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Final Research Report

Western Gray Whales off Sakhalin Island, Russia: A Joint Russia-U.S. Scientific Investigation July-September 2003

David W. Weller[1,4], Alexander M. Burdin[2,3], Amanda L. Bradford[1],

Yulia V. Ivashchenko[2], Grigory A. Tsidulko[2], Aimée R. Lang[1], Robert L. Brownell, Jr.[1]

[1]National Marine Fisheries Service, NOAA
Southwest Fisheries Science Center
La Jolla, California 92037 USA

[2]Kamchatka Branch of Pacific Institute of Geography
Far East Division, Russian Academy of Sciences
Petropavlovsk, Kamchatka, 683000 RUSSIA

[3]Alaska Sealife Center
Seward, Alaska 99664

[4] Corresponding Author Contact: E-mail: dave.weller@noaa.gov; Tel: 1+858-546-5674

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SUMMARY

Research on the western gray whale (*Eschrichtius robustus*) population summering off northeastern Sakhalin Island, Russia, has been ongoing since 1995. This collaborative Russia-U.S. research program has produced important new information on the present day conservation status of this critically endangered population. This report reviews recent findings from 2003 research activities and combines such with data from previous years, in some cases ranging back to 1994. Photo-identification research conducted off Sakhalin Island in 2003 resulted in the identification of 75 whales, including 11 calves and two previously unidentified non-calves. When combined with data from 1994-2002, a catalog of 131 photo-identified individuals has been compiled. The population size is estimated to be approximately 100 individuals and non-calf and calf survival rates are 0.95 and 0.70, respectively. Of the 131 whales photo-identified, 108 (82.4%) have now been biopsy sampled. From genetic analysis of samples collected through 2002, an overall male biased sex ratio of 59.1% males and 40.9% females was determined. The sex ratio for calves was 68.0% male and 32.0% female. Previous genetic research on the western gray whale population documented clear genetic differentiation from the eastern population on the basis of mitochondrial DNA haplotype frequencies. Nuclear DNA markers used to measure the differentiation and relative levels of genetic diversity in the nuclear genome between the western and eastern populations confirm the earlier conclusion (based on mtDNA) that the two populations are genetically distinct and further suggests negligible gene flow of either sex between populations. A minimum of 23 reproductive females has been observed since 1995 and their most common (74.4%) calving interval is three or more years. Three whales were recorded as "skinny" in 2003, a total number lower than recorded in previous years. In addition to the clear biological difficulties that western gray whales are facing, the recent onset of large-scale oil and gas development programs near their summer feeding ground pose new threats to the future survival of the population.

INTRODUCTION

Western gray whales were thought to be extinct as recently as 1972 (Bowen, 1974), but are known to survive today as a small critically endangered remnant population (Berzin, 1974; Brownell and Chun, 1977; Brownell *et al*., 1997; Clapham *et al*., 1999; Würsig *et al*., 1999, 2000; Weller *et al*., 1999a, 2002a; 2003a; Hilton-Taylor, 2000). In contrast to the recovery from low numbers of the eastern gray whale, the western population remains severely depleted and is thought to number approximately 100 individuals (Weller *et al.*, 2002a, 2003a, 2004; Wade *et al*., 2003).

Although the historic distribution of western gray whales is thought to have extended from the northern coastal reaches of the Okhotsk Sea to southern China, the present day range appears to be considerably more restricted (Weller *et al*., 2002a, 2002b, 2002c, 2003b). Despite relatively extensive aerial and ship-based marine mammal surveys within the geographic range of western gray whales, sightings outside of the area off northeastern Sakhalin Island, Russia are uncommon (e.g. Berzin *et al.,* 1988, 1990, 1991;

Miyashita *et al*., 2001; Weller *et al*., 2002a, 2002c, 2003b). Sighting records from Soviet aerial and vessel surveys in the Okhotsk Sea during the 1960s, 1970s, and 1980s (e.g. Berzin, 1974; Berzin *et al.,* 1988, 1990, 1991), and results from recent surveys between 1998 and 2001 (Sobolevsky, 2000, 2001; Blokhin *et al*., 2002; Weller *et al*., 2002b) indicate that gray whales aggregate predominantly along the shallow-water shelf off northeastern Sakhalin Island during summer-autumn (also see Blokhin *et al*., 1985; Blokhin, 1996). This region of the Okhotsk Sea is characterized by high benthic biomass densities (Koblikov, 1986), and is the only currently known feeding ground for western gray whales (e.g. Blokhin *et al.,* 1985; Brownell *et al*., 1997; Weller *et al*., 1999a, 2002a).

The wintering ground(s) of the western gray whale population remains unknown. Sightings of this species in other parts of its distribution, including waters off Japan, South Korea and China are rare (see reviews by Zhu, 1998; Kato and Tokuhiro, 1997; Kato and Kasuya, 2002; Weller *et al*., 2002a). However, some reliable records from the South China Sea suggest that the wintering grounds are located off southern China (Henderson, 1972, 1984, 1990; Wang, 1978, 1984; Zhu, 1998).

A joint Russia-U.S. research program on western gray whales off Sakhalin Island, Russia, was initiated in 1995 as part of the Marine Mammal Project under Area V: Protection of Nature and the Organization of Reserves within the U.S.-Russia Agreement on Cooperation in the Field of Environmental Protection. Important findings from this ongoing Russia-U.S. collaborative study, highlighting the fragile state of the western gray whale population, include: (1) the eastern and western gray whale populations are geographically and genetically isolated population units (LeDuc *et al*., 2002; Lang *et al*., 2004); (2) the western population is small, with only 131 whales identified between 1994 and 2003 during 264 days of survey effort (this report) and mark-recapture assessments estimating the population to be about 100 individuals (Wade *et al*., 2003); (3) survival of calves is low, estimated at slightly below 0.71 (Bradford *et al*., 2003, submitted); (4) the sex ratio shows a male bias of 59.1% male to 40.9% female (this report); and (5) the number of known reproductive females is only 23 (this report). Additional findings, showing pronounced seasonal site fidelity and annual return of most whales to this part of the northeastern Sakhalin Island coast, emphasize the importance of this region as a primary (and only currently known) feeding ground for the western population (Weller *et al*., 2004).

Based largely on the research results mentioned above, the World Conservation Union (IUCN) listed the western gray whale population as *Critically Endangered* in 2000 (Hilton-Taylor, 2000; Weller *et al*., 2002a). The Scientific Committee of the International Whaling Commission has also expressed serious concern about the status of the western population (IWC, 2002a). As a result of this, in 2001 an IWC *Resolution* was passed that called for the continuation and expansion of long-term research and monitoring of the population and concerted action by range states and others to pursue actions to eliminate human-related mortality and disturbance of this population (IWC, 2002b).

This report reviews findings from 2003 research activities of the joint Russia-U.S. research program and combines such with data from previous years, in some cases ranging back to 1994. Discussion of the current status of the western gray whale population, a review of threats to its continued survival (including potential impacts associated with large-scale oil and gas development activities on the summer feeding ground), and research recommendations are provided.

METHODS

Between 1997 and 2003, western gray whale studies conducted by our Russia-U.S. research program off northeastern Sakhalin were sponsored by a variety of agencies (Table 1). Photo-identification research methodologies employed during the 2003 field study were identical to those employed during earlier studies by our team between 1997 and 2002. The overall consistency in research design, data collection techniques and data analysis maintained in 2003 allowed some inter-annual comparisons to be made. Additional information, collected during more limited surveys off Piltun in 1994 and 1995 (Brownell *et al.*, 1997; Weller *et al.*, 1999a), is also presented here to better describe inter-annual trends and facilitate a long-term interpretation for some results. Data from these 1994 and 1995 studies include gray whale photographs obtained between 7-12 September 1994 during the filming of a wildlife documentary by H. Minakuchi (for description see Weller *et al*., 1999a) and from 14-20 August 1995 during a pilot study to determine the feasibility of conducting boat- and shore-based research in the study area (Brownell *et al.,* 1997).

Study Area

Zaliv Pil'tun (referred to as Piltun Lagoon) is on the northeastern shore of Sakhalin Island, Russia (Fig. 1). The lagoon is approximately 90 km long and 15 km across at its widest point. A single channel connecting the inner lagoon with the Okhotsk Sea occurs at 52° 50' N and 143° 20' E, and has considerable biological influence on the surrounding marine environment. A lighthouse, near the lagoon channel, served as the base from which studies reported here were conducted. The near-shore marine environment of the study site is mostly sand substrate, characterized by a gradually sloping and broad continental shelf. Water depths within 5 km of shore are mostly less than 20 m deep. Despite the similarly of Piltun Lagoon to the coastal lagoons used by eastern gray whales off Baja, whales do not enter this lagoon.

