A preliminary estimate of abundance of the Eastern North Pacific stock of gray whales in 2000/01 and 2001/02

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ABSTRACT

The southbound migration of the Eastern North Pacific stock of gray whales (*Eschrichtius robustus*) was documented recently by the National Marine Fisheries Service from 13 December 2000 to 5 March 2001 and from 12 December 2001 to 5 March 2002. Research protocol was essentially identical to that used in previous surveys. This involved single observers independently searching for whales and recording data on effort and sighting time, location, count and direction-headed. In 2000/01, 1,689 pods (2,754 whales) were counted during 592.6 hrs of standard watch effort when visibility was recorded as fair to excellent. In 2001/02, there were 1,711 pods (2,800 whales) counted during 531.7 hrs. The southbound migration in 2000/01 was more protracted than any other observed migration, with many whales still traveling south 3 weeks later than typical. However, in 2001/02, the migratory timing was normal, with the southbound migration ending in mid-February. Data analysis procedures were essentially the same as those used in previous years, although some correction factors were kept the same between years until analytical programs are revised. Accordingly, all results presented here are considered **preliminary and are subject to change**. The provisional abundance estimate from the 2000/01 census is 18,761 whales (CV = 10%; 95% log-normal confidence interval = 15,429 to 22,812), and the 2001/02 provisional estimate is 17,414 whales (CV = 10%; 95% log-normal confidence interval = 14,322 to 21,174). Both of these estimates are well below the previous (1997/98) estimate of 26,635 whales (CV = 10.06%; 95% log-normal confidence interval = 21,878 to 32,427). These low estimates might have been caused by an unusual number of whales that did not migrate as far south as Granite Canyon in these seasons, or the abundance may have declined following the high mortality rates observed in 1999 and 2000.

KEYWORDS: GRAY WHALES; *ESCHRICHTIUS ROBUSTUS*; MONITORING; SURVEY, SHORE-BASED; ABUNDANCE ESTIMATE

INTRODUCTION

The National Marine Fisheries Service (NMFS) has conducted shore-based counts of the Eastern North Pacific stock of gray whales (*Eschrichtius robustus*) 20 times between 1967 and 1998 at Granite Canyon (or Yankee Pt) near Carmel, California (Table 1). Convenient access to this site and the narrowness of the whales' migratory corridor in this area have permitted an efficient counting process that has been repeated through many seasons (Reilly, 1984; Laake *et al.*, 1994; Hobbs and Rugh, 1999; Buckland and Breiwick, in press; Hobbs *et al.,* in press). All of these counts were done during the two-month southbound migration (Rugh *et al*., 2001), which is less protracted than the three-month northbound migration (Pike, 1962). The routine nature of these counts lends to inter-annual trend analyses. For example, Buckland and Breiwick (in press) showed there has been an increase of 2.5% per annum (SE = 0.3%) between 1967/68 and 1995/96.

The primary objective of the studies in 2000/01 and 2001/02 was to continue these standardized counts for the purpose of extending the trend analysis. Of particular interest is that this may be the first large whale stock that has been monitored through the recovery process as it approaches its carrying capacity. An additional incentive to conduct the study in 2001/02 was to assess the abundance after two years (1999 and 2000) in which unusually high counts of dead gray whales had been reported (LeBoeuf *et al*., 2000; Norman *et al*., 2000; NMFS, unpubl. data).

METHODS

Field methods

Systematic counts of gray whales were conducted from 13 December 2000 to 5 March 2001 and 12 December 2001 to 5 March 2002, covering most of the duration of the southbound migration past the Granite Canyon research station, 13 km south of Carmel, in central California. Observation sheds provided a writing platform with some protection from the elements. Average eye height above sea level was 22.5 m. Although the field of view covered >150°, observers generally searched through an arc of only 40-50° near the standard azimuth, a line perpendicular to the coastline (241° magnetic) intersecting the survey site. A total of 10 people took part in the shore-based counts in 2000/01 and 15 in 2001/02 (see Acknowledgments). Most of these observers were experienced at cetacean surveys, and 6 had previous experience with gray whale counts at Granite Canyon prior to December 2000. Three 3-hour standard watch shifts covered the 9 daylight hours from 0730 to 1630. Observers were rotated to keep a balance of effort in each of the three shifts.

Standard watch procedures were the same as in previous surveys (Rugh *et al.*, 1990; 1993). Each observer searched for whales independently and hand-recorded entries onto a data form. When a gray whale pod was first sighted within the primary viewing range, the time, horizontal bearing and vertical angle were recorded as a "north sighting." Magnetic compasses in Fujinon 7x50 binoculars provided the horizontal bearings ($\pm$ 2°), and 14 reticle marks in the binoculars provided vertical angles relative to the horizon (detailed in Rugh *et al.*, 1993; Kinzey and Gerrodette, 2001). A chart was available to help predict the time and vertical angle at which the pod would cross the standard azimuth. The time, horizontal bearing and vertical angle were recorded a second time (the "south sighting"), as close to the standard azimuth as possible. Entries included a pod size estimate, any unusual behaviors and calf sightings. During periods of routine search effort, observers recorded the number of times each pod was sighted within the viewing area ("cue counts"). These counts were treated in the analysis as cues per pod and compared between seasons as a quantifiable index of relative visibility. Also, observers recorded start and end times of systematic search effort and times of environmental changes, which included visibility (subjectively categorized from 1 to 6 for excellent to unacceptable), sea state (Beaufort scale) and wind direction.

In addition to the primary watch, a second, independent watch was conducted once or twice daily from 29 December 2000 to 11 February 2001 and 2 January to 7 February 2002. The paired watch (in "South Shed") had a field of view and station conditions nearly identical to those of the primary watch (in "North Shed"). This provided an independent sighting record, allowing for comparisons between observers and an estimation of the number of whales missed within the viewing area. Methods applied were as described in Rugh *et al.* (1993).

