}}{(1 - S_x)} && \text{if} \quad a = x \end{aligned} \tag{14}$$

where $R_{-\infty,a}^{s,\mathrm{m/f}}$ is the number of animals of stock *s* of age *a* that would be recruited in the pristine population; $U_{-\infty,a}^{s,\mathrm{m/f}}$ is the number of animals of stock *s* of age *a* that would be unrecruited in the pristine population; and $N_{-\infty,0}^{s}$ is the total number of animals of stock *s* of age 0 in the pristine population.

The value for $N^{s}_{-\infty,0}$ is determined from the value for the pre-exploitation size of the 1+ component of the population using the equation:

$$N^{s}_{-\infty,0} = K^{s,1+} / \left(\sum_{a=1}^{x-1} \prod_{a'=1}^{a-1} S^{s}_{a} + \frac{1}{1-S_{x}} \prod_{a'=0}^{x-1} S^{s}_{a'} \right) \tag{15}$$

It is not possible to make a simple density-dependent population dynamics model consistent with the abundance estimates for ENP gray whales (Reilly 1981; 1984; Cooke 1986; Lankester and Beddington 1986; Butterworth *et al.* 2002). This is why recent assessments of this stock (e.g. Punt and Wade 2012) have been based on starting population projections from a more recent year (denoted as τ) than that in which the first recorded catch occurred. The analyses are therefore based on the assumption that the age-structure at the start of $\tau = 1930$ is stable rather than that the populations were at their pre-exploitation equilibrium sizes at the start of some much earlier year. The choice of 1930 for the first year of the simulation is motivated by the fact that the key assessment results are not sensitive to a choice for this year from 1930-1968 (Punt and Butterworth 2002; Punt and Wade 2012). The determination of the age-structure at the start of 1930 involves specifying the effective 'rate of increase', γ, that applies to each age-class. There are two components contributing to γ, one relating to the overall population rate of increase (γ^{+}) and the other to the exploitation rate. Under the assumption of knife-edge recruitment to the fishery at age 1, only the γ^{+} component (assumed to be zero following Punt and Butterworth 2002) applies to ages a of age 0. The number of animals of age a at the start of $\tau = 1930$ relative to the number of calves at that time, $N^{s,*}_{\tau,a}$, is therefore given by the equation:

$$N^{s,*}_{\tau,a} = \begin{cases} 1 & \text{if } a = 0 \\ N^{s,*}_{\tau,0}\, S^{s}_{0} & \text{if } a \le 1 \\ N^{s,*}_{\tau,a-1}\, S^{s}_{a-1}\,(1-\gamma^{+}) & \text{if } 1 < a < x \\ N^{s,*}_{\tau,x-1}\, S^{s}_{x-1}(1-\gamma^{+}) / (1 - S^{s}_{x}\,(1-\gamma^{+})) & \text{if } a = x \end{cases} \tag{16}$$

where B^{s}_{τ} is the number of calves in year τ (=1930) and is derived directly from equations 5 and 6 (for further details see Punt [1999]):

$$B^{s}_{\tau} = \left(1 - \left[1/(N^{s,f}_{\tau} b^{s}_{-\infty}) - 1\right] / A^{s}\right)^{1/z^{s}} \frac{K^{s,1+}}{N^{s,1+*}_{\tau}} \tag{17}$$

The effective rate of increase, γ^{s}, is selected so that if the population dynamics model is projected from 1930 to 1968, the size of the 1+ component of the population (both groups) in 1968 equals a pre-specified value, P^{s}_{1968}.

z and A

A^{s}, z^{s} and S^{s}_{0}, are obtained by solving the system of equations that relate $MSYL^{s}_{1+}$, $MSYR^{s}_{1+}$, S^{s}_{0}, S_{1+}, $f_{\max}$, a_{m}, A^{s} and z^{s}, where $f_{\max}$ is the maximum theoretical pregnancy rate (Punt 1999).

Parameter estimation

The method for estimating the parameters of the model (i.e. selecting 5,000 sets of equally likely values for the parameters a_m, S_0^s, S_{1+}, $\tilde{S}$, K_{1+}^north, K_{1+}^PCFG, A^north, A^PCFG, z^north, and z^PCFG) is based on a Bayesian assessment (Punt and Butterworth 2002; Wade 2002; Punt and Wade 2012). The algorithm for conducting the Bayesian assessment is as follows:

(a) Draw values for the parameters S_{1+}, f_max, a_m, K_{1+}^north, K_{1+}^PCFG, P_{1968}^north, P_{1968}^PCFG, $\tilde{S}$, $MSYR_{1+}^s$, $MSYL_{1+}^s$, CV_{add}^north (the additional variance for the estimates of 1+ abundance at Carmel, California in 1968), CV_{add}^PCFG (the additional variance for the estimates of 1+ abundance from northern California to Southeast Alaska in 1968 – had such a survey taken place) from the priors (see Table 3 for the reference priors).

(b) Solve the system of equations that relate $MSYR_{1+}^s$, $MSYL_{1+}^s$, S_0^s, S_{1+}, f_max, a_m, A^s and z^s to find values for S_0^s, A^s and z^s.

(c) Calculate the likelihood of the projection for each area, given by[6]:

$$-\ell\mathrm{n}L = 0.5\ell\mathrm{n}\,|\mathbf{V}+\Omega| + 0.5\sum_i\sum_j(\ell\mathrm{n}N_i^\mathrm{obs} - \ell\mathrm{n}\hat{P}_i^{1+})[(\mathbf{V}+\Omega)^{-1}]_{i,j}(\ell\mathrm{n}N_j^\mathrm{obs} - \ell\mathrm{n}\hat{P}_j^{1+}) \qquad (18)$$

where N_i^obs is the i^th estimate of abundance[7] (Tables 4a, 4b), $\hat{P}_i^{1+}$ is the model-estimate corresponding to N_i^obs, $\mathbf{V}$ is the variance-covariance matrix for the abundance estimates, and Ω is a diagonal matrix with elements given by $E(CV_{add,t}^2)$:

$$E(CV_{add,t}^2) = CV_{add}^2\,\frac{0.1+0.013P^*/\hat{P}_t}{0.1+0.013P^*/\hat{P}_{1968}} \qquad (19)$$

(d) Steps (a) – (c) are repeated a large number (typically 1,000,000) of times.

(e) 5,000 sets of parameters vectors are selected randomly from those generated using steps (a) – (c), assigning a probability of selecting a particular vector proportional to its likelihood. The number of times steps (a) – (c) are repeated is chosen to ensure that most of the 5,000 parameter vectors are unique.

The expected value for the estimate of abundance of the north area is taken to the total 1+ abundance (north group and PCFG combined) while the abundance estimates for the PCFG area are assumed to pertain to the PCFG only.

Model Scenarios

Thirteen models were run (Table 5). These included a reference model (Table 3) and 12 variants. These models do not represent a comprehensive set of options, but were used to

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[6] This formulation assumes that the observed data relate to the medians of sampling distributions for the data. Alternative assumptions (such as that the observed data relate to the means of the sampling distributions) will be inconsequential given the extent of uncertainty associated with the estimates of abundance.

[7] The shore-based abundance estimate for year *y*/*y*+1 is assumed to pertain to abundance at the start of year *y*+1.

explore how the model behaved under certain conditions (e.g., parameter constraints) with respect to providing inference about the probability of the PCFG being within OSP.

Results and Discussion

Ultimately it was not possible to draw a definitive conclusion as to whether the PCFG is within OSP. Across all 13 model variants, the estimated probability of the population being above *MSYL* (i.e., *MNPL*), and hence within OSP ranged from ≈ 0.35 on the low end (models F and G) to 0.83 (model M) and 0.88 (model K) on the high end (see Table 6). In the latter two models (K and M), bycatch mortality was fixed at zero, which is not realistic. For the remaining 11 models, the probability was ≤ 0.70, which is fairly equivocal.

The time series of PCFG abundance estimates indicates that a rapid phase of population growth occurred between 1998 and 2001 associated with a pulsed immigration event (≈ 25 – 30 immigrants per year from the north group to the PCFG), followed by no substantial trend in abundance since then (Figure 1). A key reason for the inability to draw definitive conclusions about OSP is because it is unclear whether the stability of the PCFG over the last decade is best explained by it being at or near carrying capacity or whether it has been regulated at a lower level by some other processes.

Unfortunately, the time-series of abundance estimates for the PCFG is largely uninformative regarding population growth rate since it is relatively flat (no information about growth rate or density-dependence) apart from the short period of growth explained by an atypical immigration event. Consequently, estimates for population growth at *MNPL*, the value of *MNPL* itself (as a fraction of K), carrying capacity, and hence the current population depletion level (percentage of carrying capacity) for the PCFG were influenced strongly by the prior distributions. For example, the upper prior limit for K for the PCFG was 500 for models A – D, and the posterior median estimates for K ranged from 265 – 293 with upper 95% estimates close to 500, whereas, the upper prior limit was 1000 for models E – M, and the posterior median estimates for K ranged up to 441 with upper 95% estimates close to 800 or higher for most of these models (Table 6). Thus, in all of these models, the right tail of the posterior distribution for K was truncated to some extent by the upper bound for the prior for K (Figure 2), implying non-trivial (and sometimes substantial) probability that carrying capacity could be as high as the specified upper bound (and thus substantial probability that current population size is below *MNPL*).

Constraining both *MSYR* and *MNPL* for the PCFG to equal those of the north group (thus drawing on north group data to estimate some PCFG growth parameters; models J through M) did not substantially improve inference. For models J and L, the probability of the PCFG being within OSP was 0.44 and 0.52, respectively (Table 6). Models K and M included the additional constraint of fixing annual bycatch at zero, and model M also assumed zero annual immigration. The posterior distribution for carrying capacity was reasonably unconstrained by the prior (Figure 2) and the carrying capacity estimates were ≤ 250 animals (Table 6) for these two models (and also for model I, where *MNPL* and bycatch, but not *MSYR*, were constrained). Even so, the estimated probability of the population being within OSP was not definitive in these cases (probability = 0.83 and 0.88), and the assumptions of zero bycatch (models I, K, M) or full population closure (model M) are not justified for the PCFG (Weller *et al*. 2013), so these models do not represent realistic scenarios anyway. However, the estimates for these models provided the insight that bycatch mortality and movement between the north group and PCFG makes it difficult to estimate other population parameters, given the nature of the time series of abundance estimates (since parameters were not estimated well for other models that did not include the same constraints). Specifically, the only way for the model to mimic population stability when the population is assumed to be closed to bycatch or emigration is for the population to be at or near K (when K is estimated to be small), but many possible levels of K can explain the data when the population is allowed to be open (with some population losses due to bycatch and emigration).

