April 2000

Distribution and abundance of marine mammals at San Clemente Island and surrounding offshore waters: results from aerial and ground surveys in 1998 and1999.

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ADMINISTRATIVE REPORT LJ-00-02

Table of Contents

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Abstract

The abundance and seasonality of marine mammal species utilizing San Clemente Island, California and surrounding offshore waters is described from data collected during aerial line-transect, photogrammetric, and ground surveys conducted in 1998-99. Short-beaked common dolphins (*Delphinus delphis*) occurred year-round and were the most abundant marine mammal in the study area ($\hat{N}$ = 26,238, CV = 0.30). Common dolphin abundance was 2.5 times greater during the warm-water months of May through October ($\hat{N}$ = 38,851, CV = 0.39) than during the cold-water months of November through April ($\hat{N}$ = 14,834, CV = 0.37). Dall's porpoise (*Phocoenoides dalli*), northern right whale dolphins (*Lissodelphis borealis*) and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) were present only during the cold-water months of November-April. Of these cold-water species, Pacific white-sided dolphins were the most abundant ($\hat{N}$ = 1,649, CV = 0.44), followed by northern right whale dolphins ($\hat{N}$ = 754, CV = 0.40) and Dall's porpoise ($\hat{N}$ = 370, CV = 0.62). Risso's dolphin abundance was three times higher during cold-water months ($\hat{N}$ = 1,500, CV = 0.40) than during warm-water months ($\hat{N}$ = 513, CV = 0.56). Bottlenose dolphins were the least abundant dolphin ($\hat{N}$ = 207, CV = 0.50) and were found year-round, primarily in association with Risso's dolphins. Gray whales (*Eschrichtius robustus*) were the most abundant whale during the months of January through April, when a daily average of 424 whales (CV = 0.29) were within the study area during the peak of migration. Numbers of migrating gray whales found in these waters suggests that a significant fraction of the entire population traverses this area during both southbound and northbound migrations. Fin whales (*Balaenoptera physalus*) were present year-round and were the next most abundant whale species ($\hat{N}$ = 48, CV = 0.26). Blue whales *(Balaenoptera musculus*) were present primarily during the late spring and summer ($\hat{N}$ = 40, CV = 0.39), with one exception of a southbound whale seen in November. Humpback whales were encountered only twice, in April of 1998 and 1999 ($\hat{N}$=12, CV = 0.46). Cuvier's beaked whales (*Ziphius cavirostris*) were encountered four times during the cold-water months of November through April ($\hat{N}$ = 153, CV = 0.52). California sea lions (*Zalophus californianus*) were the most abundant pinniped in the study area: over 3,900 sea lions were counted ashore at San Clemente Island during an April 1999 census, with an additional 2,100 animals at sea estimated from aerial line-transect surveys. Fewer than 200 harbor seals (*Phoca vitulina*) and northern elephant seals (*Mirounga angustirostris*) are found hauled out on San Clemente Island at any one time. Pinnipeds at San Clemente Island predominately use the area in the vicinity of Mail Point, although other haulouts include Castle Rock, China Point, South Point (Pyramid Head), and Northwest Harbor Islet. Sea otters (*Enhydra lutris*) were encountered on three occasions on the west side of San Clemente Island during aerial line-transect surveys. The origin of these animals is unknown, but they may represent vagrants from nearby San Nicolas Island.

Introduction

In 1996, the U.S. Navy requested that the U.S. National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC) conduct a marine mammal survey of San Clemente Island (SCI) and its associated offshore training ranges. The goal of the proposed survey was to provide the Navy with baseline information on the abundance and distribution of marine mammals, which was to be incorporated into a programmatic environmental impact statement (EIS) to address environmental impacts of fleet operations. A comprehensive marine mammal survey was initiated by the NMFS/SWFSC in April of 1998 and was completed in July of 1999. The survey effort included an aerial line-transect abundance survey of offshore waters surrounding San Clemente Island, quarterly aerial photogrammetric and ground surveys of pinniped rookeries along the San Clemente Island shoreline, and opportunistic aerial photogrammetric surveys of gray whales and common dolphins. The following report summarizes the results of those surveys.

Materials and Methods

1. Aerial line-transect surveys

The distribution and abundance of marine mammals in the vicinity of San Clemente Island and offshore waters was determined with aerial surveys using line-transect methods (Buckland et al. 1993). Surveys were conducted with a twin-engine Partenavia aircraft equipped with bubble windows. A team of three marine mammal observers and one data recorder searched for marine mammals from an altitude of 213 m (700 ft) and an airspeed of 185 km/hr (100 kts) along a series of 33 transect lines ranging in length from 6 to 103 km (Figures 1-2). Transect lines were surveyed from April 1998 through June 1999 and an effort was made to survey the entire area 1-2 times per month. The study area was divided into *inshore* and *offshore* geographic strata. Inshore transects covered a 522 km^2 area within 5.5 km (3 nautical miles) of San Clemente Island; offshore lines covered an additional 7,830 km^2 area largely south and west of San Clemente Island. Strata were designed to allow geographically stratified estimates of pinniped densities to be calculated (higher densities of pinnipeds were expected near rookeries). The total size of the study area (excluding the 153 km^2 area of San Clemente Island and associated offshore rocks) is 8,352 km^2. Areas were obtained using ArcView GIS.

Two ‘primary observers’ (hereafter referred to as the ‘primary observer team’) searched for marine mammals from side bubble windows. A third observer (hereafter referred to as the ‘secondary observer’) searched from a prone position through a belly window in the rear of the aircraft. The role of the secondary observer was to detect sightings missed by the primary observer team. Accordingly, the secondary observer waited approximately 5 seconds after sighting animals before stating their presence. Sighting data from both observer ‘teams’ were used to calculate the fraction of groups missed by all three observers. Effort and sighting information was relayed from observers to a data recorder, who entered information into a laptop computer linked to the aircraft's GPS system. Primary observers measured the angle to each marine mammal sighting using hand-held clinometers, and the secondary observer used calibrated hatch marks applied to the belly window. The perpendicular distance (PD) to each sighting was calculated as

$$PD = \tan\left(90 - angle\right) \cdot altitude \qquad (1).$$

Animal densities were estimated for each species using line-transect methods (Buckland et al. 1993), the software program DISTANCE 3.5 (Thomas et al. 1998), and the equation

$$\hat{D}_{i,j,k} = \sum_{i=1}^{2} \sum_{k=1}^{2} \frac{n_{i,j,k} \cdot f(0)_{j,k} \cdot \overline{S}_{i,j,k}}{2 \cdot L_i \cdot g(0)_{j,k}} \qquad (2),$$

where

$n_{i,j,k}$ = number of groups of species *j* of group size stratum *k* detected in area *i;*
f(0) = probability density function (km^{-1}) evaluated at zero perpendicular distance;
$\overline{S}_{i,j,k}$ = mean group size of species *j* of group size stratum *k* seen in area *i;*
L_i = Length of transect line (in km) surveyed in area *i;* and
$g(0)_{j,k}$ = probability of detecting a group of species *j* of group size stratum *k* on the transect line.

The probability density function, *f(0),* was estimated with the program DISTANCE 3.5. Model choices were the half-normal (with hermite polynomial and cosine series expansions), hazard rate (w/cosine) and uniform (w/cosine and simple polynomial). Model selection was based on minimizing Akaike's Information Criteria (AIC; Akaike 1973). Where appropriate, the largest 5-10% of perpendicular distances were truncated to improve model fits (Buckland et al. 1993). Probability density functions were estimated separately for three species groups: (1) pinnipeds; (2) delphinids (dolphins and porpoises); and (3) whales. These species groupings are based on subjective impressions of detectability, which is influenced by sighting cues such as body size, blows, and the number of animals in a group. Within the delphinid species group, sighting data were further stratified by group size, using AIC to objectively select group size strata. This resulted in two group size strata of 1-25 and ≥ 26 animals, which split the sample approximately in half. Pinniped and whale sighting data were not stratified by group size owing to low group size variance within each species category. Environmental factors, such as Beaufort sea state, influence the sightability of all the above species groups, however, sample sizes were insufficient to further stratify by Beaufort sea state, with the exception of the pinniped species group. Therefore, delphinid and whale density estimates reflect data collected during Beaufort sea states 0-4. Separate pinniped density estimates were generated for 'calm' (Beaufort 0-2) and 'rough' (Beaufort 3-4) sea states and overall densities calculated as the effort-weighted mean of the two estimates. We also examined whether it was more appropriate to stratify by group size or sea state for the delphinid species group by performing an exploratory analysis using the program DISTANCE 3.5. This exploratory analysis favored group size stratification over sea state stratification, as evidenced by lower AIC values. In addition, the exploratory analysis demonstrated that delphinid density estimates were similar whether or not Beaufort sea state strata were utilized, which suggests a degree of pooling robustness in the detection function models used (Buckland *et al*. 1993). Abundance estimates for each species ($\hat{N}$), were calculated by multiplying animal density ($\hat{D}$) by the size of each respective study area.

Line-transect theory assumes that all objects on the transect line are detected; in other words, *g(0)* = 1 (see denominator of Equation 2). However, this is an unrealistic assumption for aquatic diving species that may be easily overlooked from a fast-moving aircraft. Observers may fail to detect animals for two reasons: (1) *perception bias*, where animals are available to be seen, but are missed due to adverse survey conditions (whitecaps, glare, swell) or failure to recognize animals that are visible; and (2) *availability bias*, where an animal is diving and is thus out of visual range of the observers (Marsh and Sinclair 1989). To avoid underestimating animal densities, it is important to correct for availability and perception bias. Using published dive profile data, we estimated the availability bias component of *g(0)* for several species as the simple fraction of time that a species spends at or near the surface, with consideration to the amount of time an animal is visible to an aerial observer searching from an aircraft cruising at 185 km h^{-1}. Following Barlow et al. (1988), we modeled the availability bias component of *g(0)* as follows:

$$g(0)_{availability} = \frac{s+t}{s+d} \qquad (3),$$

where *s* is the average length of time spent at or near the surface, *t* is the window of time during which an animal is within visual range of the aerial observer, and *d* is the average dive duration. In calculating availability bias, we estimated the window of time (*t*) in which an aerial observer had to detect an animal to be 10 seconds, during which time the aircraft would have traveled approximately 500 meters. Where available, dive data were obtained directly from the literature for California sea lion (Feldkamp 1989), northern elephant seal (Le Boeuf 1994), harbor seal (Stewart and Yochem 1989a, 1989b), Cuvier's beaked whale (Barlow et al. 1997; Barlow 1999), humpback whale (Dolphin 1987), minke whale (Stern 1992), and blue whale (Barlow et al. 1997). For Dall's porpoise, we estimated availability bias using dive and observation data obtained from aerial surveys of harbor porpoises (Laake et al. 1997), a species of similar size and perhaps, metabolic and diving constraints. For fin whales, we assumed that availability bias was equal to that calculated for blue whales. Calculating availability bias for gray whales was problematic, as dive data indicate they are at the surface only 5% of the time (Harvey and Mate, 1984; Rugh 1984). However, it is clear from aerial observations that gray whales are visible for a much greater fraction of time because they travel close to the surface when submerged and they often occur in groups of several animals. For this reason, we estimated $g(0)_{availability}$ using Equation 3 and by assuming that gray whales are visible not only during the mean 4.4 second surfacing interval reported by Harvey and Mate (1984), but also for up to 15 seconds prior to and after this interval, when they are swimming just below the surface. For delphinids, we did not estimate an availability bias component of $g(0)$, since these species usually occur in medium to large-sized groups, with some individuals always visible at or near the surface. For small groups of delphinids (<10 animals), availability bias may be more important; however, these small groups make up only a negligible contribution to overall density estimates. We estimated the *perception bias* component of $g(0)$ for the pinniped and dolphin/porpoise species groups using the method of Forney and Barlow (1993), where $g(0)_{perception}$ represents the minimum proportion of groups seen by at least one observer team:

$$g(0)_{perception} \geq \left(2 - \frac{g(0)_{both}}{g(0)_{primary}}\right)\frac{g(0)_{both}}{g(0)_{primary}} \qquad (4),$$

and

$$\frac{g(0)_{both}}{g(0)_{primary}} = \frac{n_{both}\, f(0)_{both}}{n_{primary}\, f(0)_{primary}} \qquad (5),$$

where

n_{both} = number of sightings made by the primary and secondary observer teams combined;
$n_{primary}$ = number of sightings made by the primary observer team;
$f(0)_{both}$ = probability density function evaluated at zero perpendicular distance for primary and secondary sightings combined;
$f(0)_{primary}$ = probability density function evaluated at zero perpendicular distance for primary sightings;
$g(0)_{both}$ = the fraction of groups seen on the trackline by both observer teams combined;
and
$g(0)_{primary}$ = the fraction of groups seen on the trackline by the primary observer team.