Offshore distribution of whale sightings was documented through a shore-based 25-power binocular on a fixed-mount, as per Rugh *et al.* (in press). No correction factor, other than for probability of detection by distance, was applied for whales passing the site beyond 3 nm because aerial surveys conducted in the past (Shelden and Laake, in press) have estimated that only 1.28% of the whale population travels beyond the viewing range of shore-based observers– approximately 3 nm offshore. Until the analysis is complete, it is assumed that the offshore distribution of whales in recent years has not changed from distributions documented in the past.

Analysis

Population abundance calculations from the observer counts follow the analytical procedures described in Hobbs *et al*. (in press). These methods account for: 1) whales passing during periods when there is no observational effort (prior to and after the census season, at night or when visibility is poor); 2) whales missed within the viewing range during on-effort periods; 3) differential sightability by observer, pod size, distance offshore and various environmental conditions; 4) errors in pod size estimation; 5) covariance within the corrections due to variable sightability by pod size and 6) differential diel travel rates of whales.

Calculation of crossing times

The recorded sighting time and location closest to the standard azimuth (usually within a few degrees of this bearing) were converted to estimate the time and vertical angle at which each pod crossed this line. This was based on the assumption that southbound migrating gray whales travel at 3 kt and maintain a course parallel to shore (c.f. Swartz *et al*., 1987). The time from the beginning to the end of the survey season was partitioned into effort periods (time between 0730 and 1630 with visibility 4 or better and an observer on watch) and non-effort periods. Each sighting was assigned to the effort or non-effort period into which it fell as a function of the calculated time it crossed the standard azimuth. Whale sightings were eliminated from the analysis if they crossed this line prior to the start of an effort period or if they had not crossed the line by the end of an effort period.

Correction for missed pods and bias in recorded pod sizes

Corrections for whale pods missed within the viewing area during a systematic watch are usually estimated from the paired, independent observation records. However, in this preliminary analysis, it is assumed that observer performance in the most recent seasons was similar to that in 1997/98 (Hobbs and Rugh, 1999). Bias in the recorded pod size resulting from under-estimation of pod size by observers is removed by an additive correction which has been estimated for each pod size, *i*, from data collected during earlier surveys (Laake *et al*., 1994), with the variances and covariances calculated in Hobbs *et al*. (in press). The total number of whales, W_e, passing the observation site during effort period *e*, represented by pods recorded as size *i*, was estimated as:

$$W_e = \sum_{i=1}^{i_{\max}} \frac{(i+b_i)}{p_i} m_{i,e}$$

where $m_{i,e}$ is the observed number of pods of size *i* in effort period *e*, b_i is the estimated additive bias correction for pods estimated as size *i* from Laake *et al*. (1994) and p_i is the estimated average probability of detection for pods estimated as size *i* from Hobbs and Rugh (1999).

The total number of whales passing the site during usable effort periods, *W*, was estimated as:

$$W = \sum_{e=1}^{E} W_e$$

where *E* is the total number of useable effort periods during the season.

Correction for whales passing during non-watch periods (f_t)

The rate of whales passing the site through time was modeled by a normal distribution with Hermite polynomials added to adjust for skewness, kurtosis and higher moments (Buckland *et al*., 1993). The model defines a bell-shaped rate function, *q*(*t*), of expected whales per day that was integrated to correct for periods when no watches were conducted. The correction factor, f_t, was defined as the ratio of the area under *q*(*t*) integrated over the entire survey period, *Q*, to the area under q(t) integrated only over watch effort periods.

Correction for nocturnal travel rates (f_n)

The night passage rate, f_n = 1.020 (SE = 0.023), used by Buckland *et al.* (1993) was also used here. This night passage rate was based on data from radio-tagged gray whales near Granite Canyon (Swartz *et al.,* 1987) indicating slightly higher passage rates at night. This result has been substantiated by Perryman *et al*. (1999) using thermal imagery at the Granite Canyon station.

Synthesis

The total number of whales passing during watch periods was then multiplied by corrections for whales passing when no watch was in effect (including periods with poor visibility), f_t, and differences in diurnal/nocturnal travel rates, (f_n). The total abundance estimate, N, is calculated as:

$$\hat{N} = W \cdot f_t \cdot f_n$$

The coefficient of variation, CV, is estimated by:

$$CV\left(\hat{N}\right) = \sqrt{CV^2(W) + CV^2(Q) + CV^2(f_t) + CV^2(f_n)}$$

where *CV*(*Q*) represents the variability in the observed passage rate of whales about the fitted passage rate used to estimate f_t. The *CV*(*Q*) term is much larger than the other terms and was assumed to be 10%, similar to results for 1997/98.

RESULTS

Sample size

Shore-based observations were conducted during most daylight hours from 13 December 2000 to 5 March 2001 and 12 December 2001 to 5 March 2002 (Fig. 1). Southbound whales were seen throughout most of these periods. During the 2000/01 gray whale census, there was a total of 1,689 pods of gray whales recorded from the primary (North) observation shed. Watches were maintained for a total of 592.6 hrs from the primary shed, 254.3

hrs from the secondary (South) shed, and 55.6 hrs on the fixed, high-power binoculars. During the 2001/02 census, 1,711 pods were recorded during 531.7 hrs from the primary shed, 151.0 hrs from the secondary shed and 53.1 hrs on the binoculars.

Visibility

Of the six subjective categories of visibility, very little time (5.4 hrs) was spent in excellent conditions in 2000/01 (Table 2a) and only 10.9 hrs in 2001/02 (Table 2b). Sighting rates indicated there were no real differences between visibilities 2-4, but sighting rates dropped in categories 5 and 6 (Fig. 2). As has been done in previous seasons (e.g. Hobbs and Rugh, 1999), categories 5 and 6 (106.2 hrs, 180 pods in 2000/01; 89.6 hrs, 151 pods in 2001/02) were deleted from further analysis and were treated as unwatched periods. The remaining categories did not need to have any corrections applied as a function of visibility.