In summary, the apparent stability of the PCFG population size for the past decade has multiple possible explanations given the limited available information. One explanation is that the population is at or near its carrying capacity and thus above *MNPL* and within OSP. However, it is also possible that the PCFG area could support more whales and that current numbers are regulated by a combination of emigration and bycatch mortality that offsets immigration and internal production (recruitment of calves born to known PCFG females). The PCFG would be expected at most to grow at around 6% per year (if it were well below *MNPL* and had the same intrinsic growth potential as the north group; Punt and Wade [2012]). It would grow at a slower rate if it is close to *MNPL* or has a lower growth rate potential than the larger north group (e.g., feeding in a less productive environment). Considering its small population size (around 200 animals), the PCFG therefore has the potential to increase at most by approximately 12 animals per year from births minus deaths, and the increase could be much smaller (e.g., just several animals per year). The PCFG can additionally grow due to immigration from the larger north group, but as modeled, immigration is offset by emigration to an extent that depends on the estimated abundance levels of the two groups relative to their respective carrying capacities. For example, if both groups are currently at the same fraction of K, PCFG immigration and emigration would be estimated to be equal. As a result, small losses from emigration and bycatch are sufficient to offset population gains from birth and immigration, especially if the PCFG has a relatively low intrinsic growth rate compared to the north group (e.g., as in models E through I; see Table 6). Moreover, bycatch mortality estimates in the models are likely underestimates of true bycatch mortality (Weller *et al.* 2013). If higher bycatch mortality rates were included in the analyses, this would decrease the estimated likelihood of the PCFG being within OSP, but true bycatch mortality rates are unknown with no good way at present of being approximated (thus we used the same values as in IWC analyses; Table 2).

Obtaining better empirical estimates of bycatch mortality, net annual immigration rates, and reducing prior uncertainty in *MSYR* and *MNPL* could potentially improve inference about the likelihood of the PCFG being within OSP.

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Table 1
Historical catches of ENP gray whales (IWC, 2011).

Year	South			PCFG Jun-Nov			PCFG Dec-May			North			Total		
	M	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**
1930	0	0	0	0	0	0	0	0	0	23	24	47	23	24	47
1931	0	0	0	0	0	0	0	0	0	5	5	10	5	5	10
1932	5	5	10	0	0	0	0	0	0	5	5	10	10	10	20
1933	30	30	60	0	0	0	0	0	0	8	7	15	38	37	75
1934	30	30	60	0	0	0	0	0	0	36	30	66	66	60	126
1935	55	55	110	0	0	0	0	0	0	16	28	44	71	83	154
1936	43	43	86	0	0	0	0	0	0	50	62	112	93	105	198
1937	0	0	0	0	0	0	0	0	0	12	12	24	12	12	24
1938	0	0	0	0	0	0	0	0	0	32	32	64	32	32	64
1939	0	0	0	0	0	0	0	0	0	19	20	39	19	20	39
1940	0	0	0	0	0	0	0	0	0	56	69	125	56	69	125
1941	0	0	0	0	0	0	0	0	0	38	39	77	38	39	77
1942	0	0	0	0	0	0	0	0	0	60	61	121	60	61	121
1943	0	0	0	0	0	0	0	0	0	59	60	119	59	60	119
1944	0	0	0	0	0	0	0	0	0	3	3	6	3	3	6
1945	0	0	0	0	0	0	0	0	0	25	33	58	25	33	58
1946	0	0	0	0	0	0	0	0	0	14	16	30	14	16	30
1947	0	0	0	0	0	0	0	0	0	11	20	31	11	20	31
1948	0	0	0	0	0	0	0	0	0	7	12	19	7	12	19
1949	0	0	0	0	0	0	0	0	0	10	16	26	10	16	26
1950	0	0	0	0	0	0	0	0	0	4	7	11	4	7	11
1951	0	0	0	0	0	0	1	0	1	5	8	13	6	8	14
1952	0	0	0	0	0	0	0	0	0	17	27	44	17	27	44
1953	0	0	0	0	0	0	6	4	10	15	23	38	21	27	48
1954	0	0	0	0	0	0	0	0	0	14	25	39	14	25	39
1955	0	0	0	0	0	0	0	0	0	22	37	59	22	37	59
1956	0	0	0	0	0	0	0	0	0	45	77	122	45	77	122
1957	0	0	0	0	0	0	0	0	0	36	60	96	36	60	96
1958	0	0	0	0	0	0	0	0	0	55	93	148	55	93	148
1959	1	1	2	0	0	0	0	0	0	73	121	194	74	122	196
1960	0	0	0	0	0	0	0	0	0	58	98	156	58	98	156
1961	0	0	0	0	0	0	0	0	0	77	131	208	77	131	208
1962	4	0	4	0	0	0	0	0	0	55	92	147	59	92	151
1963	0	0	0	0	0	0	0	0	0	68	112	180	68	112	180
1964	15	5	20	0	0	0	0	0	0	75	124	199	90	129	219
1965	0	0	0	0	0	0	0	0	0	71	110	181	71	110	181
1966	15	11	26	0	0	0	0	0	0	80	114	194	95	125	220
1967	52	73	125	0	0	0	0	0	0	109	140	249	161	213	374
1968	41	25	66	0	0	0	0	0	0	48	87	135	89	112	201
1969	39	35	74	0	0	0	0	0	0	50	90	140	89	125	214
1970	0	0	0	0	0	0	0	0	0	71	80	151	71	80	151
1971	0	0	0	0	0	0	0	0	0	57	96	153	57	96	153
1972	0	0	0	0	0	0	0	0	0	61	121	182	61	121	182
1973	0	0	0	0	0	0	0	0	0	97	81	178	97	81	178
1974	0	0	0	0	0	0	0	0	0	94	90	184	94	90	184
1975	0	0	0	0	0	0	0	0	0	58	113	171	58	113	171
1976	0	0	0	0	0	0	0	0	0	69	96	165	69	96	165
1977	0	0	0	0	0	0	0	0	0	87	100	187	87	100	187
1978	0	0	0	0	0	0	0	0	0	94	90	184	94	90	184
1979	0	0	0	0	0	0	0	0	0	58	125	183	58	125	183
1980	0	0	0	0	0	0	0	0	0	53	129	182	53	129	182
1981	0	0	0	0	0	0	0	0	0	36	100	136	36	100	136
1982	0	0	0	0	0	0	0	0	0	57	111	168	57	111	168
1983	0	0	0	0	0	0	0	0	0	46	125	171	46	125	171
1984	0	0	0	0	0	0	0	0	0	59	110	169	59	110	169
1985	0	0	0	0	0	0	0	0	0	54	116	170	54	116	170
1986	0	0	0	0	0	0	0	0	0	46	125	171	46	125	171
1987	0	0	0	0	0	0	0	0	0	48	111	159	48	111	159
1988	0	0	0	0	0	0	0	0	0	43	108	151	43	108	151
1989	0	0	0	0	0	0	0	0	0	61	119	180	61	119	180
1990	0	0	0	0	0	0	0	0	0	67	95	162	67	95	162

Year	**South**			**PCFG Jun-Nov**			**PCFG Dec-May**			**North**			**Total**		
	M	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**	**M**	**F**	**Total**
1991	0	0	0	0	0	0	0	0	0	67	102	169	67	102	169
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	21	23	44	21	23	44
1995	0	0	0	0	0	0	0	0	0	48	44	92	48	44	92
1996	0	0	0	0	0	0	0	0	0	18	25	43	18	25	43
1997	0	0	0	0	0	0	0	0	0	48	31	79	48	31	79
1998	0	0	0	0	0	0	0	0	0	64	61	125	64	61	125
1999	0	0	0	0	0	0	0	1	1	69	54	123	69	55	124
2000	0	0	0	0	0	0	0	0	0	63	52	115	63	52	115
2001	0	0	0	0	0	0	0	0	0	62	50	112	62	50	112
2002	0	0	0	0	0	0	0	0	0	80	51	131	80	51	131
2003	0	0	0	0	0	0	0	0	0	71	57	128	71	57	128
2004	0	0	0	0	0	0	0	0	0	43	68	111	43	68	111
2005	0	0	0	0	0	0	0	0	0	49	75	124	49	75	124
2006	0	0	0	0	0	0	0	0	0	57	77	134	57	77	134
2007	0	0	0	0	1	1	0	0	0	50	81	131	50	82	132
2008	0	0	0	0	0	0	0	0	0	64	66	130	64	66	130
2009	0	0	0	0	0	0	0	0	0	59	57	116	59	57	116
2010	0	0	0	0	0	0	0	0	0	57	61	118	57	61	118

Table 2
Average estimated historical bycatches

Stratum	**Average bycatch estimates**
North	0[1]
PCFG [Dec – May]	2
PCFG [Jun – Nov]	1.4[2]
South	3.4

1 – obviously not actually zero, but will be small relative to population size
2 – includes southern whales during June – November as these whales are almost certainly PCFG animals

Table 3. The prior distributions for the ENP stock of gray whales, for the reference case scenario (case B in Table 5).

Parameter	**Prior distribution**
Maximum Sustainable Yield Rate, $MSYR_{1+}^{north}$	U[0.01,0.06]
$MSYR_{1+}^{PCFG}$	U[0.01,0.06]
Maximum Net Productivity Level, $\mathrm{MNPL}^{\mathrm{north}}$ (same as $MSYL_{1+}^{s}$)	0.6
$\mathrm{MNPL}^{\mathrm{PCFG}}$	0.6
Non-calf survival rate, S_{1+}	U[0.95, 0.99]
Age-at-maturity, a_{m}	U[6, 12]
K_{1+}^{north}	U[16,000, 70,000]
K_{1+}^{PCFG}	U[100, 500]
Maximum pregnancy rate, $f_{\max}$	U[0.3, 0.6]
$CV_{add}^{\mathrm{north}}$	U[0.1, 0.3]
CV_{add}^{PCFG}	U[0.05, 0.3]
1968 abundance, $P_{1968}^{\mathrm{north}}$	U[8,000, 16,000]
1968 abundance, P_{1968}^{PCFG}	U[50, 300]
Catastrophic mortality, $\tilde{S}$	U[0.5,1.0]
Annual Immigration, $\bar{I}$	U[0,4]
Pulse Immigration, $I_{1999,2000}$	U[10, 50]

Table 4a Estimates of absolute abundance (with associated standard errors of the logs) for the ENP stock of gray whales based on shore counts (source: Laake *et al*. 2012).