Estimates of $g(0)$ for common, bottlenose, Risso's, and Pacific white-sided dolphin include only the perception bias component and resulting density estimates will probably be biased low by a small, but non-trivial amount. For Dall's porpoise, where we estimated *both* availability and perception bias, the resulting estimate of $g(0)$ represents the multiplication of the two components [$g(0)_{total} = g(0)_{perception} \times g(0)_{availability}$]. Where possible, standard errors and CVs of $g(0)$ components are calculated directly from published surface-dive cycles or taken directly from the literature, and the uncertainty in $g(0)$ is incorporated into the overall density estimates (see last term of Equation 6). For species where individual dive cycle data are unavailable, estimates of $g(0)$ are assumed to be known without error. This will result in an underestimate of the overall variance in density estimates, but at the same time, density estimates themselves will be less biased by including a $g(0)$ correction factor. Because no whale sightings were made by the secondary observer, no estimate of perception bias was made for the whale species group. However, perception bias for whales is expected to be negligible since these animals are rarely missed on the trackline when visible at the surface (Forney et al. 1995).

The variance of each density estimate was calculated as

$$\hat{\text{var}}\,\hat{D} = \hat{D} \cdot \left\{ cv(n)^2 + cv(f(0))^2 + cv(E(s))^2 + cv(g(0))^2 \right\} \quad (6).$$

The coefficients of variation (CV) of each density estimate were calculated as

$$CV = \sqrt{\frac{\hat{\text{var}}\,\hat{D}}{\hat{D}^2}} \quad (7).$$

The encounter rate variance for each species was estimated empirically from the replicate transect data using the program DISTANCE 3.5. Log-normal 95% confidence intervals of the density estimates were calculated using the Satterthwaite procedure, described in Buckland et al. (1993:120-121):

$$\hat{D}_{L95\%} = \hat{D} / C \quad (8),$$

$$\hat{D}_{U95\%} = \hat{D} \cdot C \quad (9),$$

and

$$C = \exp\left\{ t_{df}\ (0.025) \cdot \sqrt{\log_e}\ (1 + \left[cv(\hat{D}) \right]^2 \right\} \quad (10).$$

We observed clear seasonal shifts in the abundance and distribution for several species within the study area, reflecting the findings of Forney and Barlow (1998), who reported significant differences in the abundance of several cetacean species between cold and warm-water months in California. To adequately address seasonal changes in abundance, we present separate density and abundance estimates for the ‘cold-water months’ of November through April and the ‘warm-water months’ of May through October. These ‘oceanographic seasons’ reflect the presence and absence of species that have affinities for cold and warm waters, respectively. For example, cold-water species such as Dall's porpoise (*Phocoenoides dalli*), northern right whale dolphins (*Lissodelphis borealis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), and gray whales (*Eschrichtius robustus*) were seen only during the cold-water months of November through April. In contrast, blue whales (*Balaenoptera* musculus) were seen primarily during warm-water months, with the exception of one southbound migrant seen in November. Our decision to stratify the data by oceanographic season rather than by calendar season is less arbitrary and reduces bias in density estimation for species which are present only part of the year. In addition to seasonal estimates, we also report year-round estimates of density and abundance for those cetacean species that were seen during both oceanographic seasons, such as fin whales (*Balaenoptera physalus*), common dolphins (*Delphinus delphis*) and Risso's dolphins (*Grampus griseus*). Owing to the highly seasonal utilization of rookeries by the three pinniped species recorded at San Clemente Island (California sea lion, harbor seal, and northern elephant seal), we present separate seasonal estimates of density and abundance for each. Density and abundance estimates for pinnipeds are also stratified by geographic area (inshore vs offshore). Geographic and seasonal strata density estimates rely on pooling of all sighting data to estimate the parameters *f(0)* and *g(0)*. Where separate Beaufort sea state strata exist, estimates of *f(0)* and *g(0)* are based on 'calm' or 'rough' Beaufort sea state sighting data only.

Sea-surface temperatures associated with each cetacean sighting were obtained from NOAA satellite archives (NOAA, National Oceanographic Data Center, 1999), using Arc View GIS. Bottom depths for all cetacean sightings were determined from National Ocean Service (NOS) hydrographic survey data (NOAA National Geophysical Data Center, 1999), using a triangulated irregular surface model in Arc Info GIS. The distribution of bottom depths surveyed was determined by extracting latititude and longitude positions at 60-second intervals for all on-effort transect segments using the same ArcInfo model. For each species, the distribution of sighting depths was compared to the distribution of on-effort survey depths using a Kolmogorov-Smirnov goodness of fit test to examine whether species were randomly distributed with respect to seafloor depth.

2. Photogrammetric surveys

Photographs of marine mammals were taken with a Chicago Aerial Industries, Inc. model KA-76 camera equipped with image motion compensation (IMC) and a 152-mm focal length lens (Lowry et al. 1996, Lowry 1999). The camera was mounted vertically in a twin-engine Partenavia PN68 observer model aircraft. The aircraft was flown at ground speeds between 90 and 110 knots and at 183 m. Kodak Aerochrome MS Film 2448, a fine-grained, medium-speed, color transparency film or Kodak SO-359, a fine-grained, high speed color transparency film was used. This camera system was used to obtain large format (12.7 cm) images of pinniped rookeries at San Clemente Island and whales and dolphins in offshore waters. Pinniped rookeries and haulouts at San Clemente Island were photographed on six dates to determine the number and location of all California sea lions (*Zalophus californianus*), northern elephant seals (*Mirounga angustirostris*), and harbor seals (*Phoca vitulina*). Counts of California sea lions and northern elephant seals were divided by age and sex class. Two additional photogrammetric surveys to photograph common dolphins and gray whales were completed in January 1999. Photographs were taken to confirm field identifications of short-beaked common dolphins encountered in the vicinity of San Clemente Island during aerial line-transect surveys, using methods described in Perryman and Lynn (1993). Gray whales were photographed during their southbound migration to determine the percentage of pregnant females in the population (Wayne Perryman, Southwest Fisheries Science Center, personal communication).

3. Ground censuses and scat collection

Six quarterly ground censuses of all pinniped species were completed by a team of two biologists on the west shoreline of San Clemente Island near Mail Point. Each census took 2-3 days to complete. All pinniped species were counted along rookeries and haulouts on the west shoreline from Seal Cove to the vicinity of Mail Point (Figure 3). In addition to ground censuses, scat samples from California sea lions were collected to determine dietary habits (Lowry et al. 1990, Lowry and Carretta 1999).

Results

During 1998-99, 47 survey missions were scheduled, nine of which were cancelled and/or aborted due to adverse weather conditions. The remaining 38 survey missions consisted of 24 aerial line-transect surveys, 8 aerial photogrammetry missions, and 6 ground censuses at San Clemente Island (Table 1). The results of each survey type are summarized below.

Aerial line-transect surveys

A total of 7,732 km of line-transect survey effort was conducted, and effort was fairly balanced between cold (November - April) and warm-water (May - October) months (3,957 and 3,775 km, respectively) (Table 2). Totals of 1,859 and 5,873 km were surveyed in the inshore and offshore strata, respectively. Over 40% of all survey effort occurred during calm (Beaufort 0-2 sea states). Sighting conditions were calmer in the inshore stratum, where 80% of all survey effort was conducted in Beaufort sea states 0-3. In contrast, in the offshore stratum, 66% of all survey effort was conducted in Beaufort sea states 0-3 (Table 2).

Five dolphin species (*Delphinus delphis*, *Grampus griseus*, *Lissodelphis borealis*, *Lagenorhynchus obliquidens*, and *Tursiops truncatus*), one porpoise species (*Phocoenoides dalli*), six whale species (*Balaenoptera acutorostrata*, *B. musculus*, *B. physalus*, *Megaptera novaeangliae*, *Eschrichtius robustus*, and *Ziphius cavirostris*), three pinniped species (*Zalophus californianus*, *Mirounga angustirostris*, and *Phoca vitulina*), and one fissiped species (*Enhydra lutris*) were encountered during aerial line-transect surveys (Table 3).

Estimates of availability and perception bias components used to estimate *g(0)* are presented in Table 4. Availability bias for deep-diving species such as Cuvier's beaked whale and northern elephant seal was high, as evidenced by the fact that these species are submerged or diving nearly 90% of the time. Dall's porpoise and harbor seal also demonstrated a high degree of availability bias; these species are at or near the surface no more than 20-30% of the time. The perception bias component of 0.96 for Dall's porpoise is probably an underestimate, as this estimate includes data from other small cetaceans which are easier to detect than Dall's porpoise. Thus, estimates of Dall's porpoise density is probably underestimated by a small, but non-trivial amount. Plots of probability density functions, *f(0)*, for all species groups and Beaufort sea state strata appear in Figures 4-8.