Because the six visibility categories are subjective and difficult to compare between seasons, the recorded number of cues/pod were used as an empirical indicator of relative visibility of whales. There were significant differences between both 1997/98 and 2000/01 ($\overline{x}$ = 1.91 for 1997/98; $\overline{x}$ = 1.84 for 2000/01; p = 0.02, ANOVA) and between 1997/98 and 2001/02 ($\overline{x}$ = 1.73 for 2001/02; $p \ll 0.01$). This apparent decrease in annual averages suggests that sighting rates were generally better in 1997/98. However, this might instead be a reflection of differences between observers, many of whom were not available for more than one season. Because individual observers may have varying abilities or styles in recording sighting cues, the analysis of each observer's data between years is a more accurate comparison than pooling each year's results. Accordingly, cues/pod were compared between 1997/98 and 2000/01 or 2001/02 for each observer that participated in two or more of these three seasons. In all but 2 of 7 pair-wise ANOVA comparisons, there were significant differences ($p < 0.03$ in each case), and among the 5 observers who did have inter-year differences, 4 had higher sighting rates in the latter two years. Therefore, visibility was probably better in 2000/01 and 2001/02 relative to 1997/98, so visibility changes do not explain the low counts made in the most recent seasons.

Migratory timing

Prior to 2001, these gray whale surveys were usually terminated by mid-February (Table 1); however, in 2001 the watch was extended an additional three weeks because whales continued to pass the site in significant numbers through February. In 2002 the watch was again maintained until 5 March to better document the end of the southbound migration; however, the migration ended this year as it typically has in the past, on or about 15 February (Rugh *et al*., 2001).

The mean sighting date in 2000/01 was 25 January (day 55.9 with day 1 = 1 December; SE = 0.14), 10 days after the expected median date of 15 January (Rugh *et al*., 2001). However, a "peak" in sighting rates occurred on 17 January, which is within the expected time frame (Fig. 1). Sighting rates were lower than expected (relative to 1997/98) through most of this migration, but rates were higher than expected after 15 February, when the migration usually ends. A Hermite polynomial of order 5 was fit to the temporal distribution of the 2000/01 sighting data. Unlike previous years, when the sighting rates closely approximated a normal distribution, in 2000/01 there was a nearly exponential rise in sighting rates from the start of the census until the peak in mid-January, followed by an unpatterned period until rates dropped in early March.

In 2001/02, the mean date was 16 January (day 47.3; SE = 0.16), which is virtually the same as the median date observed in the 1980s and 1990s (Rugh *et al*., 2001). An apparent peak in sightings occurred on 20 January 2002. In 2001/02, a Hermite polynomial of order 4 was fit to the sighting data. The distribution had a more normal, bell-shaped curve appearance and was approximately symmetrical around the median date.

The correction factor for whales passing when no watches were in effect, f_t, was estimated to be 3.51752 (CV = 0.23%) in 2000/01 and 3.24509 (CV = 0.19%) in 2001/02.

Pod size

The mean recorded pod size was 1.63 (SE = 0.024) in 2000/01 and 1.64 (SE = 0.025) in 2001/02, during periods when visibility was adequate (<5). Sighting rates relative to each pod size are shown in Table 3. Because observers tend to underestimate pod size, bias corrections were applied as per Laake *et al.* (1994), based on aerial studies in previous years. These corrected pod size estimates are shown in Table 4 without rounding (values used in the abundance estimates are slightly different because they were based on whole integers for the respective effort periods). The mean corrected pod sizes were 2.428 (SE = 0.0194) in 2000/01 and 2.435 (SE = 0.0196) in 2001/02. A test for differences in pod size distribution showed no differences between these two years ($\chi^2_{df=6}$ = 7.57; p = 0.27).

Paired observer comparisons

During this preliminary analysis, observer performance is assumed to be the same as it was in 1997/98; therefore, the same correction factors are used in the 2000/01 and 2001/02 analyses.

Abundance estimate

In 2000/01, the estimated number of whales passing during watch periods with good visibility (<5) was 5,229 (estimated CV = 10%). Correcting for whales that passed between watch periods and including a correction for higher travel rates at night results in a total of 18,761 whales (CV = 10%; 95% log-normal confidence interval = 15,429 to 22,812)(Table 5).

In 2001/02 approximately 5,261 whales (estimated CV = 10%) passed during watch periods, resulting in a total abundance estimate of 17,414 (CV = 10%; 95% log-normal confidence interval = 14,322 to 21,174) (Table 5).

Trend analysis
Figure 3 shows abundance estimates made from data collected at or near Granite Canyon during the respective southbound migrations. There is an upward trend of 2.5% from 1967 to 1995 (Buckland and Breiwick, in press) which continued until 1997/98, but in 2000/01 and 2001/02, abundance estimates were well below this trend line. The lower bound of the 95% CI for the 1997/98 estimate (21,878) does overlap with the upper bound for the 2000/01 estimate (22,812) but not with the upper bound for the 2001/02 estimate (21,174). The abundance estimates from these latter two years are well below what would be expected if the population had continued to grow at a constant rate (projected to be near 27,500 in the year 2000 if the population had continued to grow at 2.5%).

DISCUSSION

The low abundance estimate calculated for gray whales in 2000/01 appeared at first to be complicated by an unusual migration, with whales continuing to go south well after the usual time frame and counts never reaching the high sighting rates that have occurred in other recent surveys. However, the migration timing in 2001/02 appeared to by quite typical, and yet the abundance was still low. Both of these years (2000/01 and 2001/02) had estimates that were 8,000 to 9,000 less than the estimate of 26,635 made in 1997/98 (Hobbs and Rugh, 1999). The discrepancy is even more severe if the recent estimates are compared to the projected abundance resulting from a constant increase of 2.5% (Buckland and Breiwick, in press). Several possible explanations for the low estimates are presented here.