Year	**Estimate**	**CV**	**Year**	**Estimate**	**CV**
1967/68	13426	0.094	1979/80	19763	0.083
1968/69	14548	0.080	1984/85	23499	0.089
1969/70	14553	0.083	1985/86	22921	0.081
1970/71	12771	0.081	1987/88	26916	0.058
1971/72	11079	0.092	1992/93	15762	0.067
1972/73	17365	0.079	1993/94	20103	0.055
1973/74	17375	0.082	1995/96	20944	0.061
1974/75	15290	0.084	1997/98	21135	0.068
1975/76	17564	0.086	2000/01	16369	0.061
1976/77	18377	0.080	2001/02	16033	0.069
1977/78	19538	0.088	2006/07	19126	0.071
1978/79	15384	0.080			

Table 4b Estimates of absolute abundance (with associated CVs) for gray whales in the PCFG area, 41^0-52^0N (source: Laake, 2013).

Year	**Estimate**	**CV**	**Year**	**Estimate**	**CV**
1998	101	0.062	2005	206	0.109
1999	135	0.089	2006	190	0.099
2000	141	0.093	2007	183	0.126
2001	172	0.073	2008	191	0.084
2002	189	0.048	2009	185	0.125
2003	200	0.082	2010	186	0.100
2004	206	0.072			

Table 5. Specifications for the scenarios

Case	Difference from case B
A	No Annual Immigration
B	Reference case (see Table 3)
C	$MSYL_{1+}^{s} \sim U[0.4, 0.8]$; no annual immigration $(\bar{I} = 0)$
D	$MSYL_{1+}^{s} \sim U[0.4, 0.8]$
E	$MSYL_{1+}^{s} \sim U[0.5, 0.85]$; $K_{1+}^{\text{PCFG}} \sim U[100,1000]$; $\bar{I} \sim U[0, 6]$; $I_{1999,2000} \sim U[0, 60]$
F	$MSYL_{1+}^{s} \sim U[0.5, 0.85]$; $K_{1+}^{\text{PCFG}} \sim U[100,1000]$; no annual immigration; $I_{1999,2000} \sim U[0, 60]$
G	As for F except that MSYL for the two stocks constrained to be equal and $\bar{I} \sim U[0, 6]$
H	As for F except that MSYL for the two stocks constrained to be equal
I	As for E, except MSYL for the two stocks constrained to be equal, there are no historical bycatches and no additional variance for PCFG abundance estimates
J	As for E except MSYL and MSYR for the two stocks constrained to be equal
K	As for J, but there are no historical bycatches
L	As for J, but there is no additional variance for PCFG abundance estimates
M	As for J, but there are no historical bycatches and no annual immigration

Table 6. Summaries of the posterior distributions for selected parameters from all model scenarios (Table 5). P(N>MNPL) is probability that the 1+ population size is above the Max Net Productivity Level and thus the population is within OSP (for the north group and the PCFG). For other parameters, the posterior median and 95% credible intervals are presented. MSYR is the population growth rate at MNPL, which is estimated in terms of a proportion of abundance at MNPL.

Run	P(N>MNPL)	P(N>MNPL)		MSYR	MSYR	MNPL	MNPL	K	K
	North	PCFG		North	PCFG	North	PCFG	North	PCFG
A	0.771	0.7016	5%	0.019	0.011	0.6	0.6	20895	179
			50%	0.038	0.022	0.6	0.6	25384	265
			95%	0.055	0.045	0.6	0.6	57578	465
B	0.753	0.6418	5%	0.019	0.011	0.6	0.6	20997	194
			50%	0.037	0.022	0.6	0.6	25676	292
			95%	0.056	0.043	0.6	0.6	58693	472
C	0.847	0.659	5%	0.021	0.011	0.531	0.467	19514	183
			50%	0.042	0.021	0.702	0.612	22714	285
			95%	0.056	0.045	0.791	0.778	54866	475
D	0.836	0.643	5%	0.02	0.011	0.53	0.458	19596	191
			50%	0.042	0.02	0.701	0.612	22652	293
			95%	0.056	0.042	0.792	0.775	55224	476
E	0.8184	0.3962	5%	0.021	0.011	0.545	0.515	19447	196
			50%	0.041	0.017	0.704	0.651	22596	376
			95%	0.056	0.039	0.809	0.795	57869	920
F	0.849	0.3546	5%	0.021	0.011	0.554	0.517	19451	188
			50%	0.042	0.019	0.716	0.653	22502	439
			95%	0.056	0.039	0.811	0.8	52813	940
G	0.7988	0.3474	5%	0.02	0.011	0.543	0.543	19544	195
			50%	0.041	0.018	0.687	0.687	23164	398
			95%	0.056	0.039	0.791	0.791	58187	923
H	0.839	0.4178	5%	0.02	0.011	0.549	0.549	19622	188
			50%	0.042	0.018	0.7	0.7	22674	441
			95%	0.056	0.041	0.797	0.797	54808	927
I	0.756	0.6634	5%	0.02	0.01	0.532	0.532	19732	168
			50%	0.039	0.015	0.672	0.672	23466	250
			95%	0.056	0.033	0.778	0.778	61570	805
J	0.3386	0.4354	5%	0.017	0.017	0.515	0.515	21315	191
			50%	0.024	0.024	0.63	0.63	40607	346
			95%	0.043	0.043	0.771	0.771	47154	839
K	0.3594	0.8798	5%	0.016	0.016	0.515	0.515	20912	132
			50%	0.023	0.023	0.631	0.631	42624	241
			95%	0.049	0.049	0.762	0.762	67563	643
L	0.399	0.5168	5%	0.017	0.017	0.517	0.517	20760	193
			50%	0.025	0.025	0.647	0.647	37928	312
			95%	0.046	0.046	0.787	0.787	66508	791
M	0.5958	0.8262	5%	0.017	0.017	0.519	0.519	20112	122
			50%	0.03	0.03	0.651	0.651	27641	195
			95%	0.051	0.051	0.771	0.771	64866	772

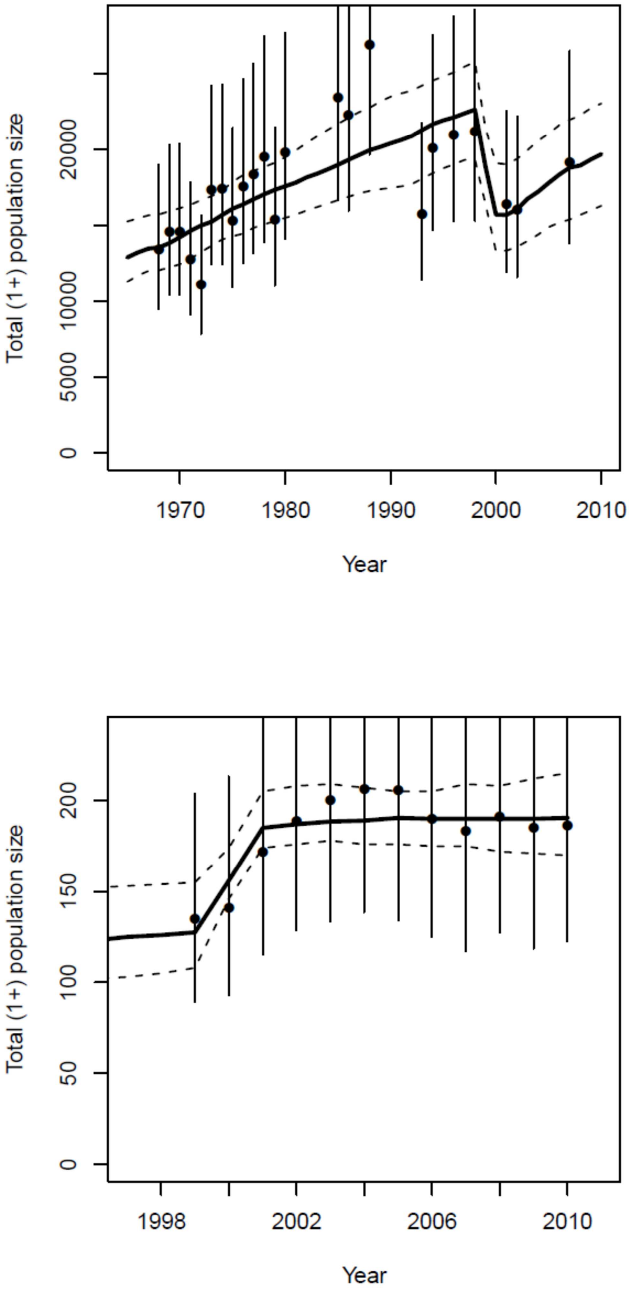

Figure 1. Abundance estimates for the north group (top) and PCFG (bottom) from the reference model (model B). Points and error bars represent actual estimates (Calambokidis *et al*, 2012). Solid line represents posterior median estimates (dotted lines represent 90% credible intervals). Estimates from all models (A – M) are similar.