Short-beaked common dolphins (*Delphinus delphis*) were the most abundant species in the study area, with a year-round abundance of 26,238 (CV = 0.30). Common dolphin densities were 2.5 times greater during the warm-water months of May to October (4.65 animals/km^2) than during the cold-water months of November to April (1.78 animals/km^2). Encounter rates of common dolphin were similar for both seasons (8.3 groups/1000 km and 7.41 groups/1000 km for cold and warm-water months, respectively). Most of the difference in common dolphin density estimates is attributable to seasonal differences in mean group size (182.7 and 556.3 animals for cold and warm-water months, respectively). Risso's dolphins ($\hat{N}$= 1,018, CV = 0.33) and bottlenose dolphins ($\hat{N}$ = 207, CV = 0.50) were also seen year-round, although in far fewer numbers than common dolphins. Pacific white-sided dolphins, northern right whale dolphins, and Dall's porpoise were encountered only during the cold-water months. During cold-water months, Pacific white-sided dolphins were the second most abundant cetacean species ($\hat{N}$= 1,649, CV = 0.44) after short-beaked common dolphins ($\hat{N}$= 14,834, CV = 0.37). Northern right whale dolphins ($\hat{N}$= 754, CV = 0.40) and Dall's porpoise ($\hat{N}$ = 370, CV = 0.62) were present in smaller numbers. Gray whales (*Eschrichtius robustus*) were the most commonly encountered whale, although they were only seen during the months of January through April. The mean daily abundance of gray whales in the entire study area during this migratory period was 424 (CV = 0.29). Gray whale densities in the inshore stratum (0.115 whales km^{-2}) were over three times greater than densities in the larger offshore stratum (0.032 whales km^{-2}). Fin whales (*Balaenoptera physalus*) were encountered year-round and were the next most abundant whale species with an average year-round abundance of 48 whales (CV = 0.26). Blue whales arrived in the study area in late May and were common into August, with one individual seen as late as November. Blue whale abundance in the entire study area during the warm-water months was 40 (CV = 0.38) and 4 (CV=0.68) during the cold-water months. Humpback whales were encountered only twice, in April 1998 (a cow/calf pair) and in April 1999 (two adults). An estimated 12 humpback whales (CV = 0.46) were present in the study area during the cold-water months. One minke whale was detected on-effort during the cold-water months; the resulting estimate of abundance is 8 whales (CV = 0.92). Cuvier's beaked whales (*Ziphius cavirostris*) were recorded on four occasions (one sighting was off-effort) during the cold-water months in the offshore stratum and all sightings occurred in relatively deep water. The estimated number of Cuvier's beaked whales in the study area during the cold-water months was 153 (CV = 0.52). This estimate is based on only three on-effort sightings and reflects the large $g(0)_{availability}$ correction factor (0.074) used to account for the long-diving habits of the species.

California sea lions (*Zalophus californianus*) were the most abundant pinniped species. At-sea densities of sea lions were greatest during the cold-water months of November through April in both inshore (1.19 animals km^{-2}, CV = 0.12) and offshore (0.194 animals km^{-2}, CV = 0.22) geographic strata. At-sea densities during the warm-water months of May through October were 0.750 animals km^{-2} (CV = 0.27) and 0.056 animals km^{-2} (CV = 0.26) for inshore and offshore strata, respectively. Northern elephant seals (*Mirounga angustirostris*) were detected three times and only in the offshore stratum. At-sea densities of northern elephant seals were 0.011 animals km^{-2} (CV

= 0.91) and 0.051 animals km^{-2} (CV = 1.07), for cold and warm-water months, respectively. The statistical precision of the elephant seal densities is poor, owing to the small number of sightings. At-sea densities of harbor seals (*Phoca vitulina*) were highest in the inshore stratum, ranging from 0.025 animals km^{-2} (CV = 0.63) to 0.053 seals km^{-2} (CV = 0.76) during cold and warm-water months, respectively. Harbor seal densities in the offshore stratum were 0.017 animals km^{-2} (CV = 0.64) and 0.0096 seals km^{-2} (CV = 0.72) during cold and warm-water months, respectively. A summary of density and abundance estimates for each species, stratified by area and 'season', is presented in Table 5.

Most species were encountered throughout the study area, however, some species such as the Pacific white-sided dolphin, gray whale, California sea lion, harbor seal, and elephant seal showed a higher affinity for waters in proximity to San Clemente Island (Figures 9-13). Appropriately, separate density estimates are presented for the 'inshore stratum' for bottlenose dolphins, gray whales, California sea lions, northern elephant seals, and harbor seals. The distribution of Pacific white-sided dolphin groups also showed a pattern of greater abundance closer to the island (Figure 9), but in fact, a majority of the sightings occurred in the 'offshore stratum', just beyond the edge of the 'inshore stratum'. Therefore, abundance and density estimates for Pacific white-sided dolphin are presented for the entire study area combined. In general, encounter rates of dolphins, porpoises and pinnipeds were lower in the southern half of the study area, whereas encounter rates of all whales were more uniform throughout the study area (with the exception of gray whales, which were more abundant in the northern half of the study area) (Figure 11). Sighting locations for all species are shown in Figures 9-13.

The seafloor depth and survey effort-at-depth distributions of all species for which there were 5 or more sightings are presented in Figures 14-24. In addition to these species, four sightings of Cuvier's beaked whale were encountered at depths of 687, 1,058, 1,340, and 1,519 m; two humpback whale sightings at depths of 688 and 1,091 m; and two minke whale sightings at depths of 1,103 and 1,969 m. Most species were not distributed randomly with respect to seafloor depth. California sea lions, harbor seals, common dolphins, Pacific white-sided dolphins, gray whales, Risso's dolphins, and bottlenose dolphins were encountered at seafloor depths which were significantly different ($p < 0.05$ at $\alpha = 0.05$) from the distribution of seafloor depths surveyed. Sighting depths of fin and blue whales ($0.20 < p < 0.50$), northern right whale dolphins ($p > 0.50$), and Dall's porpoise ($p > 0.50$) were not significantly different from the distribution of seafloor depths surveyed.

The range of sea-surface temperatures (SST) over which individual species were observed varied considerably (8.5 - 24.1 °C), but some species-specific patterns were noted (Figures 25 and 26). Gray whales, Pacific white-sided dolphins, northern right whale dolphins, and Dall's porpoise occurred in the coldest waters (8.5 - 16.6 °C) and all of these species were present only during the cold-water months of November to April. From October 1998 through July 1999, the study area was under the influence of a strong La Niña event, when colder than normal SSTs persisted in southern California coastal waters (CoastWatch 1999). Common dolphins, which were present year-round, were found over the greatest range of SSTs (12 - 24.2 °C, $\bar{x}$= 17.5 °C, n = 66), and they were the only cetacean species other than blue whales (16.7 - 23.4 °C, $\bar{x}$ = 19.2 °C, n = 18) to be found at temperatures exceeding 23 °C. Gray whales and Pacific white-sided dolphins were the only two species to occur at temperatures as low as 7 - 8 °C, respectively. Risso's dolphins were found in the middle range of SSTs (12.8 - 20.6 °C, $\bar{x}$ = 16.0 °C, n = 16), as were fin whales (12.6 - 18.2 °C, $\bar{x}$ = 16.1 °C, n = 28). Risso's dolphins and fin whales were year-round residents, but showed opposite patterns of seasonal abundance: densities of Risso's dolphin were three times greater during the cold-water months of November through April, while fin whale densities were three times greater during the warm-water months of May through October (Table 5).

Aerial photogrammetric surveys

The entire shoreline of San Clemente Island was surveyed six times (in April, July, and October 1998, and January, April, and July 1999). Pinniped haulout sites were identified and counts of all pinniped species ashore were made from large-format aerial photographs (Table 6). Pinnipeds were rarely hauled out on the eastern shoreline of the island and between Castle Rock and Seal Cove on the northwest side (Figure 3, Table 6). Most pinnipeds were found in the vicinity of Mail Point, although haulouts near Castle Rock, Northwest Harbor Islet, China Point, and South Point (Pyramid Head) were also utilized.

California sea lions were the most abundant species ashore during all surveys, with most animals concentrated near Mail Point (Figure 3), although numbers at Northwest Harbor Islet increased threefold to over 1,000 in 1999 (Table 6). A total of 3,941 California sea lions (including 645 pups) were counted ashore during the April 1999 photogrammetry mission. The highest number of sea lion pups recorded during the six photogrammetry missions was 1,005 counted in July of 1999. Over 1,300 sea lion pups were counted by biologists on the ground four days later. The difference between the two counts could be the result of double-counting of moving pups by biologists on the ground where views of the rookeries are oblique. In general, aerial photography counts yield more accurate pup counts, owing to the ease of counting animals in a static environment from an aerial perspective (Lowry 1999).

Numbers of harbor seals counted ashore at San Clemente Island were highly variable (Table 6) and this is probably the result of timing with respect to tidal phase. A high of 175 harbor seals were counted from aerial photographs in April 1999, with animals concentrated in four main areas: 'The Shack', NW Harbor Islet, South Point, and SHOBA (Figure 3).

At any one time, fewer than 100 northern elephant seals are hauled out on San Clemente Island, despite a current population size of over 84,000 in California waters. A majority of these seals occur at Mail Point, with the greatest numbers found in April. Individual elephant seals also haul out near China Point and Northwest Harbor Islet (Table 6). In California, the largest breeding rookeries of northern elephant seal are found at San Miguel, San Nicolas, and Santa Rosa Islands in southern California, and Piedras Blancas, Año Nuevo and Southeast Farallon Island in central California (Stewart et al. 1994, Lowry et al. 1996,).

A total of 122 common dolphins were measured from two schools photographed in January 1999. Length data, including adult females with calves, are characteristic of length frequencies of *Delphinus delphis* reported by Heyning and Perrin (1994) and agree with field identifications of

Delphinus delphis recorded during the aerial line-transect surveys. Short-beaked common dolphins are the most abundant cetacean species in California waters (Barlow 1995, Forney et al. 1995, Forney and Barlow 1998) and accordingly, a majority of common dolphins that strand in southern California are the short-beaked species *Delphinus delphis* (Southwest Fisheries Science Center, unpublished data). Previous vessel surveys of the California coast have shown that the long-beaked species, *Delphinus capensis*, is concentrated near the northern Channel Islands of Santa Cruz, Santa Rosa, Anacapa, and San Miguel (Barlow et al. 1997). A few sightings of *Delphinus capensis* have been recorded in the southern California Bight near Long Beach and San Diego, but otherwise they are rarely seen in this area. Heyning and Perrin (1994) reported that long-beaked common dolphins have a more nearshore distribution than the short-beaked species. No sightings of *Delphinus capensis* have been recorded offshore of San Clemente and San Nicolas Islands, despite considerable survey effort in this region. Based on the above evidence, we assume that all sightings of common dolphins the waters surrounding San Clemente Island during the 1998-99 aerial surveys are of the short-beaked species, *Delphinus delphis*.

Approximately 100 gray whales were photographed in southern California around San Clemente Island and the northern Channel Islands of San Miguel, Santa Rosa, Santa Cruz, and Anacapa during the southbound migration of 1998-99. Analyses of the photographs are in progress, but preliminary results show that very few pregnant gray whales were detected, which reflects findings of low calf production from ground surveys conducted at Point Piedras Blancas during the northbound migration (Wayne Perryman, Southwest Fisheries Science Center, personal communication).

Ground surveys

Ground censuses of the western shoreline between Seal Cove Point and 'The Shack' were conducted by a team of two biologists in April, July, and October 1998 and January, April, and July 1999 (Table 6). Each census took 2-3 days to complete. The main goal of these surveys was to collect scat samples of California sea lions for dietary analyses and to supplement aerial photographic counts of pinnipeds near Mail Point. Lowry (1999) has shown that counts from aerial photographs are superior to ground counts, and we recommend using aerial counts from Table 6. In addition to each ground count, approximately 50 California sea lion scat samples were collected from the Mail Point area during each visit. These samples are currently being examined. Information on the diets of California sea lions at San Clemente Island from previous collections has been published elsewhere (Lowry et al. 1990, Lowry and Carretta 1999).