Photo-Identification Surveys

Boat-based photo-identification surveys were conducted on all good weather days during the 2003 study period. Identical methodology was employed during each survey, with the primary objective of encountering and photographically identifying as many whales as possible. Previous photo-identification data gathered in the Piltun area between 1995 and 2002 used mainly right-side dorsal flank markings for identification (Brownell *et al.*, 1997; Weller *et al.*, 1999a, 2003a), and for the sake of intra- and inter-annual reliability, we continued this methodological approach. Attempts were made to simultaneously photograph and videotape the right dorsal flank of each whale, followed then by photos of the left dorsal flank and flukes (for example see Fig. 2). However, the majority of whales identified to date now have images of right and left flanks as well as ventral surface of flukes in the photo-identification catalog, thereby allowing for useful identification images to be collected from nearly any body region.

Photographic surveys involved slow travel in a 4.5-m outboard-powered inflatable boat. The research team consisted of a boat driver, data recorder, digital video camera operator, and 35-mm camera photographer. Systematic visual search by observers on the survey vessel was maintained until a whale sighting was made. Upon initial sighting of a group, the survey vessel slowed to idle speed, and maneuvered to a vantage point approximately 50 m from the whale(s). From this position, observations on group location (as determined by Global Positioning System, or GPS), time, behavior, and number of whales were recorded.

The research vessel was then moved within approximately 30 m of the whale group and individuals were photographed. During the photographic effort, a running commentary regarding the image frame and video counter number as related to particular whales was recorded onto data sheets. Measures of water depth (as determined by digital depth sounder), location (as determined by GPS), and environmental conditions were recorded every 3-5 min throughout each photographic session.

A group was defined as either a solitary individual, or two or more whales observed in close spatial proximity (within several body lengths of each other), and swimming in close association and generally coordinating their diving or direction of movement (see Clapham, 1993). Group size estimates were based on field observations, and represented the product of a consensus among observers on the survey vessel. The term "calf" is used here to refer to young of the year. In all cases, calves were initially identified by their small body size compared to that of a mature female and constant association with a particular adult female.

RESULTS

Photo-Identification Catalog

Between 1994 and 2003, 131 western gray whales have been identified during 264 boat-based surveys off northeastern Sakhalin Island (Table 2). Forty-two of the whales in the photo-catalog were animals first identified as calves, while the remaining 89 whales were considered non-calves (i.e. adults or subadults).

Survey Effort

Twenty-two photo-identification surveys, including 41.6 hrs spent in direct observation of 219 whale groups, were conducted between 15 July and 13 September 2003 (Table 3).

Sea surface temperature and salinity in during these surveys, as measured from our research vessel during Beaufort Sea State conditions ≤ 3 (winds ≤ 7-10 kts), ranged from -1.5–6.5° C and 30-36 ppt, respectively (Table 4). On average, 11.4 min (± s.d. 0.23) were spent with each group and 3060 photographic images and 4.0 hrs of digital video footage were obtained during the 2003 research effort (Table 3).

Distribution Patterns and Group Size

The mean water depth in which all groups (including solitary whales) were encountered was 11.6 m (± s.d. 4.90, *n* = 216, range = 3.0 – 24.1 m) with 94.9% (*n* = 205) of all groups distributed in waters < 20 m deep (Fig. 3). The mean water depth for non-calf (i.e. groups containing no calves) and mother-calf group (i.e. groups containing a female(s) with dependent offspring) locations was 14.3 m (± s.d. 3.69, *n* = 136) and 6.6 m (± s.d. 2.55, *n* = 35), respectively (Fig. 3). Group locations, as determined by GPS derived coordinates, were generally within 5 km of shore (Fig. 4). On several occasions, exceptional sea conditions allowed us to expand our more typical survey coverage to include areas ~60 km north and up to 25 km south of the entrance to Piltun Lagoon. In all cases, whales photographed to the north and south were individuals known to also occur off the lagoon channel mouth. Many surveys documented individual whales moving distances of 50 km or more in less than 24 hours, while other whales demonstrated strong site fidelity (sometimes over days) to relatively small regions.

Mean group size for all 219 groups encountered during 2003 was 2.3 (± s.d. 1.43) with a range of 1-9 whales per group (Table 5). A majority (69.4%) of all groups observed (*n* = 152) were composed of two whales or less (Fig. 5). The mean group size for non-calf groups and mother-calf groups were 1.9 (± s.d. 1.15, *n* = 138) and 2.3 (± s.d. 0.91, *n* = 35), respectively.

Individual Recognition and Occurrence Patterns

Seventy-five naturally marked individual whales, including 11 calves, were identified during 2003 (Table 6). The mean number of months in which whales were identified during 2003 was 2.0 (± s.d. 0.70) with a range of 1-3 months (Fig. 6). Fifty-seven whales (76.0%) were sighted in two or more months while 24.0% (*n* = 18) were sighted in only a single month. Of the 18 whales sighted in only one month, 11.1% (*n* = 2) were identified in July, 38.9% (*n* = 7) in August and 50.0% (*n* = 9) in September.

Resighting and Site Fidelity Patterns

The 75 whales identified during the 2003 field season consisted of 64 non-calves (i.e. adults or subadults) and 11 young of the year calves (Table 6). Of the 64 non-calves identified, 96.9% (*n* = 62) had previous sightings in the Piltun area during 1994-2002 photographic efforts (Table 6). Sighting frequencies for photo-identified individuals, based on a one-sighting-per-day criterion, ranged between 1-17 with an overall mean of 5.8 (± s.d. 3.77) sightings per whale (Fig. 7). The rate at which individual whales were first identified during each field season between 1994 and 2003 is presented in Figure 8.

The rate of increase in this function was quite limited in 2003, with only two additional non-calves identified.

Abundance Estimates

The photographic dataset collected between 1997 and 2003 was used to make a quantitative assessment of western gray whale abundance following the methodology described in Wade *et al*. (2003) for similar estimates calculated for the period 1997 to 2002. The present dataset included encounter histories of 129 individually identified whales spanning 25 monthly capture occasions from 1997 to 2003. Huggins' closed capture estimator was used to estimate the number of individuals annually associated with the study area. However, photo-identification results have suggested that some whales can be absent from the study area during any given field season. Therefore, temporary emigration probabilities estimated from the application of Pollock's robust design model to the photographic dataset (see below) were used to estimate the total population size of whales off northeastern Sakhalin Island from the initial closed capture estimates. Total abundances from 1997 to 2003 were estimated as 64 (SE=5, 95% CI=55-75), 75 (SE=5, 95% CI=66-85), 86 (SE=3, 95% CI=80-93), 77 (SE=5, 95% CI=68-87), 91 (SE=3, 95% CI=84-98), 98 (SE=4, 95% CI=90-106), and 99 (SE=5, 95% CI=90-106), respectively. Similarly, Lincoln-Peterson estimates of biennial abundance for the periods 1997-1998, 1999-2000, and 2001-2002 were estimated as 74 (SE=4, 95% CI=69-87), 85 (SE=3, 95% CI=82-95), and 101 (SE=4, 95% CI=96-112).

Survival Estimates

Pollock's robust design model with Huggins' closed capture estimator was fitted to the aforementioned 129 individual whale encounter histories spanning 25 monthly capture occasions from 1997 to 2003 to estimate survival rates of calves and non-calves (Bradford *et al*., submitted). Analysis protocols were identical to those used for the 1997 to 2002 survival estimation detailed in Bradford *et al*. (2003). Constant non-calf and calf (first-year post-weaning) survival and random temporary emigration that is either constant, group varying (between whales >2-yr-old and <2-yr-old, >3-yr-old and <3-yr-old, or >4-yr-old and <4-yr-old), time varying, or group and time varying were assumed. The effects of various combinations of time, survey effort, and an individual *residency* covariate were examined in models of capture probability. Using AICc model selection, models incorporating individual heterogeneity in residency patterns and higher temporary emigration probabilities for younger whales provided better fits to the data. Non-calf and calf (first-year post-weaning) survival were estimated as 0.951 (SE=0.0135, 95% CI=0.917-0.972) and 0.701 (SE=0.0944, 95% CI=0.492-0.850), respectively, averaging across the best models (n = 13) in order to account for model uncertainty.

Mother-Calf Pairs

Ten mother-calf pairs and one already weaned calf (mother currently unknown) were identified during 2003, totaling 10 mothers and 11 calves, and ranked among some of the most frequently sighted whales. The observed Gross Annual Reproductive Rate (GARR) for 2003 was 14.7% (Table 6). Nine of these 10 (90%) 2003 mothers had previous sightings in the study area prior to 2003 and six (60.0%) were sighted in 2002 while pregnant. Four (40.0%) of the 10 females were recorded as mothers in previous years. Of the six females observed with a calf for the first time in 2003, one was a new individual not previously identified between 1994 and 2002 while the remaining five were sighted in four years (*n* = 2), five years (*n* = 2) or seven years (*n* = 1) prior to 2003.