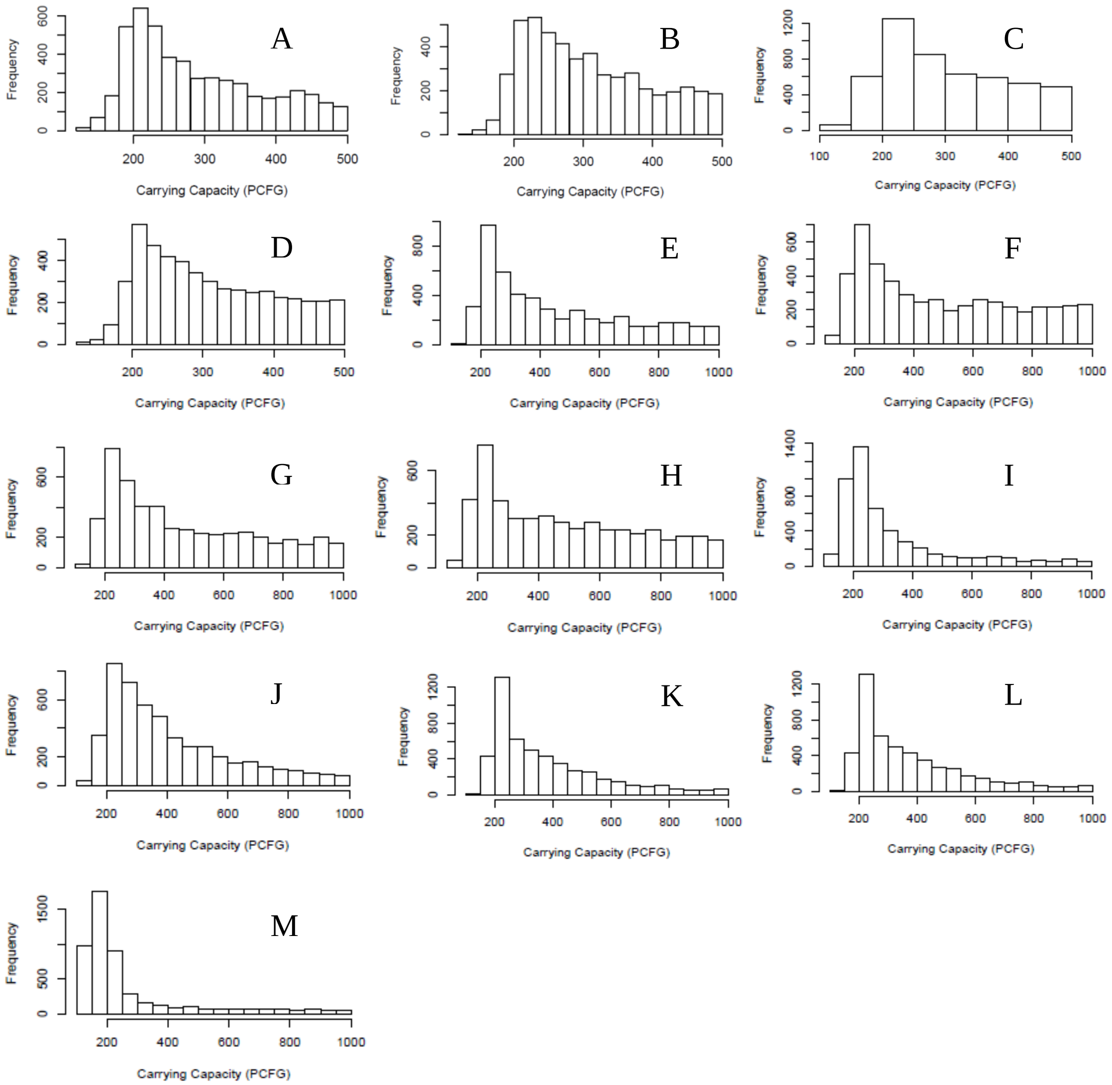

Figure 2. Posterior distributions for carrying capacity for the PCFG, for model scenarios A through M.

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SC/68A/CMP/WP/07

Population Assessment Update for Sakhalin Gray Whales

Justin G. Cooke[1], Olya Sychenko[2], Alexander M. Burdin[2], David W. Weller[3], Amanda L. Bradford[4],Aimee R. Lang[3], and Robert L. Brownell, Jr.[3]

ABSTRACT

The population assessment of gray whales *Eschrichtius robustus* feeding off Sakhalin is updated. An individually based population model, with one summer feeding area and up to two wintering areas, is fit to photo-id data collected off Sakhalin during 1995-2018 (Burdin *et al.* 2019), sex determinations from biopsies (Lang 2010), tracking of whales from Sakhalin to the eastern North Pacific (Mate *et al.* 2015), and photo-id matches of gray whales between the Sakhalin and Mexico catalogues (Urbán *et al.* 2019). The results show that the Sakhalin feeding population increased at 3.4-4.8% per year over the 20 years to 2018, but with significant inter-annual fluctuations in calving rates and calf survival. It is not possible to verify with these data whether the increase is still continuing, and recent declines in prey availability in the Piltun feeding ground, the main feeding ground for mother-calf pairs within the population, imply that a continued increase cannot be assumed.

The aged 1+ population size in 2018 of the Sakhalin feeding population is estimated at 191 whales, excluding calves (CL 171-214). The proportion of the population that migrates to the eastern North Pacific is estimated to be 45-80%, therefore it is likely that a western breeding population that migrates through Asian waters still exists.

1. INTRODUCTION

Gray whales (*Eschrichtius robustus*) have been regularly reported during the summer months (June to October) off northeastern Sakhalin Island since the early 1980's (Brownell *et al.* 1997) and have been intensively studied there every year since 1995 (Burdin *et al.* 2019).

Initially the Sakhalin gray whales were assumed to be a remnant of the western gray whale population formerly hunted in Korean and southern Japanese waters until the 1960s. The timing of gray whales catches in the Korean grounds was suggestive of a migration to a wintering ground in Asian waters (Kato and Kasuya 2002). Later, tagging results and photo-id and genetic matches showed that at least some of the Sakhalin gray whales migrate to breeding grounds in Mexican waters along with the bulk of the eastern North Pacific gray whale population (Weller *et al.* 2012; Mate *et al.* 2015; Urbán *et al.*

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[1] CEMS, Höllenbergstr. 7, 79312 Emmendingen, Germany. Email: jgc@cems.de
[2] Kamchatka Branch of Pacific Institute of Geography, Russian Academy of Sciences, Far East Division, Petropavlovsk, Kamchatka 683000, Russia
[3] Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA
[4] Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA

2019). Also, many individuals observed off SE Kamchatka during 2006-11 and 2018 and during 1999-2019 in Baja California, Mexico, have been matched with those off Sakhalin and with each other (Yakovlev *et al*. 2013, Burdin et al. 2019, Urbán *et al*. 2019).

However, sightings of Sakhalin-matched gray whales off the Pacific coast of Japan in spring are suggestive of the possibility that at least some of the gray whales seen off Sakhalin undertake a western North Pacific migration that may lead to a western North pacific calving area whose location is unknown (Weller *et al*. 2016; Nakamura et al. 2019).

In an analysis of the data on movement between Sakhalin and the eastern North Pacific, including data from satellite tagging of individuals and photo-id matches between Sakhalin and Mexico, Cooke (2016) concluded that 30-100% of Sakhalin whales migrate in winter to the eastern North Pacific. Thus, those data alone could not confirm or exclude the possibility of a western breeding migration. The further data collected since then make it possible to refine this estimate.

This paper updates the assessment of Cooke et al. (2017) for the Sakhalin feeding aggregation, using photo-id and biopsy data from the Russian Gray Whale Project (Burdin *et al*. 2019), supplemented by data on long-range movements from tracking (Mate et al. 2015) and matches between Sakhalin and Mexico (Urbán et al. 2019), and sex determinations from biopsies (Lang 2010 and subsequent data).

2. MATERIAL AND METHODS

2.1. Data

Photo-identification data from the Russian Gray Whale Project were available for each summer season (June to September) from the Piltun area of north-eastern Sakhalin from 1997 to 2018, with some data also collected in 1994 and 1995. A total of 280 distinct individual whales had been catalogued as of 2018. The catalogue has been published and annually updated since 2006 (Weller *et al*. 2006).

Genetic sex determinations from biopsy were available for 156 whales (89 males and 67 females) for this analysis. A total of 152 calves have been identified. Of these calves, 130 could be linked to an identified mother (in all but one case by observed association, the remaining case genetically). Of the 152 observed calves, 76 have been sexed genetically: 30 female and 46 male.

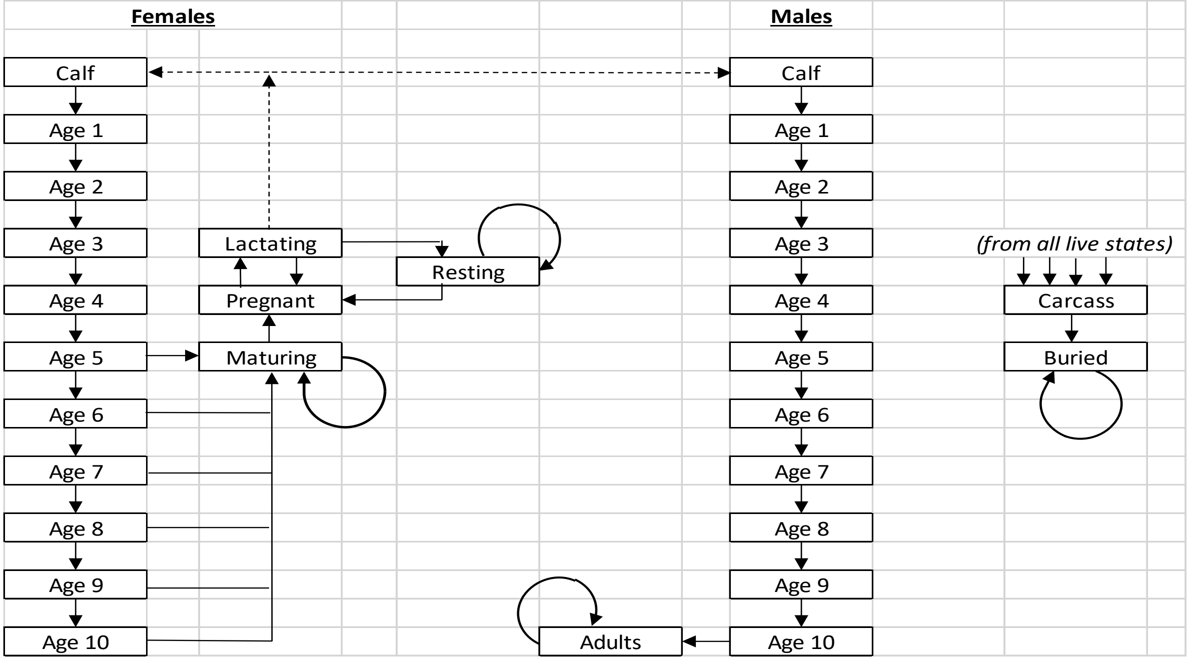
The three records of known whales successfully satellite-tracked from Sakhalin to the eastern North Pacific (Mate *et al*. 2015) were used.