Conclusions

San Clemente Island and associated offshore waters support a wide diversity of marine mammal species and the area is an important migratory corridor for gray and blue whales. Numbers of gray whales found during individual survey flights indicate that a significant fraction of the entire population passes through this region during southbound and northbound migrations. Humpback whales were encountered on only two occasions, in April 1998 and April 1999. The lack of humpback sightings in the San Clemente Island study area suggests that either the main migratory corridor occurs offshore of this region, as suggested by Forney and Barlow (1998), or that humpback whales passed through the area during brief periods when no aerial surveys occurred. Fin whales were found year-round throughout the study area, but were most abundant from May through October. Blue whales arrived in the study area in May and remained until late summer. Dall's porpoise, northern right whale dolphins, and Pacific white-sided dolphins utilize the San Clemente Island study area from late autumn to mid-spring, when sea-surface temperatures are coldest. Risso's dolphins were present year-round but were three times more abundant during cold-water months. Short-beaked common dolphins are found in the study area year-round and are the most abundant marine mammal in this region. Densities of common dolphins were 2.5 times greater during warm-water months. Density comparisons between past aerial surveys in southern California waters (Forney et al. 1995) and the present study are only meaningful within the same cold-water season and geographic area. In addition, a sufficient number of sightings exist for only a few species to make comparisons worthwhile. Common dolphin densities reported in the Southern California Bight by Forney et al. (5.87 animals km^{-2}) are 3.3 times greater than those reported in the present study (1.78 animals km^{-2}). However, the density estimate from Forney et al. (1995) includes both short and long-beaked common dolphins (*Delphinus capensis*), because at that time our observers could not distinguish the two species from the air. Differences in prevailing oceanographic conditions and spatial coverage between the two surveys are likely to account for the remaining difference. Densities of Risso's dolphin were similar between the Forney et al. (1995) surveys and the present study (0.202 and 0.180 animals km^{-2}, respectively). There were a sufficient number of sightings for six other species to make meaningful density comparisons: Pacific white-sided dolphin (0.057 and 0.197 animals km^{-2}), northern right whale dolphin (0.137 and 0.09 animals km^{-2}), bottlenose dolphin (0.068 and 0.034 animals km^{-2}), Dall's porpoise (0.034 and 0.044 animals km^{-2}), fin whale (0.0011 and 0.0027 animals km^{-2}), and gray whale (0.014 and 0.051 animals km^{-2}). The considerably greater densities of gray whales and Pacific white-sided dolphins observed from the present study may be explained by differences in survey design: the Forney et al. (1995) surveys covered a much larger area which included deep offshore waters that are not typical habitat for gray whales and Pacific white-sided dolphins, whereas the present survey was restricted to more coastal waters. Seasonal patterns of abundance of Risso's dolphins, Pacific white-sided dolphins, northern right whale dolphins, Dall's porpoise, fin whales, and blue whales were similar between this study and aerial surveys near San Nicolas Island, California, in 1993-94 (Carretta et al. 1995) and aerial and ship surveys in 1991-92 in the Southern California Bight (Forney and Barlow 1998). The seasonal pattern of higher common dolphin abundance during warm-water months agrees with recent aerial surveys near San Nicolas Island (Carretta et al. 1995), but is opposite to that reported by Forney et al. (1995) for the entire Southern California Bight. Three species of pinnipeds are commonly found on San Clemente Island: California sea lions, harbor seals, and northern elephant seals. California sea lions are the predominate species, with 3,300 to 4,000 animals photographed ashore during the spring and summer of 1999 and an estimated 800 to 2,100 animals at sea. As recently as 1997, one male Guadalupe fur seal (*Arctocephalus townsendi*) has been seen at Mail Point hauled out with California sea lions (NMFS, unpublished data).

Acknowledgments

Aerial survey observers and data recorders were Wes Armstrong, Karin Forney, Jim Gilpatrick, Mike Henshaw, Kathy Hough, Greg O'Corry-Crowe, Peter Perkins, Ginger Rebstock, and Barb Taylor (also JVC, MSL, MSL, and CES) . Aspen Helicopters of Oxnard, California provided the aircraft. Thanks to pilots Barry Hansen, Rick Throckmorton, Pat O'Brien, Julio Coronado, and Gary Silva, the surveys were completed with the utmost level of enthusiasm and safety. Jan Larsen and Linda Ayres of the North Island Naval Air Station Environmental Division provided support prior to and throughout the surveys. Robert Tahimic and the Fleet Area Control and Surveillance Facility, SCORE detachment, provided range-scheduling support, keeping our flights missile-free. Mary Hollinger of NOAA's National Oceanographic Data Center provided support for the retrieval of archived sea-surface temperature satellite images. Jay Barlow kindly reviewed drafts of the manuscript.

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Table 1. Scheduled survey dates for the 1998-99 San Clemente Island marine mammal project.

Survey Number	Date	Survey Type	Comments
	1998		
1	4-Apr	Line Transect	285 km transect effort
2	13-Apr	Photogrammetry	Pinniped rookery
3	14-15 Apr	Ground census	Pinniped rookery
4	9-May	Line Transect	506 km transect effort
5	16-May	Line Transect	92 km transect effort
6	30-May	Line Transect	385 km transect effort
7	13-Jun	Line Transect	470 km transect effort
8	27-Jun	Line Transect	Aborted, Weather
9	11-Jul	Line Transect	Cancelled, Weather
10	18-20 Jul	Ground census	Pinniped rookery
11	20-Jul	Photogrammetry	Partial survey, aborted due to weather
12	25-Jul	Line Transect	Cancelled, Weather
13	26-Jul	Photogrammetry	Pinniped rookery
14	8-Aug	Line Transect	243 km transect effort
15	16-Aug	Line Transect	279 km transect effort
16	13-Sep	Line Transect	416 km transect effort
17	27-Sep	Line Transect	217 km transect effort
18	11-Oct	Photogrammetry	Pinniped rookery
19	10-Oct	Line Transect	511 km transect effort
20	17-Oct	Line Transect	461 km transect effort
21	24-25 Oct	Ground census	Pinniped rookery
22	21-Nov	Line Transect	379 km transect effort
23	22-Nov	Line Transect	380 km transect effort
24	12-Dec	Line Transect	407 km transect effort
25	19-Dec	Line Transect	76 km transect effort
	1999		
26	8-Jan	Photogrammetry	Gray whale, Common dolphin
27	9-Jan	Line transect	450 km transect effort
28	15-Jan	Photogrammetry	Pinnipeds, Gray whale, Common dolphin
29	22-Jan	Line transect	161 km transect effort
30	23-Jan	Line transect	363 km transect effort
31	29-30 Jan	Ground census	Pinniped rookery
32	6-Feb	Line transect	322 km transect effort
33	27-Feb	Line transect	240 km transect effort
34	13-Mar	Line transect	323 km transect effort
35	27-Mar	Line transect	Cancelled, Weather
36	10-Apr	Line transect	329 km transect effort
37	20-21 Apr	Ground census	Pinniped rookery
38	23-Apr	Photogrammetry	Pinniped rookery
39	24-Apr	Line transect	248 km transect effort
40	15-May	Line transect	Cancelled, Weather
41	22-May	Line transect	Cancelled, Weather
42	19-Jun	Line transect	Cancelled, Weather
43	10-Jul	Photogrammetry	Pinniped rookery
44	26-Jun	Line transect	128 km transect effort
45	13-15 Jul	Ground census	Pinniped rookery
46	24-Jul	Line transect	Cancelled, Weather
47	31-Jul	Line transect	Cancelled, Weather

Table 2. Summary of all aerial line-transect survey effort (in km) completed in the San Clemente Island study area 1998-1999. Effort totals are stratified by month, geographic region, and Beaufort sea state.

	Total Effort (All Strata)			**Inshore Stratum**			**Offshore Stratum**		
	Beaufort Sea State			***Beaufort Sea State***			***Beaufort Sea State***		
Month	**BF 0-2**	**BF 3**	**BF 4**	**BF 0-2**	**BF 3**	**BF 4**	**BF 0-2**	**BF 3**	**BF 4**
January	**741.4**	**156.3**	**70.4**	**162.3**	**44.9**	**4.3**	**579.1**	**111.4**	**66.1**
February	**208.4**	**161.7**	**191.3**	**10.7**	**77.0**	**29.4**	**197.7**	**84.7**	**161.9**
March	**214.7**	**0.0**	**108.7**	**102.8**	**0.0**	**0.0**	**111.9**	**0.0**	**108.7**
April	**401.0**	**194.5**	**266.7**	**134.6**	**35.8**	**16.9**	**266.4**	**158.7**	**249.8**
May	**77.9**	**119.6**	**785.1**	**9.5**	**2.2**	**151.7**	**68.4**	**117.3**	**633.4**
June	**85.0**	**362.7**	**150.4**	**59.1**	**129.1**	**16.9**	**25.9**	**233.6**	**133.5**
July	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
August	**95.5**	**296.0**	**198.4**	**54.0**	**65.4**	**101.4**	**41.5**	**230.6**	**97.0**
September	**257.5**	**145.4**	**230.7**	**19.7**	**87.2**	**0.0**	**237.8**	**58.2**	**230.7**
October	**461.5**	**366.3**	**143.5**	**114.3**	**85.4**	**21.7**	**347.3**	**280.9**	**121.8**
November	**257.4**	**277.9**	**223.9**	**73.6**	**112.1**	**32.7**	**183.8**	**165.8**	**191.2**
December	**365.3**	**93.5**	**23.5**	**74.1**	**30.2**	**0.0**	**291.2**	**63.3**	**23.5**
Total	**3165.8**	**2173.8**	**2392.5**	**814.7**	**669.3**	**375.0**	**2351.1**	**1504.4**	**2017.5**
Fraction of Effort	**0.41**	**0.28**	**0.31**	**0.44**	**0.36**	**0.20**	**0.40**	**0.26**	**0.34**

All Effort (km)	**7732**
Cold Season (Nov - Apr)	**3957**
Warm Season (May - Oct)	**3775**
Inshore Effort	**1859**
Offshore Effort	**5873**

Table 3. Summary of species encountered during aerial line-transect surveys and species groupings used to estimate probability detection functions, *f(0)*.

Species group	Common Name	Scientific Name	Species Code
Delphinids/Porpoises	short-beaked common dolphin	*Delphinus delphis*	dd
	Risso's dolphin	*Grampus griseus*	gg
	northern right whale dolphin	*Lissodelphis borealis*	lb
	Pacific white-sided dolphin	*Lagenorhychus obliquidens*	lo
	bottlenose dolphin	*Tursiops truncatus*	tt
	Dall's porpoise	*Phocoenoides dalli*	pd
Whales	minke whale	*Balaenoptera acutorostrata*	ba
	fin whale	*Balaenoptera physalus*	bp
	blue whale	*Balaenoptera musculus*	bm
	gray whale	*Eschrichtius robustus*	er
	humpback whale	*Megaptera novaeangliae*	mn
	Cuvier's beaked whale	*Ziphius cavirostris*	zi
Pinnipeds	California sea lion	*Zalophus californianus*	zc
	northern elephant seal	*Mirounga angustirostris*	ma
	harbor seal	*Phoca vitulina*	pv
Fissipeds[1]	sea otter	*Enhydra lutris*	el

[1] No estimates of sea otter abundance were obtained from the aerial line-transect surveys, and no estimate of *f(0)* was made for this species group, owing to an insufficient number of sightings (n=3).