Observers
Because approximately half of the observers were new each season, it may be argued that there could have been more than the usual problems in finding or recording whales. However, each observer had many hours of effort paired with other observers, so there should be sufficient data to document relative performance and rule out any significant problems. This analysis will be conducted after the analytical programs have been revised (currently underway).

Change in offshore distribution
There was no obvious indication that the whales used a migratory corridor farther offshore in the most recent years relative to the past. Results from the high-power binoculars will be analyzed in the near future to check for quantifiable shifts in offshore distribution.

Visibility
If visibility was persistently lower in the 2000/01 and 2001/02 seasons relative to other years, then the counts might have been biased downwards. Yet, there was no real difference in the percent of time spent in adequate visibility (conditions 1-4) in 1997/98 (86%) and 2000/01 (85%) or 2001/02 (86%). A less subjective comparison was made by analyzing the number of sightings recorded per pod. These results show that the visibility of whales was higher in the more recent years than it was in 1997/98. Therefore, visibility is not considered to be the reason for the low encounter rates recorded in the past two years relative to 1997/98.

Migratory change
It is possible that an unusually high proportion of the population did not pass Granite Canyon in 2000/01 and/or that the migration continued well past the end of the survey effort. There has been a phenomenally regular timing of the migration during the recent past, with the southbound migration ending and the northbound beginning in mid-February (Rugh *et al*., 2001). In 2000/01, however, southbound whales continued passing the station until the effort was terminated on 5 March, when counts of southbound whales had dropped to 0.7/hr and northbound counts had risen to 1.3/hr. Small numbers of gray whales continued to travel south long after this date as evidenced from the shore-based efforts at Piedras Blancas, 130 km south of Granite Canyon (W. Perryman, Southwest Fisheries Science Center, NMFS, La Jolla, California, U.S.A., pers. comm.) and Pt Vicente, 485 km south of Granite Canyon, near Los Angeles in southern California (A. Schulman-Janiger, American Cetacean Society, San Pedro, California, U.S.A., pers. comm.). The pattern of the timing of the migration, with what appears to be a pulse passing much later than usual, is also evident in the data collected at Pt Vicente (A. Schulman-Janiger, pers. comm.). Although the migratory timing in 2000/01 was unusual, the timing appeared normal in 2001/02, yet the abundance estimate was still low. Of course, the pattern of the sighting distribution through the migration does not preclude the possibility that in both years a significant portion of the population

did not migrate as far south as Granite Canyon. Unexpectedly low abundance estimates also occurred in 1970/71, 1971/72, 1978/79 and 1992/93, yet each (except the first) was followed by several seasons with much higher estimates (Fig. 3). One of the explanations for the low estimate in 1992/93 was that varying proportions of the gray whale population remain north of Granite Canyon each year (Laake *et al*., 1994). Perhaps in some years, such as in 2000/01 and 2001/02, many whales migrated late or did not migrate as far south as Granite Canyon.

Abundance decline

If none of the other theories fully explain the low counts recorded recently, then the change may be attributed to a true drop in the size of the Eastern North Pacific stock of gray whales. Unusually high stranding rates of over 270 in 1999 (LeBoeuf *et al*., 2000; Norman *et al*., 2000) and over 300 in 2000 (NMFS, unpubl. data) relative to average rates of 38 /yr from 1995-98 (Norman *et al*., 2000) may have indicated a large die-off in this population, assuming that stranding reports reflect only a small portion of the total mortality rate. Indications of emaciated whales (LeBoeuf *et al*., 2000) and low calf production (Perryman *et al*., 2002) are suggestive of a deterioration in available resources, such as benthic amphipods in the Bering and Chukchi seas (LeBoeuf *et al*., 2000). However, observations made in 2001 and 2002 seem to indicate that there was an acute event in 1998-99, not necessarily a chronic situation. Calf counts in the southbound migration in 2001/02 are among the highest ever (A. Schulman-Janiger, pers. comm.), and aerial observations in 2001 and 2002 indicate that southbound adults are not emaciated (W. Perryman, pers. comm.)

Gray whale abundance has been estimated to be 30,000-40,000 (Scammon, 1874) or 15,000-20,000 (Henderson, 1972) prior to commercial takes in the 19th century, and models projecting into the future have estimated the maximum abundance could be 24,000-32,000 (Wade and DeMaster, 1996), 25,000-30,000 (Wade, 1998), near 35,000 (Wade and DeMaster, 1998) or 24,640-31,840 (Wade, in press). After the heavy exploitation of gray whales, especially from 1855-74, the abundance may have dropped to only a few thousand animals (Henderson, 1972). This low abundance lowered the efficiency of the hunt, reducing further takes, but it also led to conservation measures, which began in 1937 under the International Agreement for the Regulation of Whaling (Reeves, 1984). Since that time, there has been a progressive increase in abundance of this stock of whales. From 1967/68 to 1995/96, there was a 2.5% per annum increase (Buckland and Breiwick, in press). A plateau in this increase has been anticipated (Wade, 1998; Reilly, 1992), but through 1997/98, abundance estimates indicated a continuous linear rise. Until 2000/01, there was only a suggestion of density-dependence beginning to occur (Wade and DeMaster, 1998), but it has been proposed that this whale stock was close to its equilibrium level (Wade, in press). Possibly, then, the abundance estimates from 2000/01 and 2001/02 are the first time that the size of the population has shown that this stock of whales has reached the carrying capacity of its environment and the population may be approaching equilibrium.

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LITERATURE CITED

Buckland, S.T. and Breiwick, J.M. In press. Estimated trends in abundance of Eastern Pacific gray whales from shore counts, 1967/68 to 1995/96. *J. Cetacean Res. Manage*.