A matching exercise comparing the Sakhalin catalogue for 1994-2016 and the Mexican catalogues for 1999-2019 found 34 individuals common to Sakhalin and Mexico (Urbán *et al*. 2013). As noted by Cooke (2016), very few young animals from Sakhalin are observed in the Mexican lagoons. For this analyses, whales that had been seen off Sakhalin at least 6 years previously were considered candidates for matching with the Mexican catalogues, and the Mexican samples for 2006-19 were used. These criteria resulted in 41 annual sightings of Sakhalin whales in Mexico of 27 different individuals.

2.2. Model structure

2.2.1 Population model

The population model is an individually-based stage-structured population model, as shown in Fig. 1. The model runs in discrete time with a time step of one year, except that the Mexican sightings, which are made in winter, occur between two summer seasons off Sakhalin.



Two breeding stock hypotheses are considered: (i) all whales migrate to the eastern North Pacific in winter (1-stock hypothesis); (ii) some whales migrate to the eastern North Pacific and some to another wintering ground, presumed to be in the western Pacific or Asian coastal waters (2-stock hypothesis).

The reproductive females in a stock are divided into three stages: pregnant, lactating, and resting. Females are assumed not to be simultaneously pregnant and lactating. A female can become pregnant immediately following lactation, resulting in a 2-year calving interval (the minimum observed). Optionally, a female can enter the resting phase for one or more years, resulting in a 3-year or longer calving interval. The minimum age at first (successful) pregnancy is 7 years; thereafter, the probability of becoming pregnant is assumed to increase as a logistic function of age, reaching a plateau at age 12.

The basic version of the model contains a total of 24 living stages per stock: calves (2 stages: male and female); immature and maturing males (11 stages); adult males (1 stage); immature and maturing females (11 stages); and adult females (3 stages). In addition, there is an unborn stage, a "freshly dead" stage (where a carcass might be found and identified), and a "buried" stage (no further possibility of being found). This makes a total of 27 stages for the 1-stock hypothesis and 52 stages for the 2-stock hypothesis. In models with individual heterogeneity in availability, each living stage is further subdivided into 3 availability classes, resulting in 75 or 148 stages for the 1- and 2-stock hypotheses respectively.

2.2.3 Sampling model

2.2.3.1 Photo-id sampling

An animal is 'sampled' in a given year when it is photographed in that year, and the photographs have been processed and assigned to an existing known whale in the catalogue, or to a new whale which is added to the catalogue. A lactating (or post-lactation) female may be sampled alone or with its calf; likewise, a calf may be sampled alone or with its mother. The probability that a mother-calf pair has separated before it is recorded is a parameter of the model.

The sampling probabilities off Sakhalin are parameters of the model that are allowed to vary by year, stage and individual. Individual (as opposed to stage-related) heterogeneity in sampling probability is modelled by assigning each individual with equal probability to one of three availability strata. The sampling probability may also depend on various interactions between the above factors, as determined by the model-selection process.

The annual sampling probability for Mexico was estimated externally by Cooke (2016). The sampling probability of an "adult" whale (i.e. one meeting the age criteria defined above) in the Mexican breeding grounds was estimated at 0.054 per year for the years 2006-12. In the absence of an updated capture-recapture analysis of the Mexican data, the annual sampling probability is assumed to have remained constant since 2012. It would be desirable for this estimate to be updated at the earliest opportunity.

2.2.3.2 Satellite tracking

We assume that the tracking success probability is independent of breeding location. That is, we assume that if the three whales tracked from Sakhalin to the eastern North Pacific had instead migrated south in the western North Pacific, they would have been tracked there too. With this assumption, we condition on the actual number and identity of whales successfully tracked, and do not need to model the tracking probability.

This approach implies a qualitative difference in the evidentiary value of satellite-tracked animals versus long-range photo-id matches: for photo-id, the relevant sampling probability must be known or estimated, but this is not necessary for tracked animals.

2.3. Likelihood, model fitting and model selection

Table 1 lists the factors/terms included in each of the alternative models fitted. Each model was first fitted by maximum likelihood (REML) to produce estimates of model parameters and of the population trajectory. The factors/terms to include in the model were selected using the AIC criterion, to identify a preferred model. The Bayesian posterior distribution of the population trajectory was sampled for the preferred model.

In summary, each individual has a range of potential biographies, each of which consist of a time series of its putative true state in each year. Some aspects of the state are assumed to remain constant over its lifetime, such as sex and membership of a feeding and/or breeding group. Other aspects, such as age, reproductive status, live vs. dead, change from year to year according to the transition probabilities.

In addition, each individual has an observed history. The observed history may be null for some individuals (i.e. individuals that exist but have not yet been sampled). The likelihood is calculated by comparing each putative biography with the observed history. Some aspects of the comparison are probabilistic. For example, whether an individual is sampled in a given area in a given year: the likelihood depends on the relevant sampling probabilities. Other aspects, such as sex or membership of a breeding stock, are of an either/or nature. For example, if a whale is tracked to the eastern North Pacific, all its potential biographies that involve it being a western breeder are assigned a zero likelihood. Likewise, if a whale is determined through genetic sampling to be male, all the potential biographies that involve it being female get assigned a zero likelihood.

Full details of the model and fitting procedure are given by Cooke (2018).

3. RESULTS

3.1. Model selection

Table 1 shows the results of fitting various models sequentially. Because the 2-stock model provided a much better fit, it was taken as the base case, and the 1-stock model fitted as an alternative. Case A represents the minimal reasonable sampling model for the two-stock biological model: the sampling probability at Sakhalin varies by year (to account for variable research effort, due to weather, logistics and other factors) but is the same for all individuals. Allowing the sampling probability to differ between population components (subadult, male, female with calf, calf, female without calf, calf) (case B) substantially improves the fit (ΔAIC = –26.8). Allowing the relative availability of the different population components to vary by year (i.e. including a component-year interaction) (case C) further improves the fit substantially (ΔAIC –56.9). Allowing for individual heterogeneity in availability (case

D) improves the fit yet further (ΔAIC = –147.9). Including an interaction term between population component and individual availability (case E) further improved the fit somewhat (ΔAIC = –6.8).

Allowing annual variability in the calving rate (case F) also improved the fit (ΔAIC = –10.6), and allowing variability in the calf survival rate (case G) improved the fit still further (ΔAIC = –10.7). This was the best-fitting model of those considered for the 2-stock hypothesis. The 1-stock version of this model (case P) resulted in a poorer fit to the data (ΔAIC = +16.3).

The 1-stock model can, therefore, be rejected. The accepted model has two breeding stocks, annual variability in both calf production and survival, and considerable heterogeneity in availability of whales for sampling.

Table 1. Results of sequential fitting of variois models

Case	Stocks	Calf mortality	Calf production	Sighting probability	Log-like	d.f.	AIC	ΔAIC
A	2	**1**	**1**	**Year**	-2071.9	31.7	4207.2	
B	2	**1**	**1**	**Year** + PopCpt	-2054.5	35.8	4180.5	-26.8
C	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt	-1955.0	106.8	4123.6	-56.9
D	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt + Class	-1882.1	105.7	3975.8	-147.9
E	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1876.1	108.3	3968.9	-6.8
F	2	**1**	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1861.9	117.2	3958.4	-10.6
G	2	**1** + Year	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1847.4	126.4	3947.7	-10.7
H	1	**1** + Year	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1853.6	128.4	3963.9	+16.3

Bold: term fitted as fixed effects (free parameters)
Others fitted as frandom effects.
Selected model

3.2. Population size and trajectories

Table 2 lists estimates of some key demographic parameters with confidence limits. A random sample of 50 trajectories from the posterior distribution of population trajectories for the best-fitting model is shown in Fig. 2 for (a) the aged 1+ population and (b) reproductive females only. In each plot the trajectories are shown for (i) the entire Sakhalin feeding population; (ii) the western North Pacific breeding subset of the Sakhalin feeding population.

The results show that the Sakhalin feeding population has been increasing at 4.1% p.a. (CI 3.4-4.8% p.a.) over the 20 years to 2018. The aged 1+ (non-calf) population is estimated at 191 whales in 2018 (95% CI 171 - 214) and the mature female population is estimated at 45 whales (95% CI 40 - 53). The Proportion of the Sakhalin feeding aggregation that migrates to the eastern North Pacific is estimated at 45-80%, meaning that at least 20% probably migrate elsewhere, likely to wintering areas in Asian waters, given the non-occurrence of gray whales off Sakhalin in winter, when the feeding grounds are usually covered by sea ice.

4. DISCUSSION

The aged 1+ population size estimates presented here are slightly lower than those provided by Cooke (2018) for the same year and comparable stock definition, because that analysis included observations from the offshore feeding ground off Sakhalin and from eastern Kamchatka. However, the estimates of the mature female population size are approximately equal in the two studies, which reflects the fact that the main data used in this paper were collected in the main feeding area for mothers with calves.

The fitted model shows that the population of gray whales has been increasing. However, it is difficult from individual identification data alone to detect in the short term whether a past increasing trend is still continuing. Demographic parameters such as calf survival can only be reliably estimated some years in retrospect, because calves which apparently failed to return may be feeding elsewhere.

Recently, Labay et al. (2019) reported a much lower abundance of amphipoda, the main gray whale prey type, in the benthos of the Piltun feeding ground during 2013-16 compared with previous years (2002-2012), while the abundnace of prey in the offshore feeding ground has remained high. There has also been a shift in distribution of gray whales such that the occurrence of whales (other than calves and mother-calf pairs) in the Piltun ground has decreased, with a concomitant increase in whales in the offshore feeding ground, but mother-calf pairs continue to be observed exclusively on the Piltun feeding ground and not offshore (Yakovlev et al. 2019). Within the Piltun feeding ground, there has been a progressive southward shift of the distribution asway from the mouth of Piltun lagoon, that was especially marked in 2018 (Burdin *et al*. 2019).