Between 1995 and 2003, 23 known reproductive females have been documented. However, five calves were already weaned from their respective mothers prior to their first sighting, suggesting the possibility that as many as 28 mothers may exist. However, it is also possible that these five "independent" calves belonged to one of the 23 currently known mothers. Therefore, 23 reproductive females are known from direct observation but as many as 28 (and perhaps more) may exist. Further genetic analysis will aid in determining mother-offspring relatedness and thereby provide better resolution regarding the five independent calves mentioned here (Brownell *et al*., 2002).

Nine of the 23 known reproductive females (39.1%) have had multiple offspring during the study (1995-2003) and calving intervals recorded to date (*n* = 14) have ranged between 2-4 years with an overall mean of 2.8 yr (± s.d. 0.66). Overall, two-, three- and four-year intervals accounted for 28.6% (*n* = 4), 57.1% (*n* = 8) and 14.3% (*n* = 2) of all intervals observed, respectively. The longer calving intervals (3-4 yrs) may represent the true timing of this biological parameter but could also result from females being in poor physical condition (see next section), neonatal mortality, or predation on calves occurring prior to the arrival of females on the feeding ground (Brownell and Weller, 2002).

In addition to frequenting the study area when accompanying calves, there is also a strong tendency for reproductive females to be in the study area while pregnant (i.e. the year prior to calving) as well as while resting between pregnancies. Data to examine the occurrence of females on the feeding grounds the year prior to giving birth (i.e. while pregnant) were available for 31 cases between 1997 and 2003. In 80.6% (25 of 31) of these records, each respective female was sighted in the study area the year she was pregnant. Similarly, 24 cases between 1997 and 2003 were available for examining the presence of a respective female in the study area the year subsequent to giving birth (i.e. while resting). In 62.5% (15 of 24) of these records, females showed a return to the study area while resting between pregnancies.

Physical Condition and Health Status

During the 2003 field season, as was also true between 1999 and 2002, our team observed and documented whales that were unusually thin or also referred to as "skinny whales" (Weller *et al*., 2000, 2001,2002a, 2002d, 2003a, 2003c). This condition could be noticed, in most cases, within several minutes of approaching individuals by small boat for photo-identification purposes. Initial laboratory analysis of photographs and video collected between 1999 and 2003 revealed several morphological attributes correlated with a particular individual being described as unusually thin. Diagnostic features varied between individuals, but consisted of at least one of the following: (1) an obvious protrusion of the scapula(s) with associated thoracic depressions at the posterior and anterior insertion points of the flipper; (2) the presence of noticeable depressions or concavities around the blowholes and head; and (3) a pronounced depression along the neural/dorsal spine of the lumbar and caudal vertebrae resulting in the appearance of a bell-shaped body (see Brownell and Weller, 2001; Weller *et al.*, 2001, 2002d).

Field observations in 2003 recorded three whales as "skinny" (Table 7). This number of skinny whales is lower than reported in all years (1999-2002) since the phenomenon was first described in 1999 (Table 7). In 2003, two of the three skinny whales observed had also been recorded as skinny in 2000 or 2001. These numbers concerning skinny whales are slightly different from those reported elsewhere (e.g. Weller *et al.*, 2002d) because for the current assessment mothers accompanying calves have been removed from the data set. This measure was employed to guard against the possibility that body condition of lactating mothers may be naturally compromised, and thereby appear skinny, due to their increased energetic expenditure.

Overall, between 1999 and 2003 a total of 52 individual whales (excluding females with calves) were recorded as skinny, with 16 reported in 1999, 30 in 2000, 21 in 2001, 9 in 2002 and 3 in 2003 (Table 7). Forty-eight of these whales were of known sex, with 22 (45.8%) female and 26 (54.2%) male. For 12 whales sighted each year between 1999 and 2003, six (46.1%) were skinny in one year, four (30.8%) in two years and three (23.1%) in three years. No whales were observed to be skinny in all five years (1999-2003).

Genetic Sampling

In tandem with our ongoing photo-identification program, biopsy sampling for genetic research has also been conducted (LeDuc *et al.*, 2002; Brownell *et al.*, 2002). Fifteen biopsy samples were collected for genetic research in 2003 but laboratory analysis of these has yet to be completed. In total, 108 (82.4%) of the 131 whales photographically identified during the study have now been sampled. This number includes biopsies collected from 35 of the 42 (83.3%) calves observed between 1995 and 2003.

For all individuals (n = 93) sampled between 1995 and 2002, a male biased sex ratio of 59.1% (n = 55) males and 40.9% (n = 38) females was documented. When the subset of whales sampled as calves (n = 25) was examined, 68.0% (n = 17) were male and 32.0% (n = 8) female. The addition of fifteen samples from 2003 will add further information regarding the male bias in non-calves and calves observed thus far.

Previous genetic research on the western gray whale population has documented clear genetic differentiation from the eastern population on the basis of mitochondrial DNA haplotype frequencies (LeDuc *et al.*, 2002). More recently, a study by Lang *et al.* (2004) used bi-parentally inherited nuclear DNA markers to measure the differentiation and relative levels of genetic diversity in the nuclear genome between the western and eastern populations. For these purposes, 93 western gray whales and 126 eastern gray whales were genotyped at six polymorphic microsatellite loci. All six microsatellite loci showed higher levels of genetic diversity in the eastern population (mean H_e = 0.759) when compared with the western population (mean H_e =0.724), mirroring results found using mtDNA haplotypes. A comparison of allele frequencies between the western and eastern populations confirmed them to be genetically distinct ($p<0.001$) and indicated negligible gene flow between populations.

Offshore Photo-Identification Survey

During the first week of August 2003, a vessel-based survey was conducted along the east coast of Sakhalin Island but no gray whales were observed due to bad weather (i.e. dense sea fog). However, on 5 August, in water 3,200 m deep and approximately 50 mi offshore of southern Sakhalin Island (47° 05' N and 146° 08' E), two right whales (*Eubalaena japonica*) were encountered and digital photographs were collected for identification purposes (Burdin *et al*., 2004).

International Collaboration

As part of our broader objective to help train scientists and students from other range states where western gray whale occur, during summer 2003 Mr. Hyun Woo Kim from Pukyong National University, Republic of Korea, participated in our joint Russia-U.S. research program. Hyun Woo, a student of Dr. Zang Geun Kim of the National Fisheries Research and Development Institute, was trained in all aspects of our research program, including data collection techniques used from small boats and shore stations.

DISCUSSION

Findings from 2003 documented generally similar patterns to those observed between 1995 and 2002. Sighting frequency and site fidelity patterns, in addition to intra-seasonal occurrence, group sizes and distribution as a function of water depth all fall within the range of what has been previously reported for the population (e.g. Weller *et al*., 2003a, 2004; Burdin *et al*., 2003). Several notable changes reported in 2003, however, include: (1) the high number of calves observed (n = 11); (2) the increase in the number of known reproductive females from 17 in 2002 to 23 in 2003; and (3) the decrease in the number of skinny whales (n = 3) documented.

A number of biological parameters in concert with a variety of human-related threats, as identified during the current long-term study and discussed below, raise concern about the ability of the western gray whale population to recover from it highly depleted state and highlight the importance of continuing the long-term Russia-U.S. collaborative research and monitoring program.

Population Size

The size of the western gray whale population is small. Photo-identification studies off northeastern Sakhalin Island have identified only 131 individual whales during 264 surveys conducted over eight years. While "new" non-calf whales continue to be identified annually, the rate at which this happens is extremely low. The mark-recapture estimates of about 100 whales reported here and by Wade *et al*. (2003) closely correspond to direct counts and rate of discovery patterns derived from the multi-year photo-identification data, that also show the population size to be very small.

A possible explanation for the low number of whales identified during the study and the resulting small population size is that only a limited portion of a larger population migrates to northeastern Sakhalin Island during the summer. Several lines of evidence, however, argue against this explanation and include the following: (1) despite relatively extensive aerial and ship-based marine mammal surveys in the Okhotsk Sea between the 1960s and 1980s (e.g., Berzin *et al*., 1988, 1990, 1991) and more recently since the mid-1990s (Miyashita, 1997; Miyashita *et al*., 2001; Blokhin *et al*., 2002), sightings of western gray whales are uncommon outside of the northeastern Sakhalin Island area (Weller *et al*., 2002c, 2003b); (2) sightings of this species in other parts of its distribution including waters off Japan, South Korea and China are rare (see reviews by Henderson, 1972, 1984; Wang, 1978, 1984; Kato and Tokuhiro, 1997; Zhu, 1998; Kato and Kasuya, 2002); (3) records of gray whale bycatch and strandings anywhere within the know distribution are extremely low (e.g., Yamada *et al*., 2002; Zhu, 2002); and (4) a high proportion of all usable quality gray whale photographs that were opportunistically collected from outside of northeastern Sakhalin Island have been matched to the existing photo-catalog from the Piltun study area (Burdin *et al*., 2002; Weller *et al*., 2002c, 2003b).