Buckland, S.T., Breiwick, J.M., Cattanach, K.L. and Laake, J.L. 1993. Estimated population size of the California gray whale. *Mar. Mammal Sci*. 9(3):235-49.

Henderson, D.A. 1972. *Men & Whales at Scammon's Lagoon*: Dawson's Book Shop, Los Angeles. 313pp.

Hobbs, R. and Rugh, D. 1999. The abundance of gray whales in the 1997/98 southbound migration in the eastern North Pacific. Paper SC/51/AS10 presented to the IWC Scientific Committee, May 1999 (unpublished). 18pp. [Paper available from the Office of this Journal.]

Hobbs, R.C., Rugh, D.J., Waite, J.M., Breiwick, J.M. and DeMaster, D.P. In press. The abundance of gray whales in the 1995/96 southbound migration in the eastern North Pacific. *J. Cetacean Res. Manage*.

Kinzey, D. and Gerrodette, T. 2001. Conversion factors for binocular reticles. *Mar. Mammal Sci*. 17(2):353-61.

Laake, J.L., Rugh, D.J., Lerczak, J.A. and Buckland, S.T. 1994. Preliminary estimates of population size of gray whales from the 1992/93 and 1993/94 shore-based surveys. Paper SC/46/AS7 presented to the IWC Scientific Committee, May 1994 (unpublished). 13pp. [Paper available from the Office of this Journal.]

LeBoeuf, B.J., Pérez-Cortés M., H., Urbán R., J., Mate, B.R. and Ollervides U., F. 2000. High gray whale mortality and low recruitment in 1999: potential causes and implications. *J. Cetacean Res. Manage*. 2(2):85-99.

Norman, S., M. Muto, D. Rugh, and S. Moore. 2000. Gray whale strandings in 1999 with a review of stranding records in 1995-1998. Paper SC/52/AS5 presented to the IWC Scientific Committee, June 2000 (unpublished). [Paper available from the Office of this Journal.]

Perryman, W.L., Donahue, M.A., Laake, J.L. and Martin, T.E. 1999. Diel variation in migration rates of eastern Pacific gray whales measured with thermal imaging sensors. *Mar. Mammal Sci*. 15(2):426-45.

Perryman, W.L., Donahue, M.A., Perkins, P.C. and Reilly, S.B. 2002. Gray whale calf production 1994-2000: are observed fluctuations related to changes in seasonal ice cover*? Mar. Mammal Sci*. 18(1):121-44.

Pike, G.C. 1962. Migration and feeding of the gray whale (*Eschrichtius gibbosus*). *J. Fish. Res. Board Can.* 19(5):815-38.

Reeves, R.R. 1984. Modern commercial pelagic whaling for gray whales. Pp. 187-200 *In*: M.L. Jones, S. Swartz and S. Leatherwood (eds) The Gray Whale, *Eschrichtius robustus*. Academic Press, Inc., New York. 600pp.

Reilly, S.B. 1984. Assessing gray whale abundance: a review. Pp. 203-223 *In*: M.L. Jones, S. Swartz and S. Leatherwood (eds) The Gray Whale, *Eschrichtius robustus*. Academic Press Inc., New York. 600pp.

Reilly, S.B. 1992. Population biology and status of Eastern Pacific gray whales: Recent developments. In: D.R McCullough and R.H. Barrett (eds) *Wildlife 2001: Populations*. Elsevier Applied Science. New York.

Rugh, D.J., Ferrero, R.C. and Dahlheim, M.E. 1990. Inter-observer count discrepancies in a shore-based census of gray whales (*Eschrichtius robustus). Mar. Mammal Sci*. 6(2):109-20.

Rugh, D.J., Breiwick, J.M., Dahlheim, M.E. and Boucher, G.C. 1993. A comparison of independent, concurrent sighting records from a shore-based count of gray whales. *Wildl. Soc. Bull*. 21:427-37.

Rugh, D.J., Lerczak, J.A., Hobbs, R.C., Waite, J.M. and Laake, J.L. In press. The offshore distribution of gray whales as determined by shore-based, high-powered binoculars. *J. Cetacean Res. Manage*.

Rugh, D.J., Shelden, K.E.W., and Schulman-Janiger, A. 2001. Timing of the southbound migration of gray whales. *J. Cetacean Res. Manage*. 3(1):31-39.

Scammon, C.M. (ed.) 1874. *The Marine Mammals of the North-western Coast of North America, Described and Illustrated: Together with an Account of the American Whale-Fishery*. John H. Carmany and Co., San Francisco. x+319+vpp. [Reprinted in 1968 by Dover Publications, Inc., New York.]

Shelden, K.E.W. and Laake, J.L. In press. Aerial surveys of southbound migrating California gray whales. *J. Cetacean Res. Manage.*

Swartz, S., Jones, M., Goodyear, J. Withrow, D. and Miller, R.V. 1987. Radio-telemetric studies of gray whale migration along the California coast: A preliminary comparison of day and night migration rates. *Rep. int. Whal. Commn* 37:295-9.

Wade, P.R. 1998. A revised gray whale analysis using both southbound total population counts and northbound calf counts. Paper SC/49/AS24 presented to the IWC Scientific Committee, 1998 (unpublished). [Paper available from the Office of this Journal.]

Wade, P.R. In press. A Bayesian stock assessment of the Eastern Pacific gray whale using abundance and harvest data from 1967 to 1996. *J. Cetacean Res. Manage*.

Wade, P.R. and DeMaster, D.P. 1996. A Bayesian analysis of Eastern Pacific gray whale population dynamics. Paper SC/48/AS3 presented to the IWC Scientific Committee, 1996 (unpublished). [Paper available from the Office of this Journal.]