The cause of the reduction in prey has not been definitely determined. Depletion of the prey by the gray whales themselves and other predators has been proposed, while concern has also been expressed about potential effects of construction activity across the mouth of Piltun lagoon. Unfortunately, no benthos data were collected in 2017-18, and no collection is planned for the 2019 season. The Western Gray Whale Advisory Panel has strongly recommended resumption of the benthic sampling (WGWAP 2019).

Because of the dependence of mother-calf pairs on the inshore feeding ground, the recent reduction of prey availability might be expected to influence calf survival. However, for the reasons given above, this would require more years of monitoring for reliable detection of a change. The WGWAP has also strongly recommended continuation of the RGWP photo-identification programme.

The updated assessment in this paper strengthens the evidence for a continued western breeding population, because the number of matches of Sakhalin whales with whales in the Mexican catalogues is still less than would be expected if all Sakhalin whales would migrate to the eastern North Pacific in winter. However, an updated analysis of the full Mexican catalogues is needed to refine the estimate of the annual proportion of the eastern gray whale population that is identified.

ACKNOWLEDGEMENTS

We would like to acknowledge the work of all the volunteer biologists over the years who have assisted with data collection for the Russian Gray Whale Project based at Piltun, Sakhalin.. We are also grateful to the International Fund for Animal Welfare (Marine Conservation Program) which has provided full or partial funding for the field work since 2002.

Table 2. Estimates of key biological parameters.

	Maximum likelihood		Posterior distribution percentiles		
	estimate	SE	2.5%	median	97.5%
Population size in 2018					
Aged 1+					
Total Sakhalin	191	12	171	189	214
Western Breeding Stock	87	15	54	72	109
Reproductive females					
Total Sakhalin	45	3	40	50	53
Western Breeding Stock	19	3	10	16	27
Proportion of Sakhalin whales migrating to ENP	0.56		0.45	0.60	0.80
Growth rate 1998-2018 (Aged 1+, Sakhalin)	0.041		0.034	0.041	0.048
Survival rate					
Calves	0.65	0.07			
non-calves	0.975	0.005			

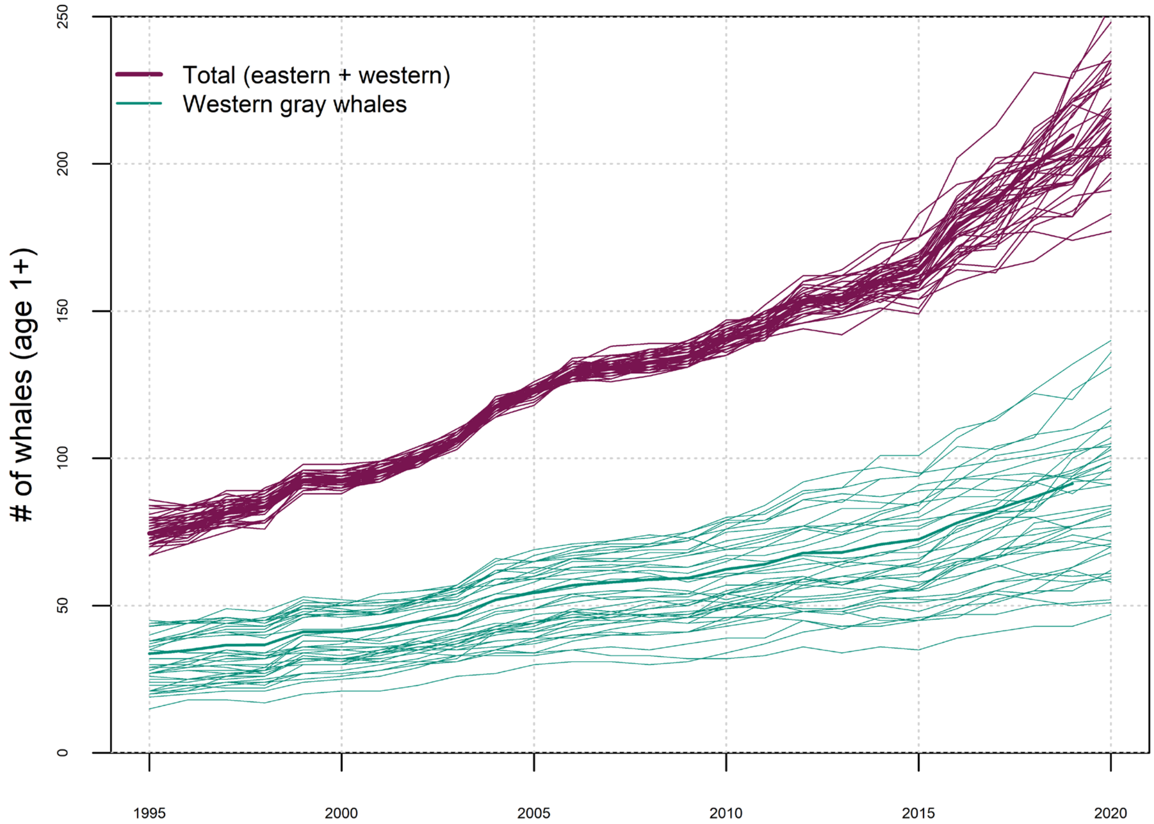


Fig. 2a. Sakhalin gray whales. Maximum likelihood population trajectory and random posterior sample of trajectories for the aged 1+ population.

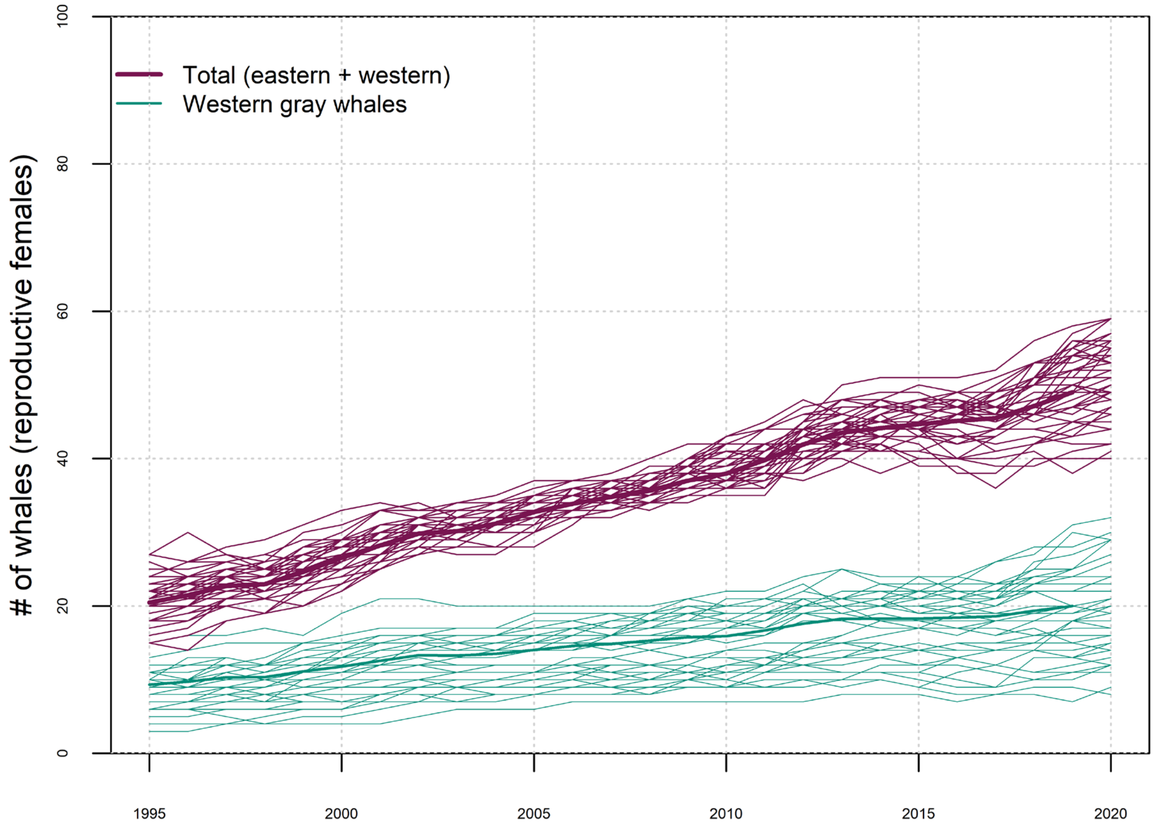


Fig. 2b. Sakhalin gray whales. Maximum likelihood population trajectory and random posterior sample of trajectories for the reproductive female population.

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
501 West Ocean Boulevard, Suite 4200
Long Beach, California 90802-4213

3 July 2019

MEMORANDUM FOR: Chris Yates
Assistant Regional Administrator
Protected Resources Division
West Coast Regional Office

FROM: Jeff Moore
Leader, California Current Marine Mammal Assessment Program
Marine Mammal and Turtle Division
Southwest Fisheries Science Center

SUBJECT: Updated estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt (**Information Memorandum)**

Observations of gray whales (*Eschrichtius robustus*) from the western North Pacific (WNP) migrating to areas off the coast of North America (Alaska to Mexico) has raised concerns that this small population could be encountered during a hunt of eastern North Pacific (ENP) gray whales proposed by the Makah Indian Tribe in northern Washington, USA. In 2013, an analysis was conducted to estimate the probability of striking (i.e. killing or seriously injuring) a WNP whale under the Makah Tribe's hunt proposal (Moore and Weller 2013; NOAA Tech Memo NMFS-SWFSC-506). This analysis was updated in 2018 (Moore and Weller 2018; NOAA Tech Memo NMFS-SWFSC-605) to account for new data and a revised draft proposal by NOAA Fisheries for governing ENP gray whale hunts by the Makah Tribe for up to 10 years. Under the draft proposal, hunting seasons would alternate between winter-spring hunts in even-numbered years and summer hunts during odd-numbered years. It is presumed that only in even-numbered years (thus, for 5 of the 10 years) would WNP whales potentially be encountered during the hunt. In each of these years, the draft proposal would allow for up to 3 gray whales to be struck. Here, we again re-estimate the probability of striking a WNP whale based on a new (higher) population size estimate and a new (lower and more precise) estimate of the proportion of WNP whales mixing with ENP whales during migration. We used the same model as the 2018 analysis (Model 2A) to generate new estimates. We estimate that for an individual strike on a gray whale, the expected probability of it being a WNP whale is 0.005 (95% Bayesian CRI: 0.003 – 0.007), up slightly from 0.004 in the 2018 analysis. For a single year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.015 (0.009 – 0.022); this is up slightly from 0.012. Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.074 (0.045 – 0.104), up slightly from 0.058.