These data, in combination, suggest that over the course of several years the entire western gray whale population (or nearly so) passes through the northeastern Sakhalin Island study area. Thus, all (or most) of the population would be accounted for in the abundance estimates reported here. Although these estimates reflect only the abundance of gray whales that frequent waters off northeastern Sakhalin Island, the lack of appreciable numbers of sighting or records of the species anywhere else within its known distribution suggests that the discovery of additional “major aggregations” of western gray whales is unlikely. Therefore, the estimates presented here (particularly estimates from the later years of the study, which have seemingly accounted for the return of whales temporarily emigrated from the study area), while collected from only a single geographic region, may represent a close approximation of the size of the entire western population.

Reproduction and Survival

Although estimates of GARR show that the western gray whale population is producing a reasonable number of calves annually, the limited number of known reproductive females (n = 23) combined with the three-year calving interval observed for most of these females is slowing the potential population growth. The interval between calves in the western population appears to vary from the typical two-year interval reported for the eastern population (Jones, 1990). If the three-year pattern of western gray whales represents a change from what was previously a two-year pattern, possibly due to nutritional stress or

disturbance, the change will decrease overall calf production in the western population by at least 20% (Brownell and Weller, 2002).
In addition, while estimates of western gray whale non-calf survival are comparable to rates reported for other baleen whale populations, calf survival (first-year post-weaning) rates are unusually low (see Bradford *et al*., 2003, submitted). This reduced recruitment of young individuals into the adult population will also negatively impact population growth.

Mother-Calf Pairs

Of the 10 females identified with calves in 2003, six had not previously been recorded with a calf. One of these six females was a "new" whale added to the photo-catalog in 2003 while the remaining five had been sighted during multiple years (range = 4-7 yrs) between 1994 and 2002. Several likely explanations may account for the high number of females first reported as mothers in 2003, including that these five whales: (1) are first time mothers; 2) had previous calves but lost them prior to arrival on the feeding ground; or 3) had weaned their calves prior to being first observed in that corresponding field season (this may account, in part, for the five calves sighted between 1997 and 2003 that were already independent of their mother when first observed).

The annual return of reproductive females while pregnant, resting and lactating indicates that the Sakhalin Island feeding ground is of significant importance to the continued survival of this population. That is, both lactating and pregnant females are under especially high energetic demands, therefore it is imperative that they feed in regions capable of meeting their elevated energetic requirements. If it is assumed that the elevated energetic requirements of reproductive females leads them to seek out the highest quality feeding areas, then the behavior of these females suggests that this feeding ground is vital to population recovery. This hypothesis is further supported by the fact that observations of mother-calf pairs have never been reported from any other region where western gray whales are occasionally sighted, including the nearby offshore feeding area.

Genetics

Given the small size of the western population and its isolation from the eastern population, the potential for continued loss of genetic diversity due to genetic drift or removal of individuals with rare alleles is of concern. The limited number of females in the population, as indicated by the male-biased sex ratio (at both the non-calf and calf levels), may limit maximum fecundity rates and in turn slow population recovery. The male bias observed for calves indicates lower recruitment of females into the adult population. This pattern further perpetuates the problem of a limited number of females being available to reproduce.

Future directions of our genetic research on western gray whales (Brownell *et al*., 2002; Lang *et al*., 2004) will provide significant new information regarding the population and include the following: (1) combine nuclear genetic data from microsatellite analysis with mitochondrial data to determine if sex-specific patterns of gene flow exist; (2) examine relatedness of individuals; (3) determine potential paternity of animals first identified as calves, allowing differential male reproductive success to be explored; (4) estimate the effective population size (number of breeding adults); (5) determine the level of genetic diversity present within the population and thereby evaluate loss of genetic diversity through inbreeding; and (6) catalog DNA "fingerprints" of all individuals sampled to facilitate matching to stranded animals and whales caught directly or taken incidentally in fishing gear.

Skinny Whales

Although the number of skinny whales observed in 2003 has declined since the phenomenon was first observed in 1999 (Weller *et al*., 2000, 2001,2002a, 2002d, 2003a, 2003c) the cause of such remains unexplained (see Brownell and Weller, 2001) and continues to be a point of concern for this critically endangered population. Possible explanations for the observed deterioration in physical condition and apparent health status of some whales may include any of the following factors, alone or in combination: 1) natural or human produced changes in prey availability or habitat quality; 2) physiological changes related to stress; or 3) disease. The most likely cause of this condition is clearly related to nutritional stress but the underlying reason(s) for the condition remains unknown (Brownell and Weller 2001).

During 1999 and 2000 the eastern gray whale population experienced unusually high mortality of immature/adult whales, with annual stranding rates approximately ten times greater than reported during the previous decade (LeBoeuf *et al*., 2000; Brownell *et al*., 2001; Moore *et al*., 2001). Coincident with the high mortality, estimates of calf production in 1999, 2000 and 2001 were the lowest recorded in an eight-year time series of data (Perryman and Rowlett, 2003). Although the causal mechanism(s) responsible for this event are poorly understood, some researchers hypothesize that eastern gray whale benthic prey biomass had been depleted due to the combined influence of increased annual water temperatures in the Bering Sea and over grazing of the feeding grounds by a population that may now exceed pre-exploitation levels (LeBoeuf *et al*., 2000; Moore *et al*., 2001).

While the above explanations regarding the eastern population appear plausible, observations of skinny western gray whales between 1999 and 2003 are less easily explained. It is impossible to think that the western population, at approximately 100 individuals, over grazed its benthic food base or exceeded the carrying capacity of the feeding grounds (Brownell and Weller, 2001). The interplay between benthic prey communities and environmental parameters such as primary production, ice, water temperature, and fresh water inflow from coastal lagoon systems (such as Piltun Lagoon) due to snow melt and river/stream system input, for example, may be at least partially responsible. It is also possible, however, that influences from industrial activities near the feeding ground (see following section on *Threats to the Population*) and other potential factors in the southern range of the western population are contributing to the skinny whale phenomenon, and any connection to similar events in the eastern population are purely coincidental. For example, the poor physical condition noted for some whales between 1999 and 2003 may be compounded by cumulative physiological stress correlated with long-term exposure to anthropogenic variables such as underwater noise (Richardson *et al*., 1995; Brownell and Yablokov, 2001).

Various pathologies and exposure to other potentially deleterious agents like contaminants and pollution could also be important contributors to the poor physiological condition of the whales observed to be skinny. Regardless of the causes, any disruption of normal feeding behaviors, total cumulative time spent feeding, or feeding locations off northeastern Sakhalin is of concern for all whales, but especially those observed to be skinny in addition to mother-calf pairs that are under high energetic demands (Weller *et al*., 2002d).

Therefore, it is essential that these skinny whales, and any others observed to be skinny in the future, continue to be carefully monitored to evaluate their survival. As such, a detailed photographic analysis examining the status of whales determined to be skinny in 1999-2003 in presently underway and will provide a more refined evaluation of potential fattening or further wasting. As part of this analysis, an inter-individual comparison of physical condition for females with calves will be conducted. This approach will provide a baseline index of physical condition specific to reproductive females and offer individual variation to be documented.

Offshore Survey

Although the offshore survey in 2003 produced no data due to continuous fog, a survey of the area in 2002 produced a high number of photographic matches of whales from offshore Sakhalin Island to those identified nearshore (Burdin *et al*., 2002). This area is a region where some gray whales have been observed feeding in recent years (Sobolevsky, 1998; Miyashita *et al*., 2001; Blokhin *et al*., 2002; Burdin *et al*., 2002, 2003; Weller *et al*., 2002c, 2003a, 2003b). Although whales show significant intra- and inter-annual site fidelity to the coastal waters (<10km from shore) off Piltun Lagoon, some individuals are not always present (e.g. Weller *et al*., 1999a, 2003a). While the primary feeding habitat for the western gray whale population is in relatively nearshore waters, it appears that a secondary prey base is also available, at least during some years, further offshore. The occurrence of some whales in both nearshore and offshore areas in a single season documents intra-area movement, likely related to foraging behavior. Inter-area movements of the nature described here are not unexpected as whales in the nearshore area have been documented to travel > 50 km in less than 24 hours. Therefore, it is possible for individual whales to transit between the offshore area (about 60-65 km southeast of the nearshore area) and the nearshore area in less than a day and possibly even faster. Eastern gray whales along the California coast have been estimated to travel 115-144 km a day during southbound migration (Swartz, 1986; Rugh *et al*., 1999). If this travel rate is applied to the current situation, whales may move between the offshore and nearshore area half a day or less. However, travel rates on the feeding ground may not be directly comparable to travel speed during migration. Further, the high level of photographic resightings between the nearshore and offshore areas demonstrates that the two areas are not utilized by distinct subunits of the population.