Wade, P.R. and DeMaster, D.P. 1998. The population dynamics of the Eastern Pacific gray whale: is density-dependence occurring? Abstract in the Twelfth Biennial Conf. on the Biology of Marine Mammals, Monaco, January 1998.

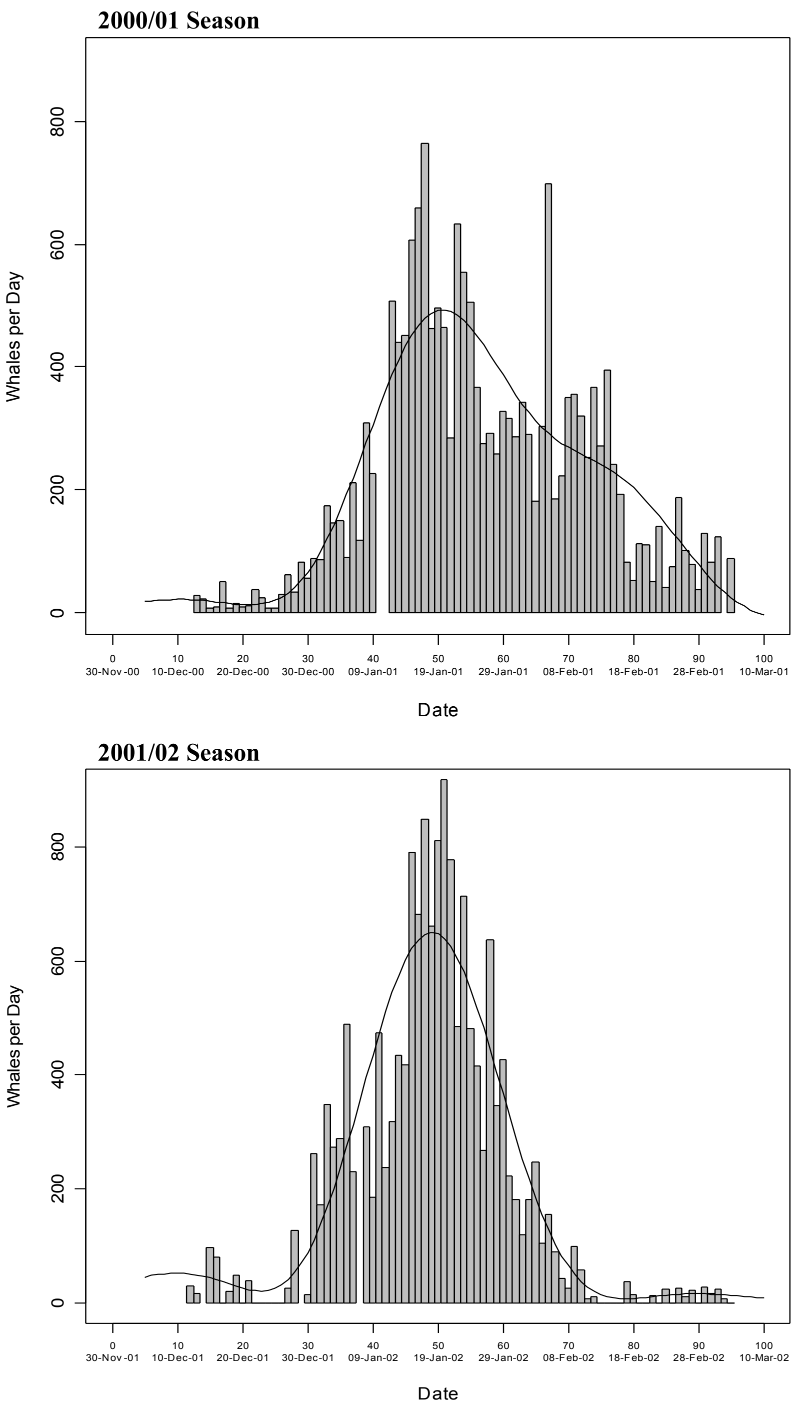

Fig. 1. Observed number of whales per day and Hermite polynomial fit to the data.