The new analysis is available in the form of a new draft Technical Memorandum by Jeff Moore and David Weller. This draft is attached.

Attachment:
Draft Tech Memo titled: “Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2019 Update” (Authors: Jeff Moore and David Weller, SWFSC)

cc:
SWFSC-MMTD: Dave Weller, Lisa Ballance
WCR: Steve Stone
F/GC: Laurie Beale, Caitlin Imaki

doi:XXXX

NOAA Technical Memorandum NMFS

XXXX 2019

Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2019 Update

Jeffrey E. Moore and David W. Weller

NOAA-TM-NMFS-SWFSC-XXX

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries, is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

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doi:XXXX

NOAA Technical Memorandum NMFS

XXXX 2019

Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2019 Update

Jeffrey E. Moore and David W. Weller

Marine Mammal and Turtle Division, Southwest Fisheries Science Center
National Marine Fisheries Service, National Oceanic and Atmospheric Administration
8901 La Jolla Shores Drive, La Jolla, CA 92037 USA

NOAA-TM-NMFS-SWFSC-XXX

U.S. DEPARTMENT OF COMMERCE
Wilbur L. Ross, Secretary of Commerce

National Oceanic and Atmospheric Administration
Benjamin P. Friedman, Acting NOAA Administrator

National Marine Fisheries Service
Chris W. Oliver, Assistant Administrator for Fisheries

ACKNOWLEDGEMENTS

We extend our gratitude to the NOAA Fisheries West Coast Regional Office and Southwest Fisheries Science Center for their contributions to, and support of, this work.

EXECUTIVE SUMMARY

Observations of gray whales (*Eschrichtius robustus*) from the western North Pacific (WNP) migrating to areas off the coast of North America (Alaska to Mexico) raised concerns that this small population could be encountered during a hunt of eastern North Pacific (ENP) gray whales proposed by the Makah Indian Tribe in northern Washington, USA. In 2013, an analysis was conducted to estimate the probability of striking (i.e. killing or seriously injuring) a WNP whale under the Makah Tribe's hunt proposal (Moore and Weller 2013). This analysis was updated in 2018 (Moore and Weller 2018) to account for new data and a revised draft proposal by NOAA Fisheries for governing ENP gray whale hunts by the Makah Tribe for up to 10 years. Under the draft proposal, hunting seasons would alternate between winter-spring hunts in even-numbered years and summer hunts during odd-numbered years. It is presumed that only in even-numbered years (thus, for 5 of the 10 years) would WNP whales potentially be encountered during the hunt. In each of these years, the draft proposal would allow for up to 3 gray whales to be struck. Here, we again re-estimate the probability of striking a WNP whale based on a new (higher) population size estimate and a new (lower) and more precise estimate of the proportion of WNP whales mixing with ENP whales during migration. We used the same model as the 2018 analysis (Model 2A) to generate new estimates. We estimate that for an individual strike on a gray whale, the expected probability of it being a WNP whale is 0.005 (95% Bayesian CRI: 0.003 – 0.007), up slightly from 0.004 in the 2018 analysis. For a single year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.015 (0.009 – 0.022); this is up slightly from 0.012. Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.074 (0.045 – 0.104), up slightly from 0.058.

INTRODUCTION

Two gray whale (*Eschrichtius robustus*) populations are recognized in the North Pacific Ocean. Significant mitochondrial and nuclear genetic differences have been found between whales in the western North Pacific (WNP) and those in the eastern North Pacific (ENP) (LeDuc *et al*., 2002, Lang *et al*. 2010, Lang *et al*., 2011). The ENP population ranges from wintering areas in Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas (Fig. 1). An exception to this generality is the relatively small number (100s) of whales that summer and feed along the Pacific coast between Kodiak Island, Alaska, and northern California (Weller *et al*., 2013). These whales are collectively called the Pacific Coast Feeding Group (PCFG). The International Whaling Commission (IWC) has defined PCFG whales as individuals observed between 1 June and 30 November from 41°N to 52°N in two or more years (IWC, 2012), and NOAA Fisheries has adopted this definition in recent assessments (Weller *et al.*, 2013). The usual and accustomed (U&A) fishing grounds of the Makah Indian Tribe are off the coast of northern Washington, USA, and overlap with a portion of the PCFG summering area (Fig. 1).

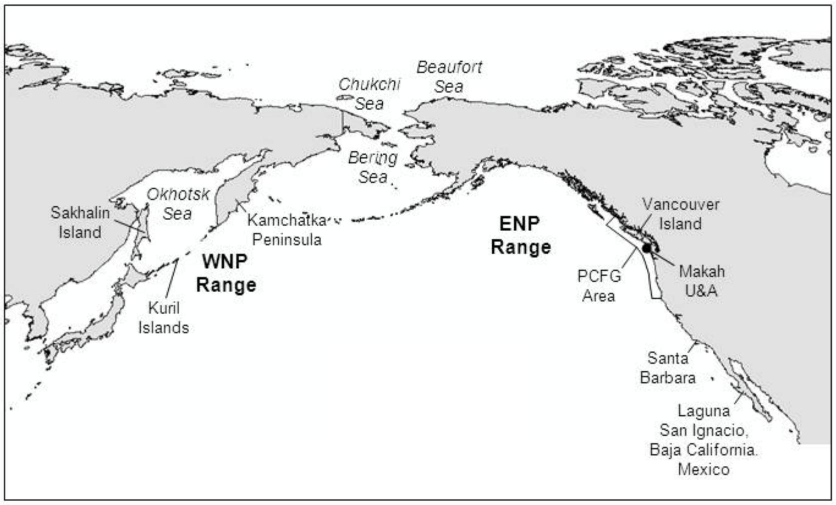

Figure 1. Areas in the western and eastern North Pacific mentioned in the report.

The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia (Weller *et al*., 1999; Weller *et al*. 2012), and in nearshore waters of the southwestern Bering Sea off the southeastern Kamchatka Peninsula (Tyurneva *et al*., 2010). The historical distribution of gray whales in the Okhotsk Sea greatly exceeded what is found today (Reeves *et al*., 2008). Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford *et al*., 2008), indicating they use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010). A small number of whales observed off Sakhalin have also been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*., 2003).

Mixing of whales identified in the WNP and ENP has been observed (Weller *et al*., 2012). Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off Santa Barbara, California in March 1995. Between 2010 and 2012 three whales outfitted with satellite transmitters were tracked moving from Sakhalin in the WNP to the ENP (Mate *et al*., 2015). Finally, photographic matches between the WNP and ENP, including matches between Sakhalin, Vancouver Island and Laguna San Ignacio and other nearby lagoons in Baja California, Mexico (Fig. 1), have further confirmed use of areas in the ENP by whales identified in the WNP (Weller *et al*., 2012, Urbán *et al*., 2019). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales in the WNP and ENP have been found (LeDuc *et al*. 2002, Lang *et al*., 2011).

In 1995, following the 1994 delisting of ENP gray whales under the U.S. Endangered Species Act, the Makah Indian Tribe notified NOAA Fisheries of its interest in re-establishing limited ceremonial and subsistence whale hunting. The decision-making history on this issue is complex and not described here except to note that in 2005, the Makah Tribe submitted a detailed proposal for hunting ENP gray whales in the coastal portion of its U&A off northern Washington, USA, as part of a request for a waiver of the U.S. Marine Mammal Protection Act's (MMPA) take moratorium (16 USC 1371(a)(3)(A)). Subsequently, observations of WNP gray whales migrating through areas off the coast of North America (Alaska to Mexico) emphasized the need to evaluate the probability of a WNP gray whale being encountered in aboriginal hunts for ENP gray whales (IWC, 2012). Following recommendations of the Scientific Committee of the International Whaling Commission (IWC), analyses were conducted to estimate such probability in the context of the Makah Tribe's hunt proposal (Moore and Weller, 2013). These analyses informed a draft Environmental Impact Statement (DEIS), completed in 2015 (NMFS, 2015), pertaining to the Makah Tribe's MMPA waiver request.

NOAA Fisheries is presently considering a MMPA waiver and associated draft proposal that would govern a modified version of the Tribe's hunt proposal. The objective of the analysis reported here was to provide updated estimates of the probability that one or more WNP whales might be subjected to strikes[1], unsuccessful strike attempts (i.e., harpoon throws that do not penetrate), and vessel approaches during hunts and hunt training exercises considered in the draft proposal. This report is based on the methods used by Moore and Weller (2013, 2018) and incorporates updated information about the population sizes of ENP and WNP gray whales and their occurrence within the proposed hunt area.

METHODS

Hunt proposal

NOAA Fisheries' draft proposal would govern a Makah Tribe hunt of ENP gray whales in the coastal portion of the U&A (i.e., the "hunt area") over a 10-year hunt period. In odd-numbered years, the hunt would take place from 1 July through 31 October, a period when no sightings of WNP whales have been recorded in the ENP, and when gray whales generally (apart from PCFG

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[1] As described in NOAA Fisheries' DEIS (NMFS, 2015), the term "strike" is interpreted to be consistent with the IWC Schedule definition as meaning "to penetrate with a weapon used for whaling."

animals) are in northern feeding areas. Thus, hunted animals in these odd-numbered years would presumably belong to the PCFG and it is assumed that WNP whales would not be at risk from proposed hunt operations. In even-numbered years, the hunt would take place from 1 December through 31 May. This period coincides with both the southward (December to mid-February) and northward (mid-February to late May) migration of ENP whales and overlaps with the time when WNP gray whales have been sighted in the ENP. Thus, in even-numbered years there is a potential risk to WNP whales from proposed hunt operations. In each of the even-numbered years, a maximum of 3 gray whales per year could be struck (including "struck and lost" animals). Over the 10-year period of the proposed hunt, a maximum of 15 whales could be struck (in even-numbered years) that would have some probability of being WNP whales. We therefore evaluate the probability of striking at least one WNP whale per even-numbered year (out of 3 strikes) and for the 10-year period (out of 15 strikes). We also evaluate associated rates of WNP whales being subjected to aforementioned "unsuccessful strike attempts" (i.e., harpoon throws that do not penetrate) and "approaches" (i.e., whales approached by vessels during hunts and hunt training exercises).