Results from the 2002 survey (Burdin *et al*., 2002, 2003), in combination with the broader-scale photographic matching efforts reported by Weller *et al*. (2002c, 2003b) suggest that coordinated matching of gray whale images, particularly those collected in areas within the known distribution of western gray whales, are valuable in better understanding the range and movements of individual whales in this critically endangered population. Therefore, standardized photographs (i.e. right-side dorsal flank markings when possible) of western gray whales anywhere within their range should be collected and subsequently compared to the catalog of known individuals from the summer feeding ground off northeastern Sakhalin Island.

Threats to the Population

In addition to the biological difficulties that western gray whales face, the recent onset of large-scale oil and gas development programs off Sakhalin Island pose new threats to the future survival of the population (Weller *et al*., 2002a; Brownell 2004). Sakhalin Island is a region rich with large reserves of offshore oil and gas (Fig. 9) that, until recently, have been unexploited. Industrial activities on the continental shelf of this region have steadily increased in the past seven years and are scheduled to expand at a rapid pace into the future. Oil and gas development activities that may negatively impact western gray whales include: (1) disturbance from underwater noise associated with seismic surveying (Weller *et al*., 2002e), pipeline dredging, ship and air traffic and platform operations; (2) direct interactions between whales and an oil spill or other waterborne chemicals, ships, and possible entanglements in cables or lines; and (3) habitat changes related to seafloor modifications associated with dredging and sand pumping activities that may adversely impact gray whale prey.

Additional threats to the western gray whale population include continued mortality from an undetermined level of poaching (Brownell, 1999; Brownell and Kasuya, 1999; Baker *et al*., 2002) in the southern portion of the range, and possible incidental catches in the extensive coastal net fisheries off southern China, Korea and Japan (Zhou and Wang, 1994; Kato, 1998; Kim, 2000). The substantial nearshore industrialization and shipping congestion throughout the migratory corridor(s) of this population also represent potential threats by increasing the likelihood of disturbance, exposure to pollution and probability of ship strikes.

Research and Other Scientific Recommendations

Given the continued uncertainty regarding the ability of the western gray whale population to recover from its depleted state, impacts from to oil and gas development activities on the Sakhalin Island feeding ground need to be closely monitored and stringently mitigated to reduce disturbance to the lowest possible level. Where scientific knowledge is lacking, the precautionary principle should be applied as the best measure of protection. With this in mind, we recommend that the photo-identification and genetic biopsy research conducted since 1995, and reviewed here, be continued to further monitor survival of individuals, describe the overall population trend and to recommend further conservation and protection measures. At the same time, additional studies should also be done, including:

(1) Continued monitoring of the health-related status of skinny whales using a suite of techniques including benthic assessments of prey density and physiological and toxicological evaluations of blubber, skin, and fecal samples to assess the potential contribution of disease, stress, and diet. In addition, comparative studies between western and eastern gray whales, to better understand the skinny whale phenomenon that has affected both populations, are needed. This type of comparative research could provide insight into the factors causing this condition in both populations.

(2) Conduct benthic sampling of invertebrate communities inside as well as immediately outside areas where observations indicate that gray whales are feeding. Benthic sampling should lead to descriptions of prey types and estimates of prey density in these areas, within and between open-water seasons. Qualitative assessments should be made of feeding pits or other bottom features made by gray whales. Prey can be characterized by transect sampling by divers, video cameras, qualitative bottom grabs, and/or side-scan sonar. Measurements of organic carbon levels in the habitat are needed to establish a baseline to detect changes in organic substances that could be attributed to possible contamination resulting from oil and gas development and production. Similar baseline information is needed to detect and assess physical changes in the habitat resulting from oil and gas development activities.

(3) Conduct a detailed program to record underwater sounds believed to be within the hearing range of gray whales. This involves measurements of sound attenuation at various distances from industrial activity, and in various depths and habitats of gray whales. Long-term recordings, including those made during periods of darkness and inclement weather, can be achieved with hydrophone systems that are bottom mounted. Efforts should be made to characterize ambient noise levels in this area.

(4) Shore-based behavioral studies incorporating theodolite and focal animal observation techniques following those developed by Würsig *et al*. (1999) in 1997 and 1998 should be conducted concurrent to continuous acoustic monitoring to evaluate the relationship between noise and whale behavior.

(5) Although telemetry studies (radio and satellite) may provide insight regarding intra- and inter annual movement patterns and migration corridors, no such tagging should commence until first tested on eastern gray whales (preferably while feeding) to ensure safety and prove effectiveness (as *recommended* by the IWC in 2001 and 2002). Because the western gray whale population is so small, injury or in the worse case death of even a single whale (especially a female) due to tag related complications may have significant impact on this population's ability to recover.

(6) A workshop or meeting, including oil company representatives and gray whale scientists, should be convened annually to discuss past results and generate future research plans for western gray whales off northeastern Sakhalin Island and elsewhere.

(7) A review and synthesis of all photo-identification data collected between 1997 and 2003 (or beyond) should be completed to evaluate long-term estimates of survival, abundance and overall population trends.

(8) Production and publication of a western gray whale photo-identification catalog.

CONCLUSIONS

Based upon the results reported here, it is clear that the western gray whale population is struggling to survive. Recovery and growth of the population appear to be hindered by a variety of biological difficulties and the onset of large-scale oil and gas development programs that may alter the feeding ground off Sakhalin Island are of particular concern with regard to the future survival of the population.

The high rates of annual return and pronounced seasonal site fidelity to the study area displayed by most whales, especially true for females with dependent offspring and females that are pregnant, clearly indicate the population-level importance of the feeding habitat off northeastern Sakhalin Island. That is, members of the western gray whale population annually utilize this feeding area and depend upon the benthic food base available there for their survival. As no other feeding area(s) outside of northeastern Sakhalin Island have been identified, it is clear that the conservation of the western gray whale is intricately related to this particular habitat. The annual aggregation of feeding whales in this region, but not other regions, is likely a reflection of the site-specific biological richness (i.e. high benthic biomass; see Koblikov, 1986) of the area; perhaps related to enrichment of near-shore marine waters by nutrient laden tidal effluent from Piltun Lagoon and other nearby lagoon systems.

Of particular importance, with regard to the future survival of the western population, is the regular occurrence of females with dependent offspring and pregnant females off the Piltun Lagoon area. Mother-calf pairs and newly-pregnant females rank among the most commonly sighted individuals on an intra- and inter-seasonal basis off Piltun Lagoon, and no sighting records of a mother-calf pair have ever been recorded outside of this area. In general, females with calves, as well as calves weaned during the summer/fall, utilize an area approximately 60 km long (north-south) and 5 km wide (east-west). Theodolite determined locations for mother-calf pairs show that, on average, they are found 1.2 km from shore in waters 6.0 m deep while other whales (non-calf groups) are distributed, on average, 2.3 km from shore in waters 15.0 m deep (Weller *et al*., 1999b). This behavioral pattern of remaining mostly in nearshore waters may serve a variety of purposes. For example, other large whale species are known to remain near to shore when tending a calf to avoid predation and to possibly help teach feeding behavior. However, since both lactating and pregnant females are under especially high energetic demands it is imperative that they feed in regions capable of meeting their elevated physiological requirements. Thus, the seasonal site fidelity and annual return of reproductive females reported here is likely to be related to feeding and suggests that the northeastern Sakhalin Island coast, particularly the nearshore waters off Piltun Lagoon, represents special critical habitat for their summer feeding and nurturance of offspring.

In conclusion, protection of the Sakhalin Island feeding habitat, including the coastal lagoon systems that appear integrally related to the high benthic biomass in the area, is clearly paramount to successful conservation of the western gray whale population. The unique method of benthic feeding by these whales makes them an "umbrella" species (Hooker and Gerber 2004), whereby protection of their habitat provides protection for the biological diversity of the entire northeastern Sakhalin Island shelf. Thus, the feeding habitat of the western gray whale needs to be considered a "hot spot" for conservation planning now and in the future and every effort should be taken to protect its biological integrity.

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Table 1. Funding agencies, listed alphabetically, for gray whale studies between 1997 and 2003.