Table 4. Estimates of availability and perception bias used to generate overall estimate of $g(0)_{total}$ used to estimate animal densities. Values for Dall's porpoise (*Phocoenoides dalli*) were taken from published dive data on harbor porpoise. n/a indicates that data were not available or too few observations were made to estimate a parameter. The species category 'all delphinids' includes *Delphinus delphis*, *Grampus griseus*, *Lissodelphis borealis*, *Lagenorhychus obliquidens*, and *Tursiops truncatus*.

Species	Mean Dive Time (seconds)	Mean Surface Time (seconds)	$g(0)_{availability}$	$g(0)_{perception}$	$g(0)_{total}$	Published Source of Dive Data
Ziphius cavirostris	1716	126	0.074	n/a	0.074	Barlow et al. 1997, Barlow 1999
Balaenoptera musculus	234	144	0.407	n/a	0.407	Barlow et al. 1997
Balaenoptera physalus	-	-	0.407	n/a	0.407	analogy to blue whale
Balaenoptera acutorostrata	266	151.2	0.386	n/a	0.386	Stern 1992
Megaptera novaeangliae	216	192	0.495	n/a	0.495	Dolphin 1987
Eschrichtius robustus	57	34	0.482	n/a	0.482	Harvey and Mate 1984
Phocoenoides dalli[1]	n/a	n/a	0.231	0.960	0.221	Laake et al. 1997
All delphinids (1-25 animals)	n/a	n/a	n/a	0.960	0.960	n/a
All delphinids (>26 animals)	n/a	n/a	n/a	0.994	0.994	n/a
Zalophus californianus (Beaufort 0-2)	n/a	n/a	0.673	0.967	0.651	Feldkamp 1989
Zalophus californianus (Beaufort 3-4)	n/a	n/a	0.673	0.444	0.299	Feldkamp 1989
Mirounga angustirostris (Beaufort 0-2)	1392	160	0.109	0.967	0.105	Le Boeuf 1994
Phoca vitulina (Beaufort 0-2)	180	60	0.291	0.967	0.281	Stewart and Yochem 1989a, 1989b

Table 5. Number of on-effort sightings, mean group size, density, abundance, coefficient of variation (CV), and log-normal

[1]Dive data for the harbor porpoise (*Phocoena phocoena*) was used to model the availability bias component of *g(0)* for Dall's porpoise (*Phocoenoides dalli*).

95% confidence limits for all marine mammal species detected during 1998-99 aerial surveys. Density and abundance estimates are given only for those seasons and/or geographic strata in which a species was encountered. A pooled estimate of year-round abundance is given for those species that were seen year-round (Season = 'All'), with the exception of pinnipeds, for which estimates are divided by seasonal and geographic strata. Density and abundance values for pinnipeds reflect only those animals that were at sea at the time of the surveys and do not include animals hauled out on San Clemente Island at the time of the survey. See Table 6 for a summary of pinniped numbers hauled out on land. Size of geographic strata: 'All' = 8352 km^2, 'Inshore = 522 km^2, and 'Offshore' = 7830 km^2.

Species	Season	Geographic Stratum	# groups (n)	Mean Group Size ($\bar{S}$)	Density animals km^{-2}	Abundance ($\hat{N}$)	CV	L95% CI	U95% CI
DOLPHINS & PORPOISES									
Delphinus delphis	All	All	61	353.6	3.14	26,238	0.30	15,772	43,648
	Cold	All	33	182.7	1.78	14,834	0.37	8,013	27,463
	Warm	All	28	556.3	4.65	38,851	0.39	20,206	74,698
Grampus griseus	All	All	23	33.4	0.122	1,018	0.33	580	1,789
	Cold	All	16	36.3	0.180	1,500	0.40	770	2,920
	Warm	All	7	26.6	0.061	513	0.56	214	1,234
Lagenorhychus obliquidens	Cold	All	26	24.2	0.197	1,649	0.44	800	3,399
Lissodelphis borealis	Cold	All	11	12.4	0.090	754	0.40	351	1,620
Tursiops truncatus	All	All	14	10.4	0.025	207	0.50	93	459
	Cold	All	8	13.6	0.034	287	0.66	106	779
	Warm	All	6	6.2	0.015	122	0.67	37	403
	All	Inshore	10	8.4	0.090	47	0.41	24	92
	All	Offshore	4	3.3	0.0032	25	0.61	8	84
Phocoenoides dalli	Cold	All	8	3.4	0.044	370	0.62	121	1,136
WHALES									
Balaenoptera acutorostrata	Cold	All	1	1.0	0.00095	8	0.91	2	39
Balaenoptera musculus	All	All	9	1.2	0.0025	21	0.36	11	43
	Cold	All	1	1.0	0.00045	4	0.68	1	13
	Warm	All	8	1.3	0.0047	40	0.39	19	83
Balaenoptera physalus	All	All	21	1.2	0.0058	48	0.26	29	81
	Cold	All	6	1.0	0.0027	23	0.34	12	44
	Warm	All	15	1.3	0.0089	75	0.33	39	143
Megaptera novaeangliae	Cold	All	2	2.0	0.0015	12	0.46	5	30
Eschrichtius[1] *robustus*	Cold	All	31	2.9	0.051	424	0.29	239	754
	Cold	Inshore	16	2.9	0.115	60	0.30	33	109
	Cold	Offshore	15	2.9	0.032	249	0.42	107	580
Ziphius cavirostris	Cold	Offshore	3	2.0	0.019	153	0.52	57	414

[1]Gray whales were encountered only during the months of January through April.

Table 5 (continued).

Species	Season	Geographic Stratum	# groups (n)	Mean Group Size ($\bar{S}$)	Density animals km^{-2}	Abundance ($\hat{N}$)	CV	L95% CI	U95% CI
PINNIPEDS									
Zalophus californianus	**Cold**	**Offshore**	**92**	**1.6**	**0.194**	**1,522**	**0.22**	**991**	**2,336**
	Cold	**Inshore**	**190**	**1.6**	**1.19**	**620**	**0.12**	**485**	**793**
	Warm	**Offshore**	**22**	**1.1**	**0.056**	**430**	**0.26**	**258**	**717**
	Warm	**Inshore**	**67**	**1.5**	**0.750**	**391**	**0.27**	**230**	**666**
Mirounga angustirostris	**Cold**	**Offshore**	**1**	**1.0**	**0.011**	**89**	**0.91**	**15**	**554**
	Warm	**Offshore**	**2**	**1.0**	**0.051**	**401**	**1.07**	**51**	**3,164**
Phoca vitulina	**Cold**	**Offshore**	**4**	**1.0**	**0.017**	**133**	**0.64**	**33**	**533**
	Cold	**Inshore**	**2**	**1.0**	**0.025**	**13**	**0.63**	**4**	**42**
	Warm	**Offshore**	**1**	**1.0**	**0.0096**	**75**	**0.72**	**16**	**349**
	Warm	**Inshore**	**2**	**1.0**	**0.054**	**28**	**0.76**	**7`**	**114**

Table 6. California sea lions, harbor seals, and northern elephant seals that were counted during ground surveys and from photographs taken during aerial photographic surveys of San Clemente Island, California. 'Island Total' represents aerial photogrammetric counts from the entire shoreline of San Clemente Island, while 'Ground Total' represents only those animals counted by field biologists along the western shoreline from Seal Cove Point to 'The Shack.

Date	Survey type	California sea lions					Harbor seals	Northern elephant seals				Latitude (deg:min)	Longitude (deg:min)	Area
		Pups	Juv's	Adult females	Subadult males	Adult males		Pups	Juv's	Adult females	Adult males			
13 Apr 98	Photo	5	8	19	6	2			1			32:48.3	118:25.4	China Point
							20					32:49.4	118:22.3	((SHOBA))
		43	26	242	9		12		3			33:02.4	118:35.4	NW Harbor Islet
		9	7	10								32:54.5	118:32.2	Seal Cove Point
		7		2								32:54.5	118:32.0	Citadel Rock
		45	1	24								32:53.9	118:31.5	Tiki Bridge Beach
		548	25	531	7	4		8	52	22		C[3]	C[3]	Mail Point Area
							20		1			32:52.5	118:30.4	The Shack
		657	**67**	**828**	**22**	**6**	**52**	**8**	**57**	**22**	**0**			**ISLAND TOTAL**
14-15 Apr 98	Ground	7	7	8								32:54.5	118:32.2	Seal Cove Point.
		6		2								32:54.5	118:32.0	Citadel Rock
		79	3	33				1				A[1]	A[1]	Tiki Rock Area
		443	17	395	22			4	59	15		C[3]	C[3]	Mail Point Area
							28		1			32:52.5	118:30.4	The Shack
		535	**27**	**438**	**22**	**0**	**28**	**5**	**60**	**15**	**0**			**GROUND TOTAL**
26 Jul 98	Photo	7	20	307	7	5	17		1			33:02.4	118:35.4	NW Harbor Islet
				1								33:02.2	118:36.7	Castle Rock
				2	5	5						32:54.5	118:32.2	Seal Cove Point.
						1						32:54.5	118:32.0	Citadel Rock
		37	10	122	1	12						A[1]	A[1]	Tiki Rock Area
			1			1	1					B[2]	B[2]	Tiki to Mail Pt. Area
		556	48	705	25	71	1					C[3]	C[3]	Mail Point Area
						3	13					32:52.5	118:30.4	The Shack
							28					32:48.3	118:25.9	China Point
			1	5	5							32:48.2	118:25.4	China Point
							22					32:49.1	118:21.3	South Point
		600	**80**	**1,142**	**43**	**97**	**82**	**0**	**1**	**0**	**0**			**ISLAND TOTAL**
18-20 Jul 98	Ground			1	2	1						32:54.5	118:32.2	Seal Cove Point.
		28	5	96		2						A[1]	A[1]	Tiki Rock Area
		559	39	733	15	71						C[3]	C[3]	Mail Point Area
						10	16					32:52.5	118:30.4	The Shack
		587	**44**	**830**	**17**	**86**	**16**	**0**	**0**	**0**	**0**			**GROUND TOTAL**

Table 6. (Continued)