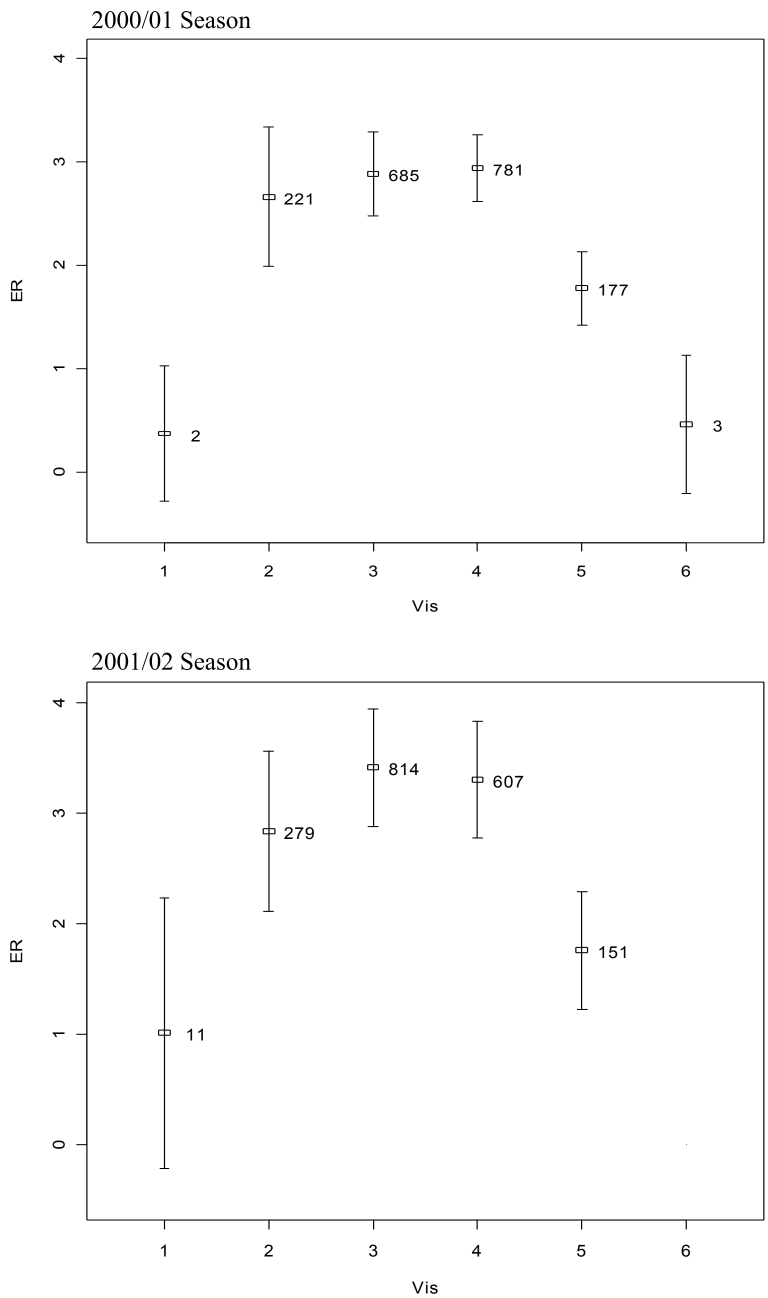

Fig. 2. Encounter rate (ER = pods per hour) by season (2000/01 and 2001/02) and visibility code (1-6, excellent to unacceptable). Error bars are 2 standard errors, and numbers indicate sample size.

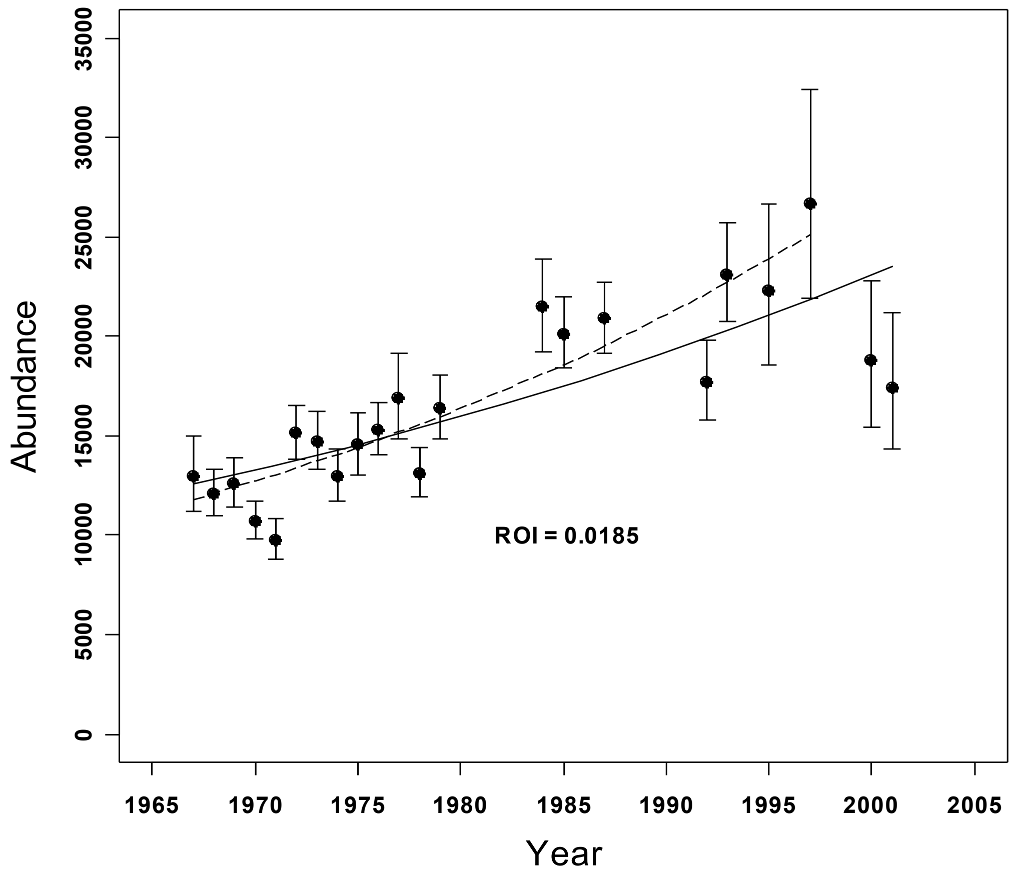

Fig. 3. Gray whale abundance estimates and 95% lognormal confidence intervals. The dashed line is fit through 1997/98 data, and the solid line is fit through 2001/02 data. Rate of increase is for the entire abundance series.

Table 1. Duration of survey effort conducted by NMFS during counts of the southbound migration of gray whales near Carmel, California.