Year	Funding Agency
1997	Exxon Neftegas Ltd., Sakhalin Energy Investment Company
1998	Exxon Neftegas Ltd., Sakhalin Energy Investment Company
1999	Sakhalin Energy Investment Company
2000	International Fund for Animal Welfare, Sakhalin Energy Investment Company, U.S. National Fish and Wildlife Foundation
2001	International Fund for Animal Welfare, Sakhalin Energy Investment Company, U.S. Environmental Protection Agency, U.S. Marine Mammal Commission, U.S. National Marine Fisheries Service
2002	U.S. Marine Mammal Commission, Ocean Park Conservation Foundation
2003	International Fund for Animal Welfare, International Whaling Commission, U.S. Marine Mammal Commission, U.S. National Marine Fisheries Service

Table 2. Survey years, survey numbers and cumulative number of whales identified 1994 to 2003.

Year	Survey Numbers	Cumulative Number of Whales Identified by Final Survey
1994	1	10
1995	2-6	39
1997	7-28	59
1998	29-63	72
1999	64-118	87
2000	119-158	93
2001	159-206	105
2002	207-242	118
2003	243-264	131

Table 3. Annual survey effort, groups encountered and whales identified 1994 to 2003.

Year	Sampling Period (mo, d)	Number of Surveys	Hours of Observation	Rolls of Film Used	Groups Encountered	Whales Identified
1994	09/07 - 09/12					10
1995	08/15 - 08/19	5	10.1	15	23	27
1997	07/09 - 09/08	22	33.4	72	114	47
1998	07/06 - 09/29	35	50.5	91	125	54
1999	06/29 - 10/13	56	122.0	160	434	69
2000	06/25 - 09/16	40	56.5	76	365	58
2001	06/25 - 09/25	48	101.8	75	448	72
2002	06/25 - 09/25	36	75.6	122	411	76
2003	07/15 – 09/13	22	41.6	85	219	75
Overall		264	494.1	696	2139	131[1]

[1] Number of whales identified annually includes resightings of individuals from previous years.

Table 4. Sea surface temperature and salinity associated with group sighting locations in 2003.

Variable	Sample Size	Mean	± S.D.	Median	Mode	Range
Temperature (°C)	20	2.6	2.92	2.75	5.0	-1.5-6.5
Salinity (ppt)	19	33.7	1.88	34	35	30-36

Table 5. Group size summary statistics 1995 to 2003.

Year	Number of Groups	Mean Group Size	Median Group Size	Mode Group Size	± S.D. Group Size	Range in Group Size
1995	23	2.3	2	2	± 1.18	1-6
1997	114	1.8	1	1	± 1.33	1-9
1998	125	2.0	2	2	± 1.02	1-6
1999	434	1.8	1	1	± 1.03	1-7
2000	365	1.6	1	1	± 0.84	1-5
2001	447	1.8	2	1	± 1.08	1-9
2002	411	1.9	2	1	± 1.28	1-9
2003	219	2.3	2	1	± 1.43	1-9
Overall	2138	1.9	1.6	1.3	± 1.15	1-9

Table 6. Annual sighting trends and resighting percentages 1994 to 2003.

Year	Whales Identified	Number of Calves	New Non-Calves	GARR	Percent Non-Calves Previously Identified
1994[1]	10				
1995[1]	27	2	20		20.0%
1997	47	2	25	4.3%	44.4%
1998	54	8	5	14.8%	89.1%
1999	69	3	12	4.3%	81.8%
2000	58	3	3	5.2%	94.5%
2001	72	6	6	8.3%	91.0%
2002	76	7	6	9.2%	91.3%
2003	75	11	2	14.7%	96.9%

[1] Data are incomplete due to the limited field effort in 1994 and 1995.

Table 7. Summary of skinny whales recorded during fieldwork 1999 to 2003.

Year	Number of Whales Photo-Identified	Number of Whales Recorded as Skinny	Percentage of Whales Recorded as Skinny
1999	69	16	23.2%
2000	58	30	51.7%
2001	72	21	29.2%
2002	76	9	11.8%
2003	75	3	4.0%

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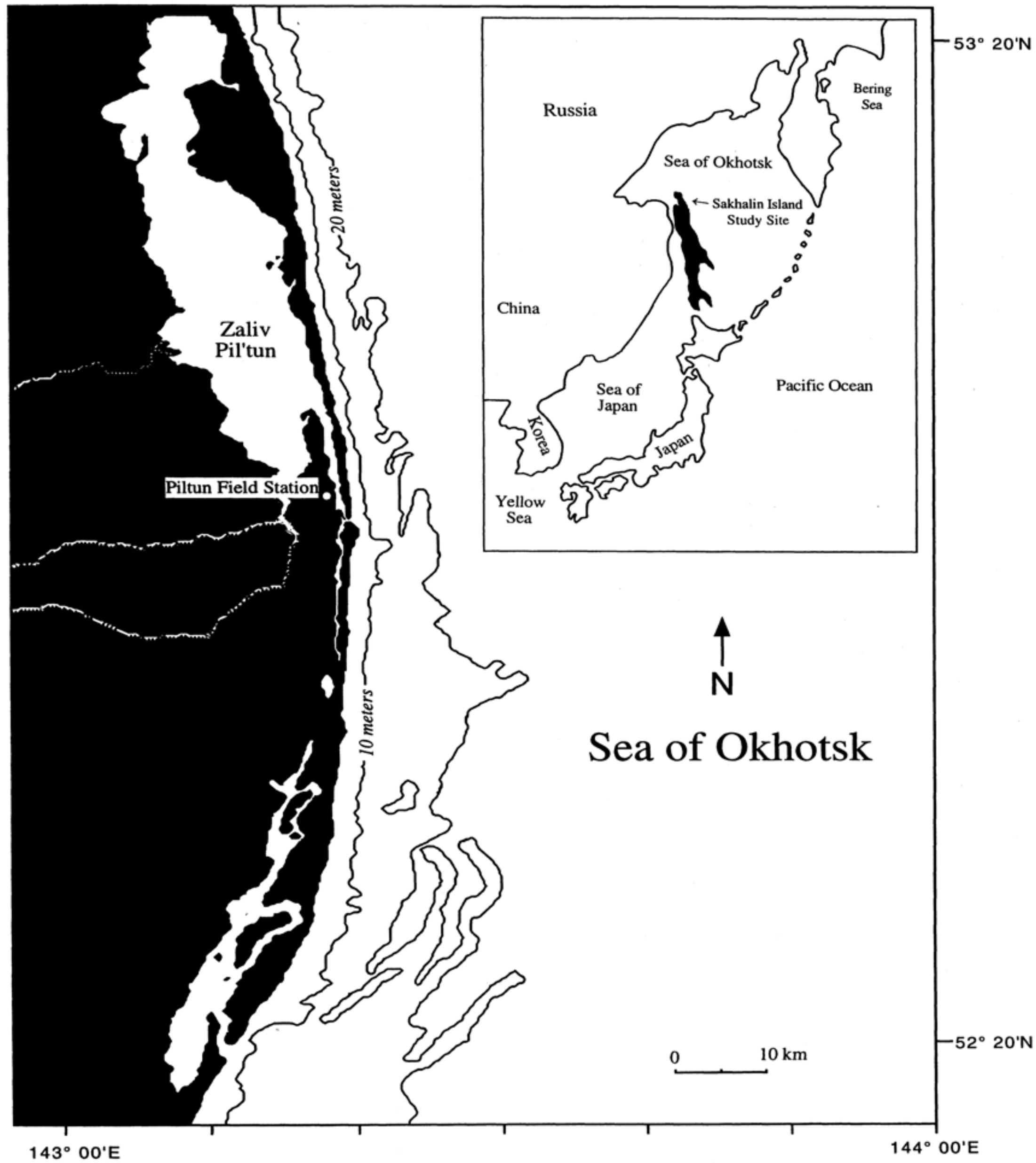

Figure 1. Map of the Piltun study area. Inset shows relative location of Sakhalin Island in the Sea of Okhotsk.

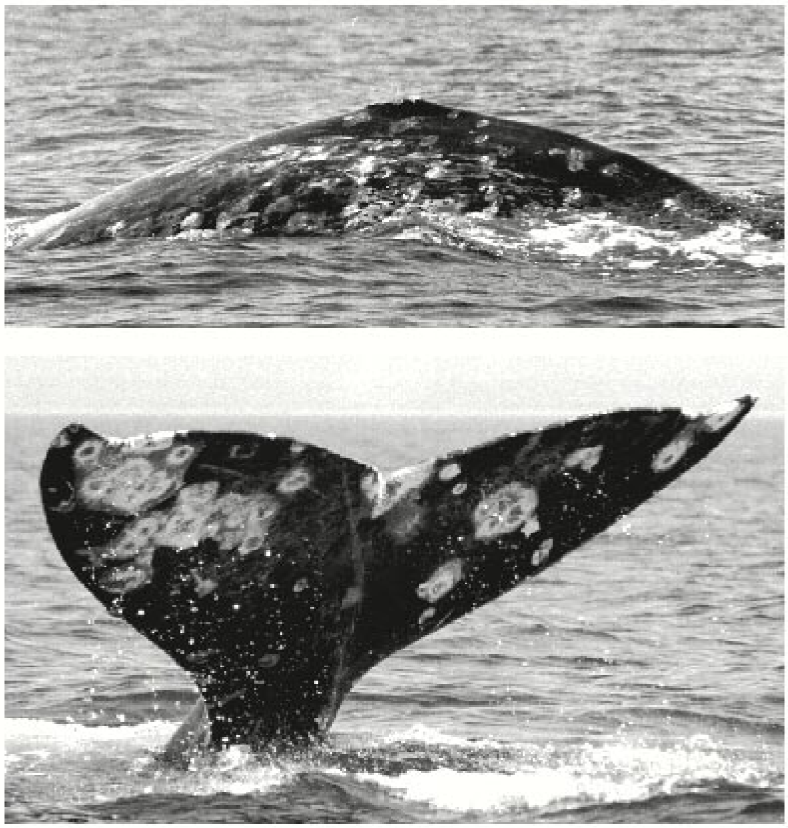

Figure 2. Pigmentation and other patterns used to photographically identify individual whales.