Date	Survey type	California sea lions: Pups	Juv's	Adult females	Subadult males	Adult males	Harbor seals	Northern elephant seals: Pups	Juv's	Adult females	Adult males	Latitude (deg:min)	Longitude (deg:min)	Area
11 Oct 98	Photo	7	7	90		2	6			1		33:02.4	118:35.4	NW Harbor Islet
				4								32:54.5	118:32.2	Seal Cove Point
		50	8	40								32:53.9	118:31.5	Tiki Bridge Beach
		389	13	348	12	10			9	14		C[3]	C[3]	Mail Point Area
							1					32:52.5	118:30.4	The Shack
		446	**28**	**482**	**12**	**12**	7	**0**	**9**	**15**	**0**			**ISLAND TOTAL**
24-25 Oct 98	Ground			3								32:54.5	118:32.2	Seal Cove Point.
		137		83	7							32:53.9	118:31.5	Tiki Bridge Beach
		417	41	398	24			7	13			C[3]	C[3]	Mail Point Area
		554	**41**	**484**	**31**	**0**	**0**	**7**	**13**	**0**	**0**			**GROUND COUNT**
15 Jan 99	Photo						3					32:59.8	118:32.8	Eastern side
							3					33:00.0	118:32.8	Eastern side
		11	61	1124	1		26					33:02.4	118:35.4	NW Harbor Islet
		15	1	94	1							32:54.5	118:32.2	Seal Cove Point
		79	19	55	2	4						32:53.9	118:31.5	Tiki Head Beach
		471	89	1143	26	14		1	15	5		C[3]	C[3]	Mail Point Area
							11					32:52.5	118:30.4	The Shack
							26					32:48.3	118:25.8	China Point
		1	4	67			present					32:48.2	118:25.4	China Point
							present					32:49.1	118:21.3	South Point
		577	**174**	**2483**	**30**	**18**	**69+**	**1**	**15**	**5**	**0**			**ISLAND TOTAL**
29-30 Jan 99	Ground	16		63								32:54.5	118:32.2	Seal Cove Point.
		3		4								32:54.5	118:32.0	Citadel Rock
		68	2	112	3							32:53.9	118:31.5	Tiki Bridge Beach
		298	64	710	30	13		6	3	13	1	C[3]	C[3]	Mail Point Area
							12					32:52.5	118:30.4	The Shack
		385	**66**	**889**	**33**	**13**	**12**	**6**	**3**	**13**	**1**			**GROUND COUNT**
23 Apr 99	Photo						17					32:50.9	118:22.8	Eastern side
							4					32:57.8	118:31.0	Eastern side
		40	95	1083	18	8	43					33:02.4	118:35.4	NW Harbor Islet
		41	9	72	1	1						32:54.5	118:32.2	Seal Cove Point
		1										32:54.5	118:32.0	Citadel Rock
		563	84	1787	25	13	1	4	51	29		C[3]	C[3]	Mail Point Area
							23					32:52.5	118:30.4	The Shack
							3					32:50.2	118:28.0	(SHOBA)
							35					32:50.1	118:27.8	(SHOBA)
							50					32:49.1	118:21.3	South Point
		645	**288**	**2942**	**44**	**22**	**175**	**4**	**51**	**29**	**0**			**ISLAND TOTAL**

Table 6. (Continued)

Date	Survey type	California sea lions					Harbor seals	Northern elephant seals				Latitude (deg:min)	Longitude (deg:min)	Area
		Pups	Juv's	Adult females	Subadult males	Adult males		Pups	Juv's	Adult females	Adult males			
20-21 Apr 99	Ground		11	28								32:54.5	118:32.2	Seal Cove Point.
				1								32:54.5	118:32.0	Citadel Rock
		6	490	786	17	13	1			59		C[3]	C[3]	Mail Point Area
		6	**501**	**815**	**20**	**13**	**1**			**59**				**GROUND COUNT**
10 Jul 99	Photo		53	283	5	16	4					33:02.4	118:35.4	NW Harbor Islet
			21	11		1						33:02.2	118:36.7	Castle Rock
			23	46	13	9						32:54.5	118:32.2	Seal Cove Point
				8	3	2						32:54.5	118:32.0	Citadel Islet
		44	35	157	5	15						A[1]	A[1]	Tiki:Area
				2		2						B[2]	B[2]	Tiki to Mail Pt. Area
		961	207	1307	51	105						C[3]	C[3]	Mail Point Area
					1	11	5					32:52.5	118:30.4	The Shack
		1005	**339**	**1814**	**78**	**161**	**9**	**0**	**0**	**0**	**0**			**ISLAND TOTAL**
14 July 99	Ground		5	43	4	2						32:54.5	118:32.2	Seal Cove Point.
				2	8	2						32:54.5	118:32.0	Citadel Rock
		83	17	155	1	14						A[1]	A[1]	Tiki Rock Area
		1243	196	964	1	71						C[3]	C[3]	Mail Point Area
						6	23					32:52.5	118:30.4	The Shack
							5							Lost Point
		1326	**220**	**1170**	**8**	**93**	**28**	**0**	**0**	**0**	**0**			**GROUND COUNT**

[1] A: Tiki Area covers from 32:54.1N, 118:31.7W to 32:53.8N,118:31.4W

[2] B: Tiki to Mail Pt. Area covers from 32:53.8N,118:31.4W to 32:53.4N, 118:31.1W

[3] C: Mail Point Area covers from 32:53.4N, 118:31.1W to 32:52.8N, 118:30.4W

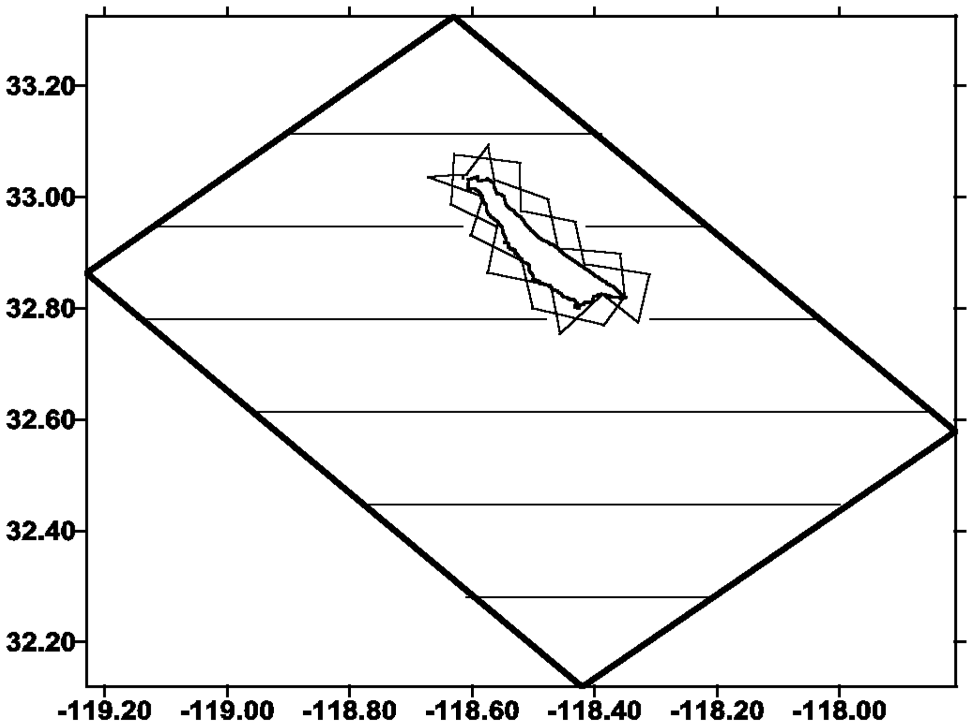


Figure 1. Study area for San Clemente Island marine mammal project, showing inshore and offshore transect lines flown during aerial line-transect surveys. Size of the study area, excluding the landmass of San Clemente Island, is 8352 km^2. Total length of inshore transects is 231 km. Total length of offshore transects is 414 km. Transects range in length from 6 to 103 km.

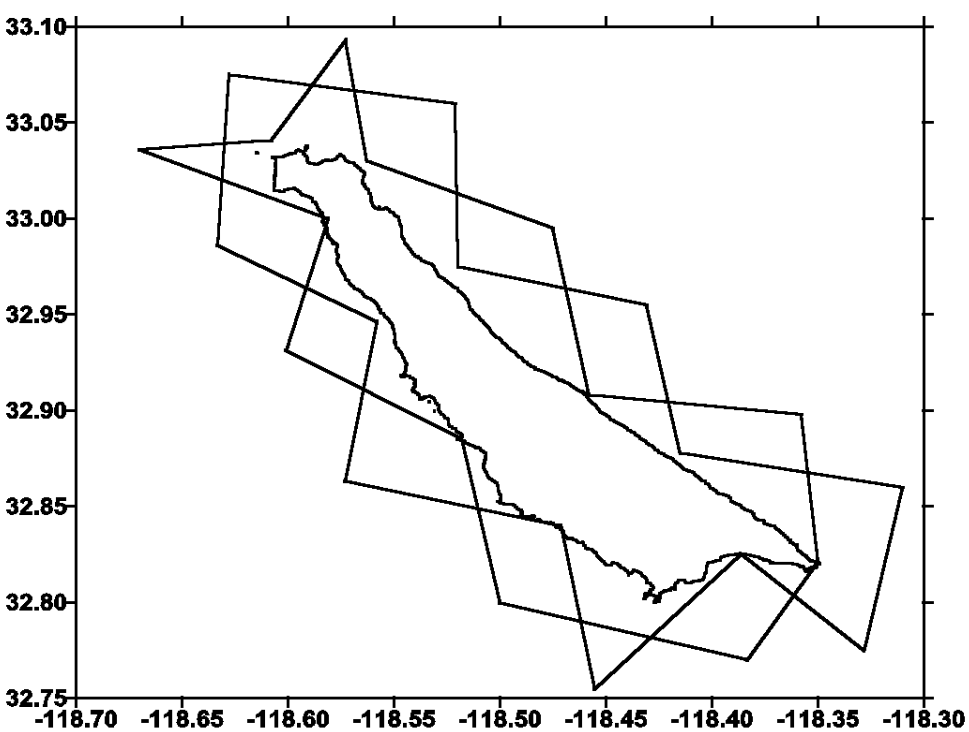


Figure 2. Inshore transect lines surrounding San Clemente Island. Lines cover the region within 5.5 km (3.0 nautical miles) of the shoreline. Size of the inshore area covered by transect lines is 522 km^2.