Start Dates		End Dates		Abundance	SE	Source
1967	18 Dec	1968	3 Feb	13,072	897	1
1968	10 Dec	1969	6 Feb	12,211	485	1
1969	8 Dec	1970	8 Feb	12,744	531	1
1970	9 Dec	1971	12 Feb	10,832	378	1
1971	18 Dec	1972	7 Feb	9,874	445	1
1972	16 Dec	1973	16 Feb	15,276	535	1
1973	14 Dec	1974	8 Feb	14,868	599	1
1974	10 Dec	1975	7 Feb	13,107	546	1
1975	10 Dec	1976	3 Feb	14,689	682	1
1976	10 Dec	1977	6 Feb	15,483	505	1
1977	10 Dec	1978	5 Feb	17,077	990	1
1978	10 Dec	1979	8 Feb	13,257	505	1
1979	10 Dec	1980	6 Feb	16,555	690	1
1984	27 Dec	1985	31 Jan	21,694	1,015	1
1985	10 Dec	1986	7 Feb	20,348	726	1
1987	10 Dec	1988	7 Feb	21,113	688	1
1992	10 Dec	1993	7 Feb	17,674	1,029	2
1993	10 Dec	1994	18 Feb	23,109	1,262	2
1995	13 Dec	1996	23 Feb	22,571	1,182	3
1997	13 Dec	1998	24 Feb	26,635	2,681	4
2000	13 Dec	2001	5 Mar	18,761	1,876	5
2001	12 Dec	2002	5 Mar	17,414	1,741	5

1 = Buckland and Breiwick (in press)
2 = Laake *et al.* (1994)
3 = Hobbs *et al.* (in press)
4 = Hobbs and Rugh (1999)
5 = This study

Table 2a. Rates of sightings of gray whale pods as a function of visibility as recorded in the primary observation shed in 2000/01.

Visibilities	Visibility Code	Hours of Effort	Number of pods	Pods per hr	SE	Avg pod size	SE
Excellent	1	5.4	2	0.37	0.25	1.500	0.500
Very Good	2	83.2	221	2.66	0.42	1.860	0.075
Good	3	237.8	685	2.88	0.24	1.723	0.038
Fair	4	266.2	781	2.93	0.19	1.485	0.032
Poor	5	99.7	177	1.78	0.18	1.395	0.048
Unacceptable	6	6.5	3	0.46	0.27	1.000	0.000
All Effort	1-6	698.8	1,869	2.68	0.12	1.61	0.022
Usable Effort	1-4	592.6	1,689	2.85	0.14	1.63	0.024

Table 2b. Rates of sightings of gray whale pods as a function of visibility as recorded in the primary observation shed in 2001/02.

Visibilities	Visibility Code	Hours of Effort	Number of pods	Pods per hr	SE	Avg pod size	SE
Excellent	1	10.9	11	1.01	0.83	2.000	0.357
Very Good	2	98.5	279	2.83	0.42	1.767	0.085
Good	3	238.6	814	3.41	0.36	1.677	0.035
Fair	4	183.7	607	3.30	0.34	1.516	0.036
Poor	5	85.8	151	1.76	0.35	1.325	0.053
Unacceptable	6	3.8	0	0.00			
All Effort	1-6	621.3	1,862	3.00	0.19	1.61	0.024
Usable Effort	1-4	531.7	1,711	3.22	0.21	1.64	0.025

Table 3. Pod size summaries (vis ≤ 4) for the respective years when counts of southbound migrating gray whales were conducted at Granite Canyon, California. Corrections are for pod size bias and for missed pods. Some rounding was done in the synthesis; therefore, totals may not be identical between tables.

Pod size	1995/96	1997/98	2000/01	2001/02
1	1,180	1,522	997	1,032
2	538	497	458	432
3	235	176	150	150
4	105	74	48	65
5	50	20	25	15
6	19	13	7	11
7	14	7	2	3
8	6	6	1	2
9	3	2	0	0
>9	1	1	1	1
Mean	1.83	1.57	1.63	1.64
SE	0.027	0.022	0.024	0.025
Number of pods	2,151	2,318	1,689	1,711
Pods x pod size	3,928	3,643	2,754	2,800
Mean corrected pod size	2.593	2.387	2.428	2.435
SE	0.0224	0.018	0.0194*	0.0196*
Number of whales**	5,578	5,534	4,101	4,166

* Standard Errors are approximated until the modeling analysis is complete.
** Number of pods x mean corrected pod size

Table 4. Estimation of total whales passing Granite Canyon during watch periods with visibility ≤ 4. (Average corrections for missed pods are from results calculated in 1997/98 (Hobbs and Rugh, 1999)). The total number of whales (5,204 and 5,249) is slightly smaller than reported in Table 5 because the pod size correction factors were applied to the pod size frequency distribution in each effort period (759 intervals in 2000/01 and 627 intervals in 2001/02), and those numbers were then rounded to the nearest integer, whereas the following totals do not reflect this rounding.

Pod size	Number pods		Average correction for missed pods	Bias-corrected pod size	Estimated total number of whales	
	2000/01	2001/02			2000/01	2001/02
1	997	1,032	1.314	1.941	2,543	2,632
2	458	432	1.226	2.646	1,486	1,401
3	150	150	1.161	3.607	628	628
4	48	65	1.146	4.25	234	317
5	25	15	1.741	5.25	229	137
6	7	11	1.108	6.25	48	76
7	2	3	1.052	7.25	15	23
8	1	2	1.055	8.25	9	17
9	0	0	1.091	9.25	0	0
10	1	0	1.155	10.25	12	0
16	0	1	1.155	16.25	0	18
All	1,689	1,711			5,204	5,249

Table 5. Estimated abundance and intermediate parameters for Eastern North Pacific gray whales counted at Granite Canyon in 2000/01 and 2001/02.

	2000/01			2001/02		
Parameter	Estimate	SE	CV (%)	Estimate	SE	CV (%)
Total pods recorded by primary observers during watch periods (*m*):	1,689			1,711		
Mean recorded pod size:	1.631	0.024	1.45	1.636	0.025	1.54
Corrected mean pod size:	2.428			2.435		
Estimated number of whales passing during watch periods (W)	5,229		10.0	5,261		10.0
Correction for pods passing outside watch periods (f_t):	3.5175	0.23	0.80	3.2451	0.19	0.63
Estimated total whales without night travel correction (Q):	18,393			17,072		
Correction for night travel (f_n):	1.02	0.023	2.25	1.02	0.023	2.25
Estimated number of whales passing Granite Canyon ($\hat{N}$):	18,761	1,876	10.0	17,414	1,741	10.0