Data

Abundance estimates - The ENP abundance estimate (for 2015/2016) is 26,960 (CV = 0.05) (Durban *et al.*, 2017). The combined Sakhalin-Kamchatka WNP abundance estimate (for 2016) is 290 (CV = 0.035) for the 1+ population (i.e., excluding calves) (Cooke 2017, Cooke 2018). This is revised from the estimate of 200 that was used by Moore and Weller (2018). We multiplied the WNP 1+ estimate by 1.099 to account for calves, thereby producing an abundance estimate for the entire population. This multiplier is based on the ratio of the population size with and without calves in 2012 (IUCN, 2012).

Mixing proportions based on sightings in the Makah Hunt Area - During spring surveys (March to May) in 1996-2012 there were 181 observed whale-days in the Makah hunt area (Calambokidis *et al*., 2014). To clarify the term "whale-day" – all sightings of an individual on a particular day collectively count as 1 whale-day (e.g., multiple sightings of the same individual on the same day count as just 1 whale-day, but the same individual seen the next day would count as a second whale-day). None of the 181 whale-days observed included WNP whales[2]; 73 (40.3%) were considered PCFG whales; and the rest (108, or 59.7%) were assumed to be migrating ENP whales.

However, rather than use 40.3% as the expected PCFG proportion in the hunt area during an even-year hunt, we use 28% for this mixing proportion (i.e. 72% of animals encountered during an even-year hunt are likely to be non-PCFG animals). This value is based on analyses summarized in a 2018 IWC workshop (IWC, 2018).

Proportion of WNP whales migrating with ENP whales - The proportion of the WNP population that migrates along the North American coast is unknown but Moore and Weller (2018) used a uniform distribution with minimum of 0.37 and maximum of 1.00. The lower bound was based on analysis by Cooke (2015) and reported to a 2015 IWC workshop on gray whale population

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[2] Although not in the Makah hunt area, Weller *et al*. (2012) report observing three WNP whales on 2 May 2004 and three more on 25 April 2008 near Barkley Sound off the west coast of southern Vancouver Island, British Columbia, Canada.

structure (IWC, 2016). The upper bound reflected the uncertain possibility that perhaps all animals migrated with the ENP population. More recently, Cooke et al. (2019) used results from an updated ENP-WNP photo-identification catalog comparison (Urbán *et al*., 2019) to estimate that approximately 0.60 (95% CI: 0.45 – 0.80) of the WNP population migrates to the North American coast.

Model

Moore and Weller (2013) considered four models in their analysis but they based final inferences on what they termed Model 2B. Moore and Weller (2018) used Model 2A instead (see their paper for justification), and we do so here as well.

Model 2A makes use of the mixing proportion/sightings data for the Makah hunt area, as well as WNP and ENP abundance estimates. WNP whales are assumed to be moving with the ENP migrants, so that the marginal probability of a WNP whale being struck is the probability that the struck whale is a migrant, P_{mig} (i.e., probability of not being a PCFG whale), multiplied by the conditional probability of being a WNP whale given that it is a migrant ($P_{WNP|mig}$). Thus, $P_{WNP} = P_{mig}P_{WNP|mig}$.

P_{mig} is defined as 1 – P_{PCFG}, where P_{PCFG} is given by an informative prior: P_{PCFG} ~ Beta (5.3648, 13.7952) which has a mean of 0.28 and SD of 0.1 (IWC 2018).

We assume that the per-capita likelihood of a migrating (non-PCFG) whale in the hunt area being a WNP whale (i.e., $P_{WNP|mig}$) is simply given by the proportion of the migrating population made up of WNP whales. This proportion depends on what fraction of the WNP population migrates along the U.S. West Coast, which we call *m*, and the relative size of the WNP to the ENP population. Thus, $P_{WNP|mig} = mN_{WNP}/(mN_{WNP} + N_{ENP})$. We described *m* as broadly uniformly distributed in our earlier analysis (Moore and Weller 2018). Here, let *m* ~ Beta (17.18, 11.45), based on Cooke *et al.* (2019). This Beta distribution has median and mean of 0.60 with 95% CRI of 0.42 – 0.77 (note that Cooke reported a maximum likelihood estimate of 0.56, median of 0.60, and 95% CRI of 0.45 to 0.80; these values cannot be described exactly by a Beta distribution, but the distribution we use is a close approximation) . N_{WNP} and N_{ENP} are treated as lognormally distributed variables with means and CVs as given above.

Estimation

Earlier analyses (Moore and Weller, 2013) used Bayesian estimation. In the 2018 analysis and current exercise, analysis was conducted using OpenBUGS software, but estimation was not strictly Bayesian because there are no new data updating the informative prior inputs. Rather, these more recent analyses were essentially Monte Carlo procedures, with distributions for the parameters of interest (e.g., probability of striking a WNP whale) being derived from random draws from informed prior distributions for the input parameters. Derived parameter distributions were summarized from two MCMC chains, each 25,000 samples in length (50,000 samples total).

Derived parameters

The key parameter of interest is the per-strike probability of striking a WNP whale. Derived from this parameter are the probabilities of striking at least one WNP out of 3 gray whale strikes (i.e., the annual probability of striking a WNP whale, for the even-numbered years) or out of 15 gray whale strikes (i.e., probability for the whole 10-year period). These are calculated as $P(x > 0) = 1 - (1 - P_{WNP})^X$, where X is 3 or 15. Additionally, we can derive the expected number of WNP strikes as $E(x) = P_{WNP}X$. Using data collected during previous hunts (NMFS, 2015), the following two assumptions were used to calculate analogous estimates for vessel approaches and unsuccessful strike attempts: (1) there will be 353 vessel approaches per year (3530 across all 10 years)[3], and (2) there will be 6 unsuccessful strike attempts for every strike in an even-year hunt[4].

RESULTS

Parameter estimates

Estimated parameters from all model sets are in Table 1. For comparison, we also show the posterior mean from the 2018 analysis. Figure 2 shows the distribution for P_{WNP}. It is straightforward to integrate across the uncertainty in P_{WNP} to obtain a single probability estimate. We did this for the probability of striking ≥ 1 WNP whale over the entire 10-year hunt period (i.e., out of 15 strikes). This probability was 0.074 (posterior mean).

Table 1. Distribution summaries for key model parameters. "Prob(WNP)" is the probability of at least 1 WNP animal being struck or subjected to unsuccessful strike attempts or vessel approaches given the specified number of events. For comparison, we also show the posterior mean from the 2018 analysis.

	2018	2019 Analysis			
Parameter	Posterior mean	Posterior mean	2.5% CRI	Posterior median	97.5% CRI
Prob(WNP) for a single interaction, i.e., P_{WNP}	0.004	0.005	0.003	0.005	0.007
Prob(WNP|3 strikes in 1 yr)	0.012	0.015	0.009	0.015	0.022
Prob(WNP|15 strikes in 10 yrs)	0.058	0.074	0.045	0.073	0.104
Prob(WNP|18 unsuccessful strike attempts in 1 yr)	0.070	0.088	0.054	0.087	0.124
Prob(WNP|90 unsuccessful strike attempts in 10 yrs)	0.299	0.365	0.243	0.367	0.483
Prob(WNP|353 approaches in 1 yr)	0.735	0.823	0.665	0.833	0.925
Prob(WNP|3530 approaches in 10 yrs)	~ 1.0	~ 1.0	~ 1.0	~ 1.0	~ 1.0
Expected WNP|3 strikes in 1 yr	0.012	0.015	0.009	0.015	0.022
Expected WNP|15 strikes in 10 yrs	0.060	0.076	0.046	0.076	0.110
Expected WNP|18 unsuccessful strike attempts in 1 yr	0.072	0.092	0.056	0.091	0.132

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[3] This number is conservative because it assumes that all approaches (hunting and training) in both even and odd years occur during the winter/spring period when WNP whales may be present. Realistically we would expect a substantial number of approaches to occur outside this period, i.e., during the summer when ocean conditions are more favorable and, in odd years, when hunting approaches are restricted to July - October.

[4] We expect zero in odd years because the draft proposal limits training strikes (which count as unsuccessful strike attempts) to the summer-fall hunting season, when WNP whales are not expected to be present.

Expected WNP|90 unsuccessful strike attempts in 10 yrs	0.361	0.458	0.278	0.455	0.658
Expected WNP|353 approaches in 1 yr	1.416	1.796	1.091	1.786	2.579
Expected WNP|3530 approaches in 10 yrs	14.16	17.96	10.91	17.86	25.79

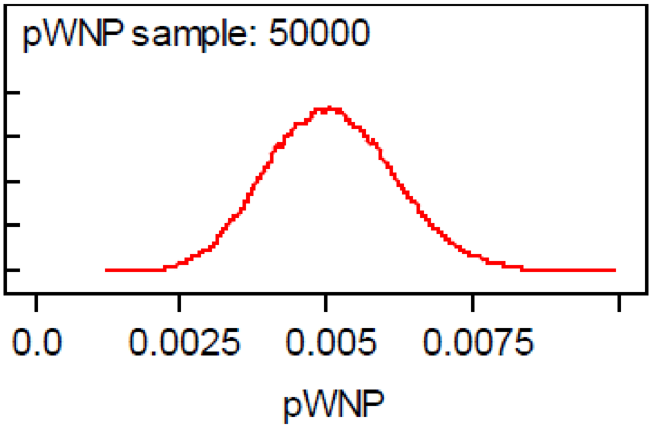

Figure 2. Posterior distribution for probability that any given strike is a WNP whale.

DISCUSSION

Estimates from our analysis may be precautionary since they assume that the Makah hunt will achieve proposed maximum strike limits, and because the assumption of Model 2A is that WNP whales are homogenously mixed with ENP whales. The likelihood of striking a WNP whale is overestimated if fewer total animals are struck or if in reality the WNP animals use a different migration corridor and are less likely to travel through the Makah hunt area. Given uncertainties associated with the model and scenario assumptions, these results serve as a rough approximation of the potential for WNP gray whales to be subjected to strikes, unsuccessful strike attempts and vessel approaches during a Makah hunt operating under a draft proposal currently being considered by NOAA Fisheries.

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