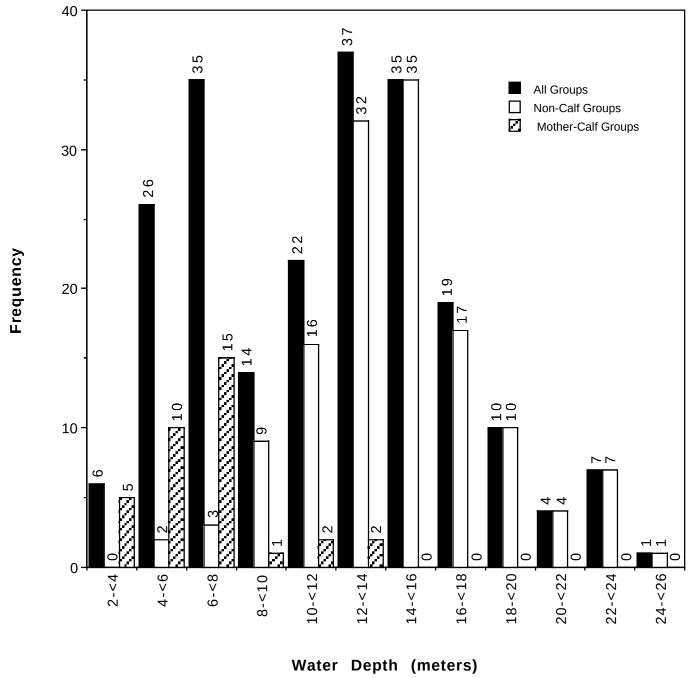

Figure 3. Distribution of water depths for locations where whale groups were encountered in 2003.

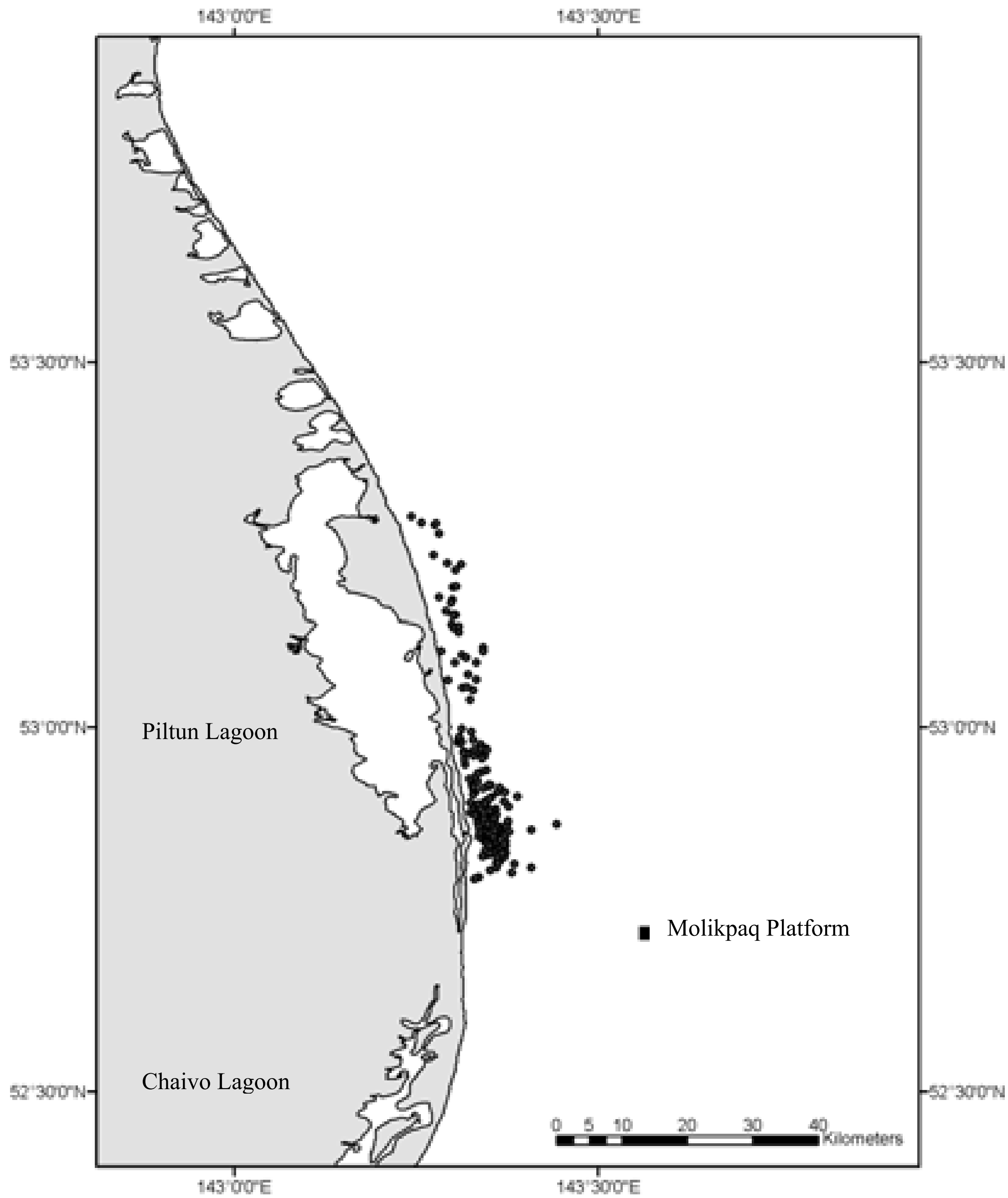

Figure 4. Distribution/locations of whale groups encountered in 2003.

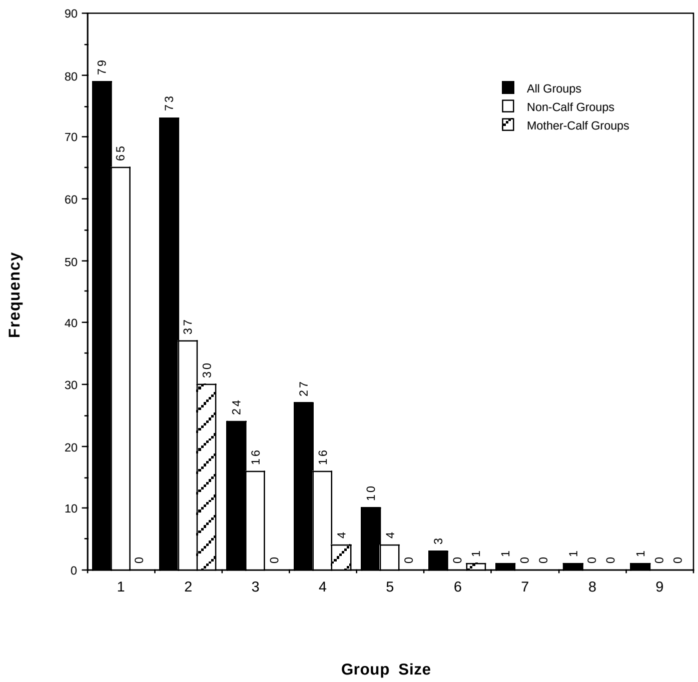

Figure 5. Distribution of group sizes for whale groups encountered in 2003.