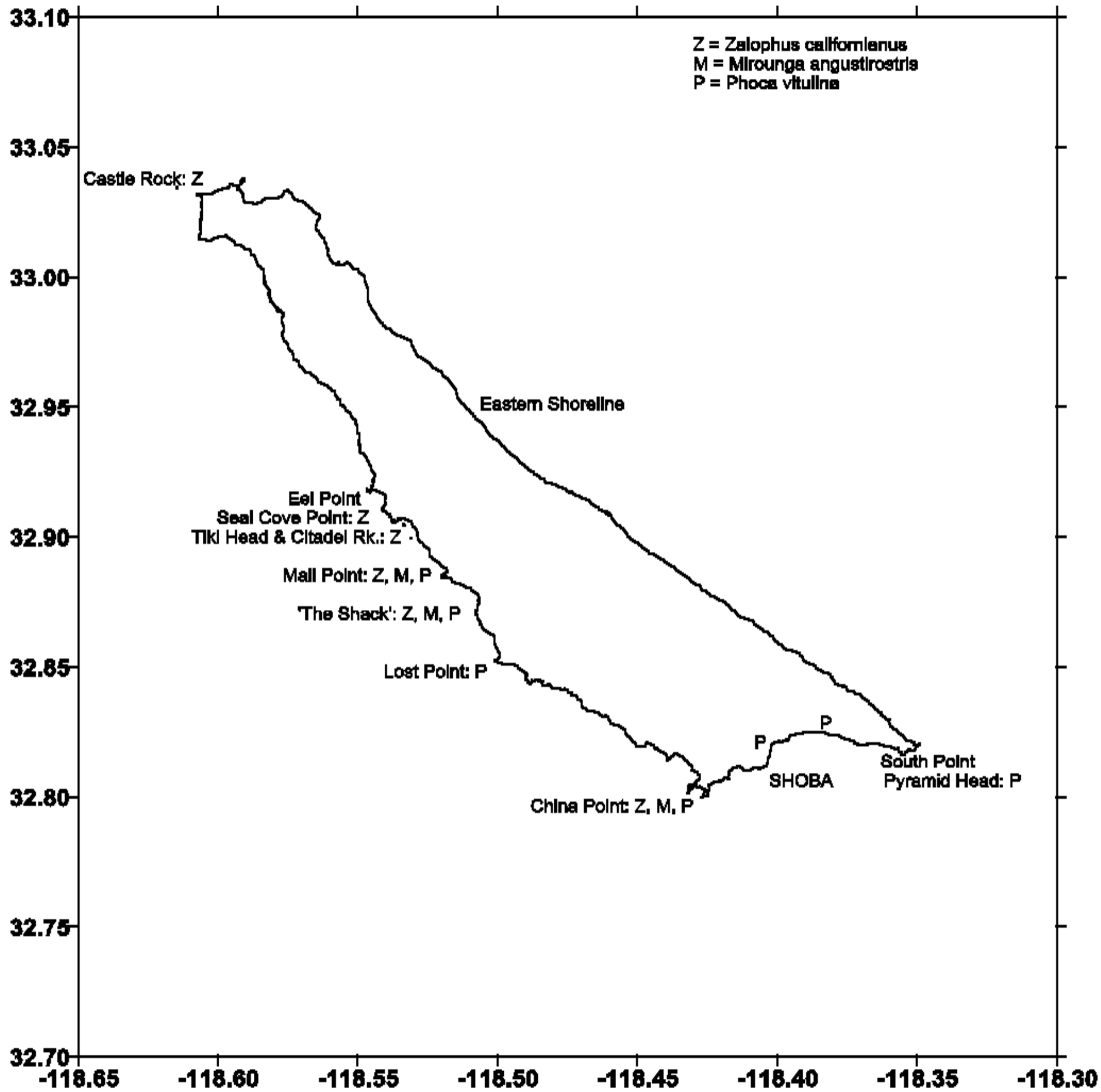


Figure 3. Pinniped haulout locations at San Clemente Island for which aerial photographic and ground counts are summarized in Table 6.

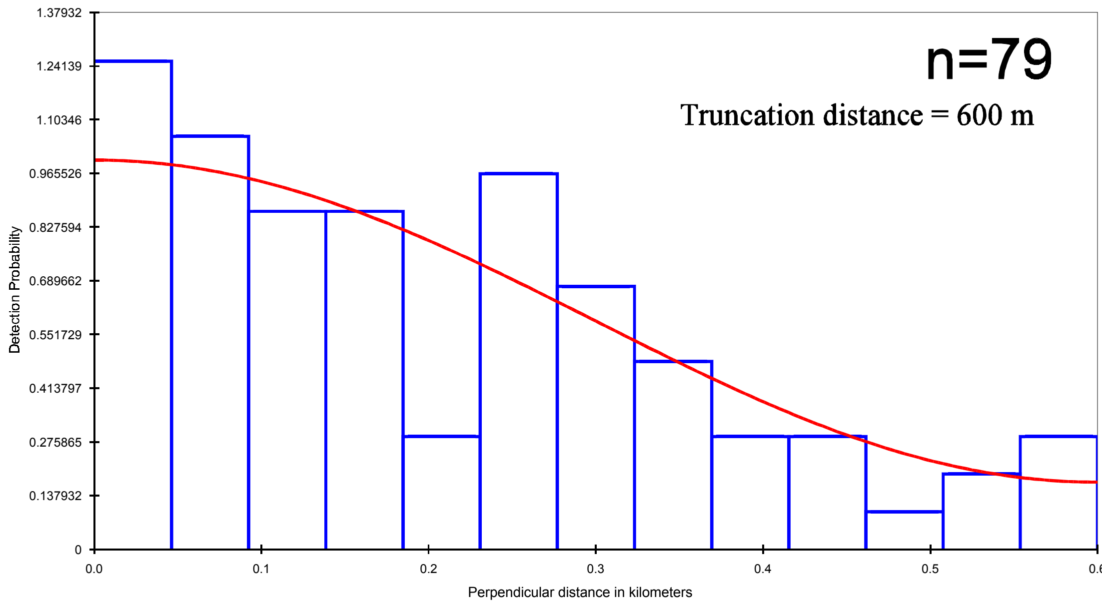


Figure 4. Probability density function for the delphinid/porpoise species group and group sizes ≤ 25 (all Beaufort sea states 0-4). The uniform key model fit with 1 cosine adjustment term is shown ($f(0)$ = 2.843 km^{-1}; χ^2 = 0.772, df = 11).

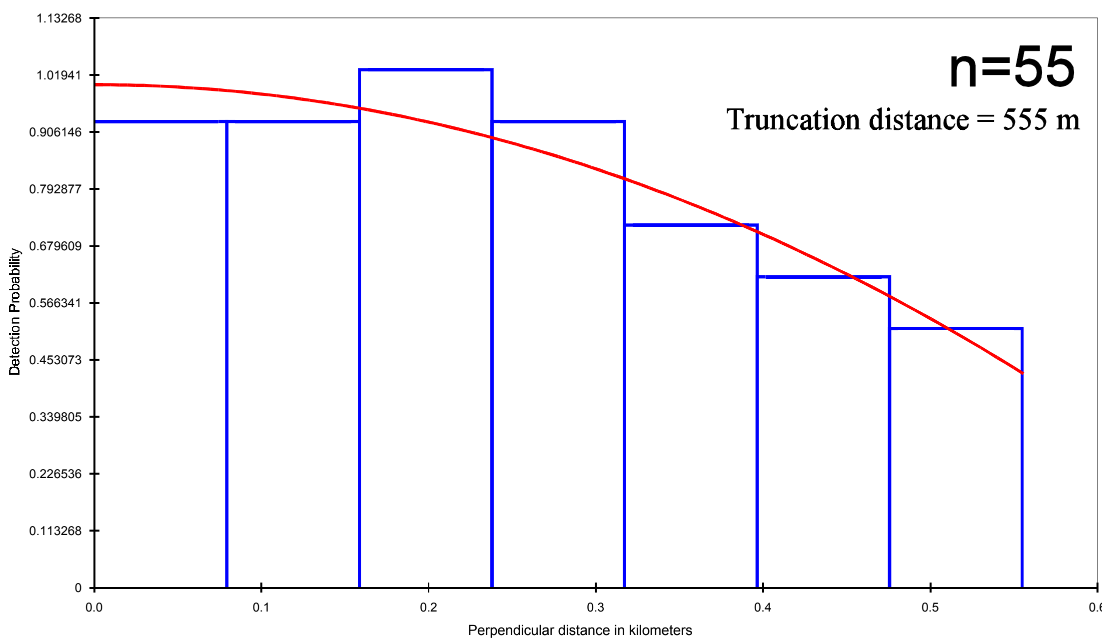


Figure 5. Probability density function fit to perpendicular sighting distance data for the delphinid/porpoise species group and group sizes > 25 (Beaufort sea states 0-4). The uniform key model fit with 2 simple polynomial adjustment terms is shown ($f(0)$ = 2.227 km^{-1}; χ^2 = 0.998, df = 5).

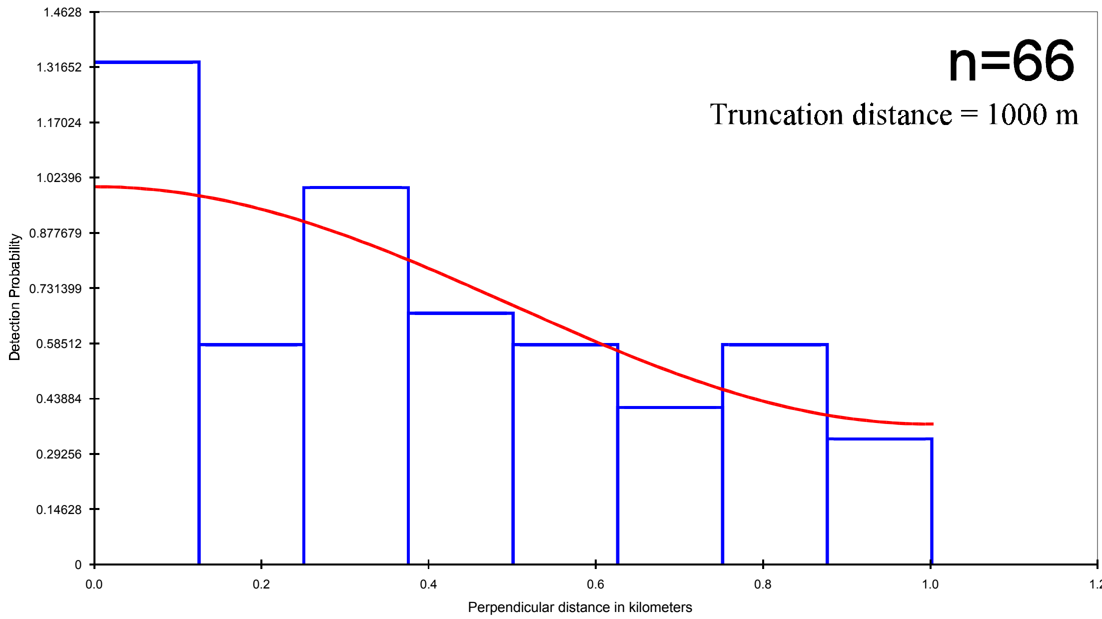


Figure 6. Probability density function fit to perpendicular sighting distance data for the whale species group (Beaufort sea states 0-4). The uniform key model fit with 1 simple polynomial adjustment term is shown (*f(0)* = 1.455 km^{-1}; χ^2 = 0.894, df = 10).

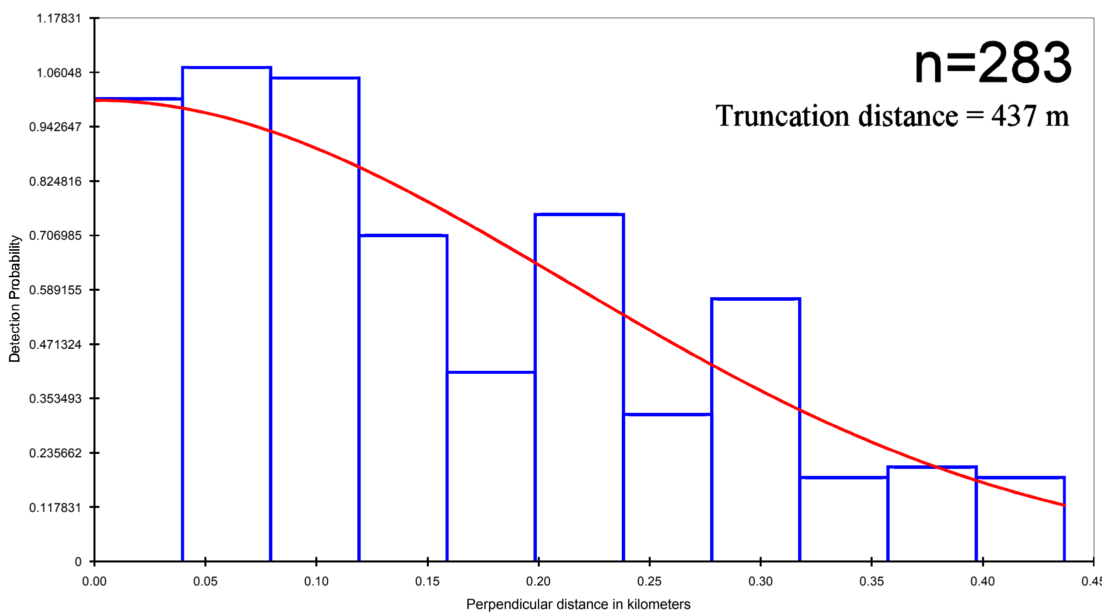


Figure 7. Probability density function fit to perpendicular sighting distance data for the pinniped species group and calm sea states (Beaufort 0-2). The half-normal model fit to the data is shown (*f(0)* = 3.905 km^{-1}; χ^2 = 0.032, df = 14).