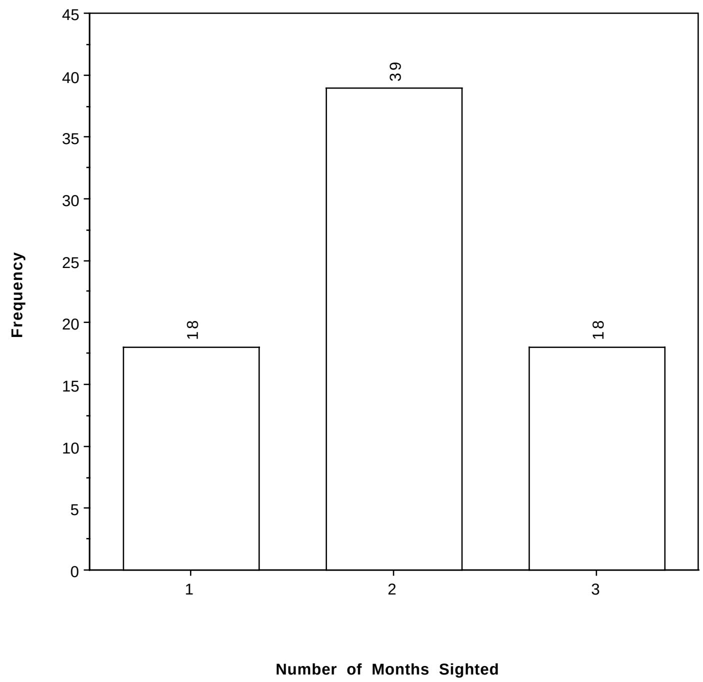

Figure 6. Monthly sighting frequencies for whales identified in 2003.

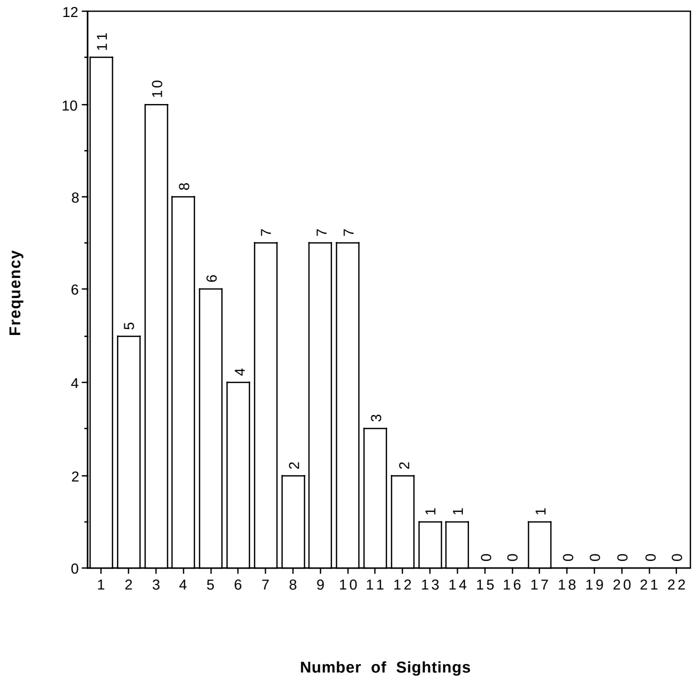

Figure 7. Sighting frequencies for whales identified in 2003.

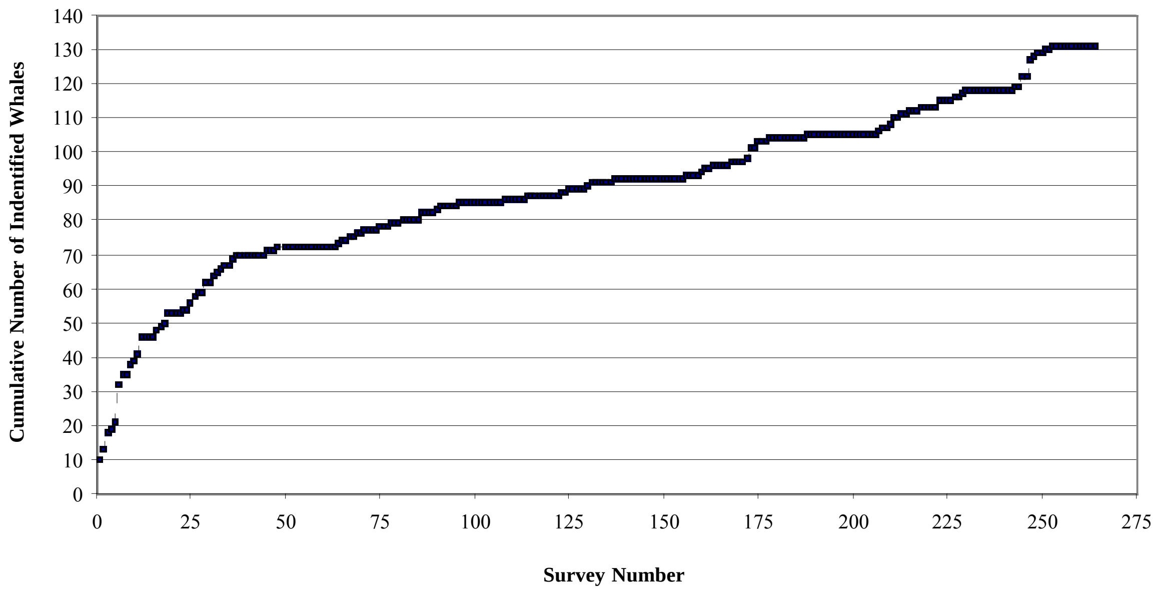

Figure 8. Rate of discovery curve for whales identified between 1994 and 2003. Each point represents a survey (n = 264).

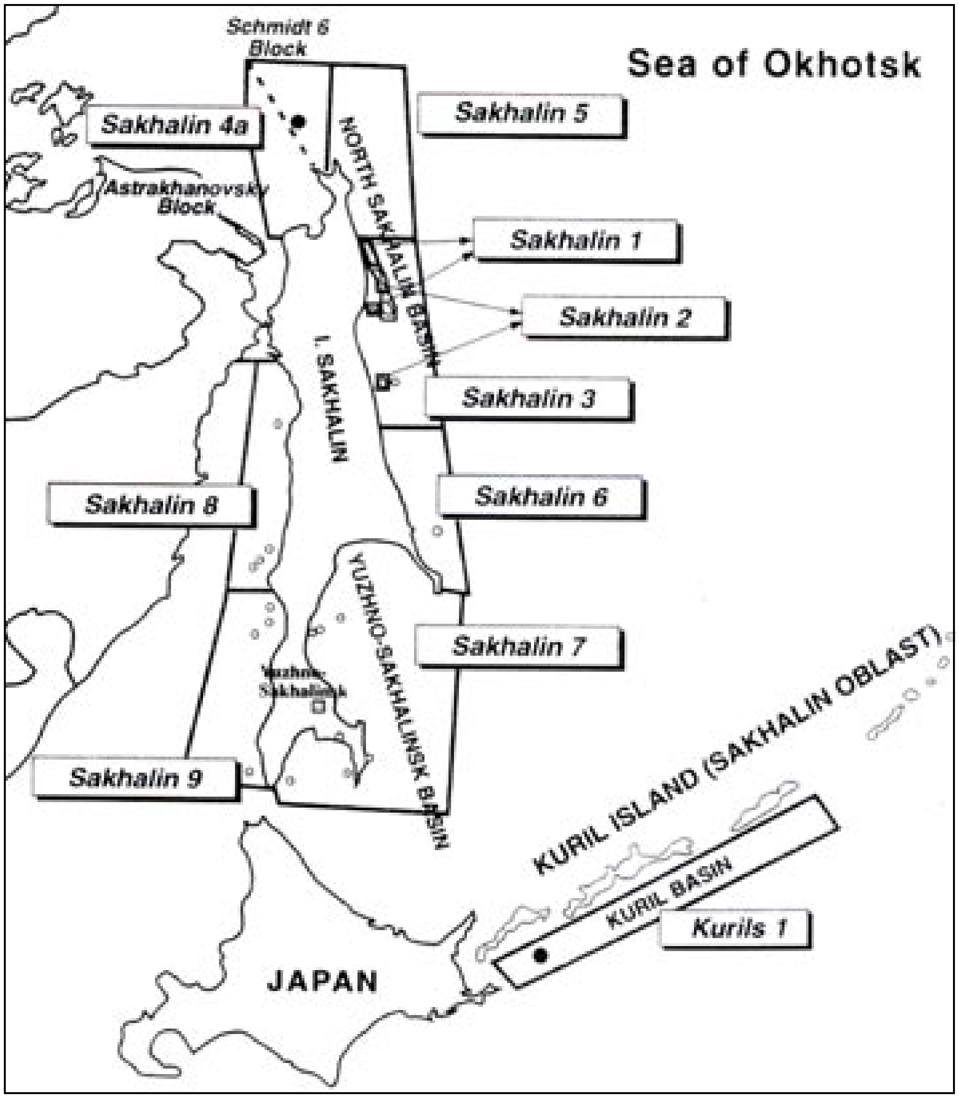

Figure 9. Locations of major offshore oil fields surrounding Sakhalin Island, Russia.