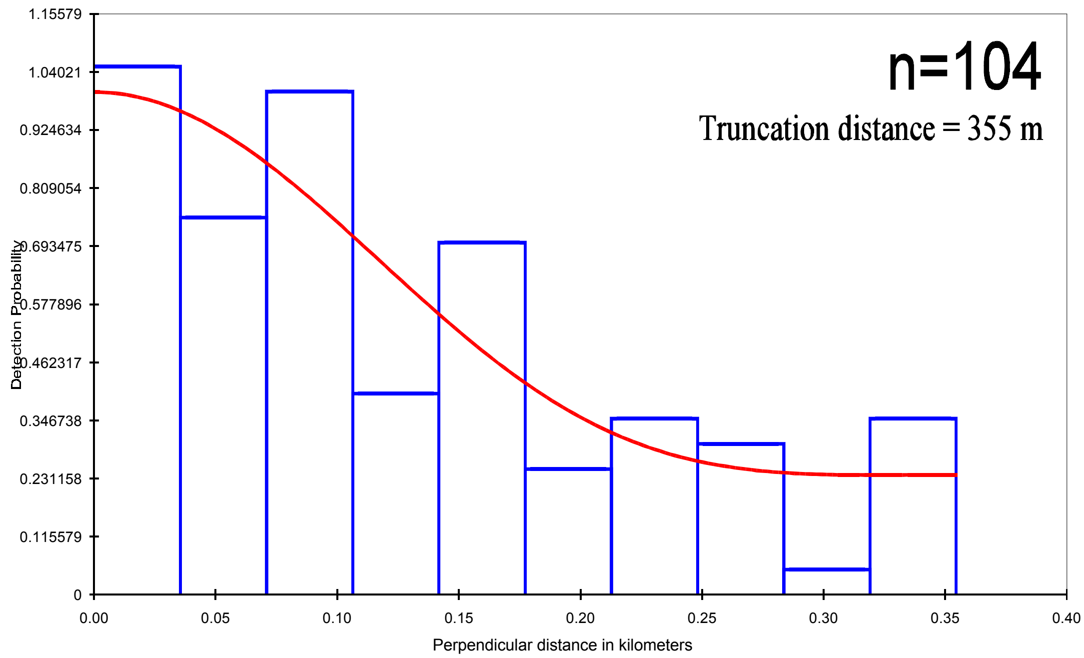


Figure 8. Probability density function fit to perpendicular sighting distance data for the pinniped species group and rough sea states (Beaufort 3-4). The uniform model fit with 2 cosine adjustment terms is shown ($f(0)$ = 5.421 km^{-1}; χ^2 = 0.154, df = 7).

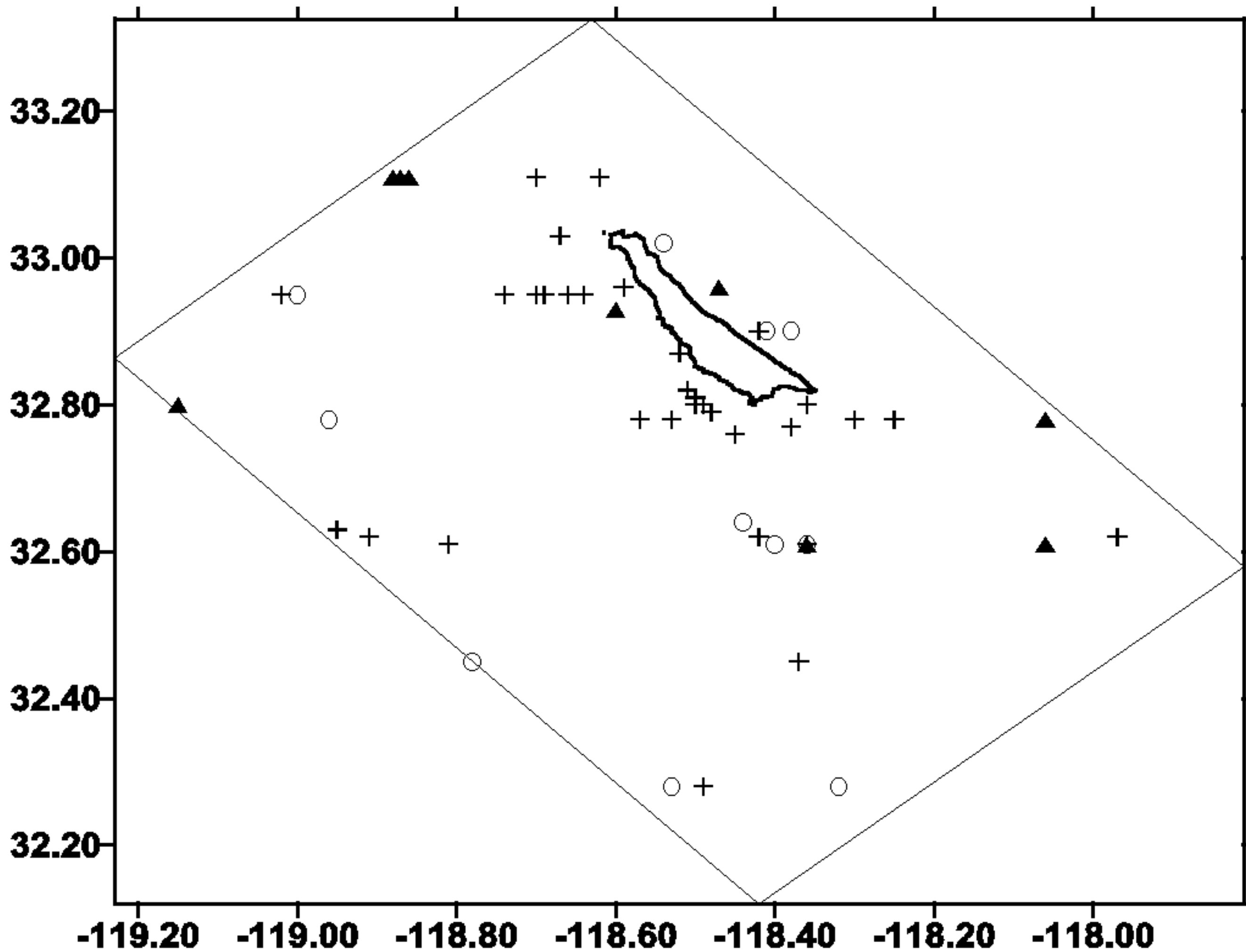


Figure 9. Sighting locations of all Pacific white-sided dolphins (*Lagenorhynchus obliquidens* = cross hatches), northern right whale dolphins (*Lissodelphis borealis* = circles), and Dall's porpoise (*Phocoenoides dalli* = filled triangles) recorded during 1998-99 aerial line-transect surveys.

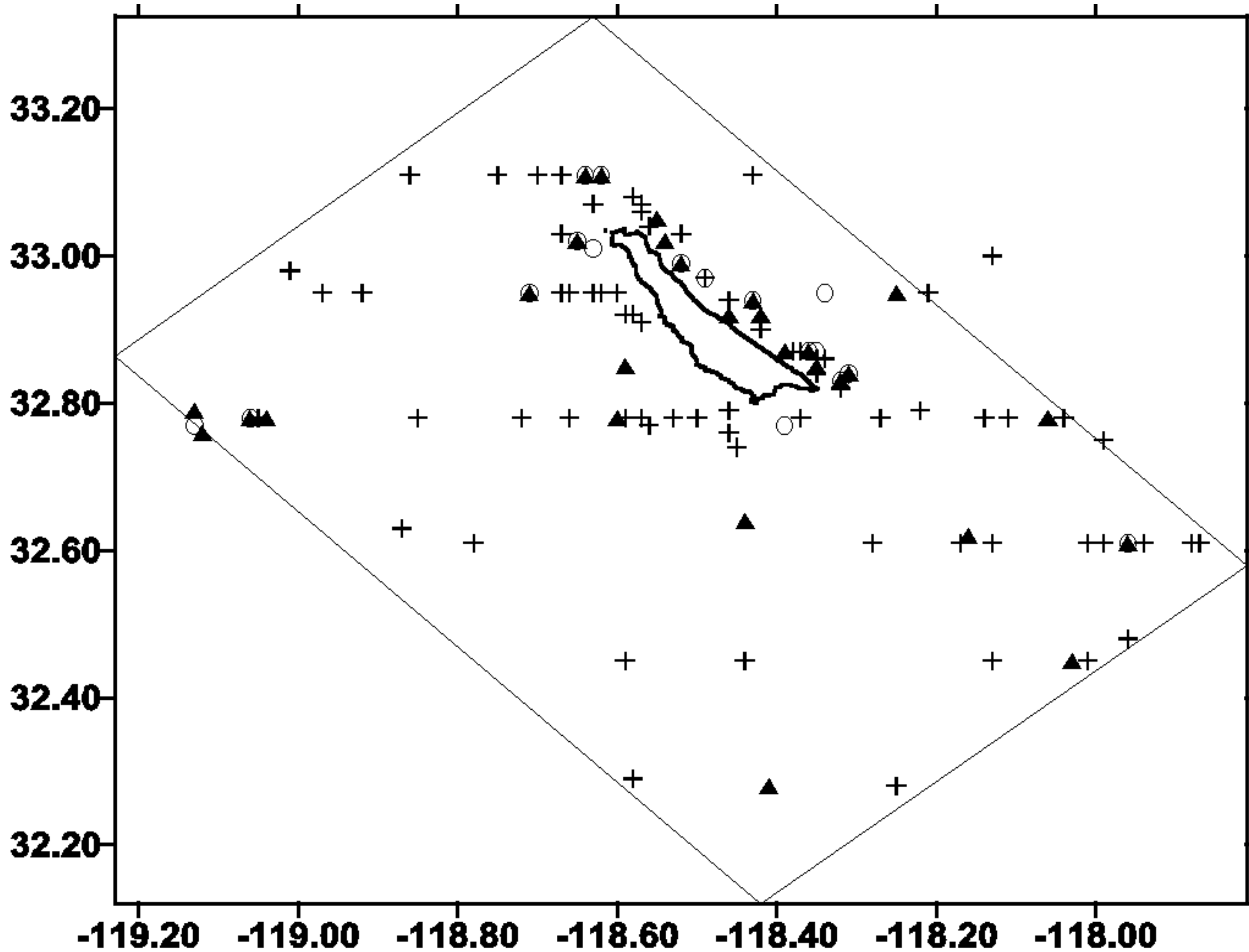


Figure 10. Sighting locations of all common dolphins (*Delphinus delphis* = cross hatches), bottlenose dolphins (*Tursiops truncatus* = circles), and Risso's dolphins (*Grampus griseus* = filled triangles) recorded during 1998-99 aerial line-transect surveys.

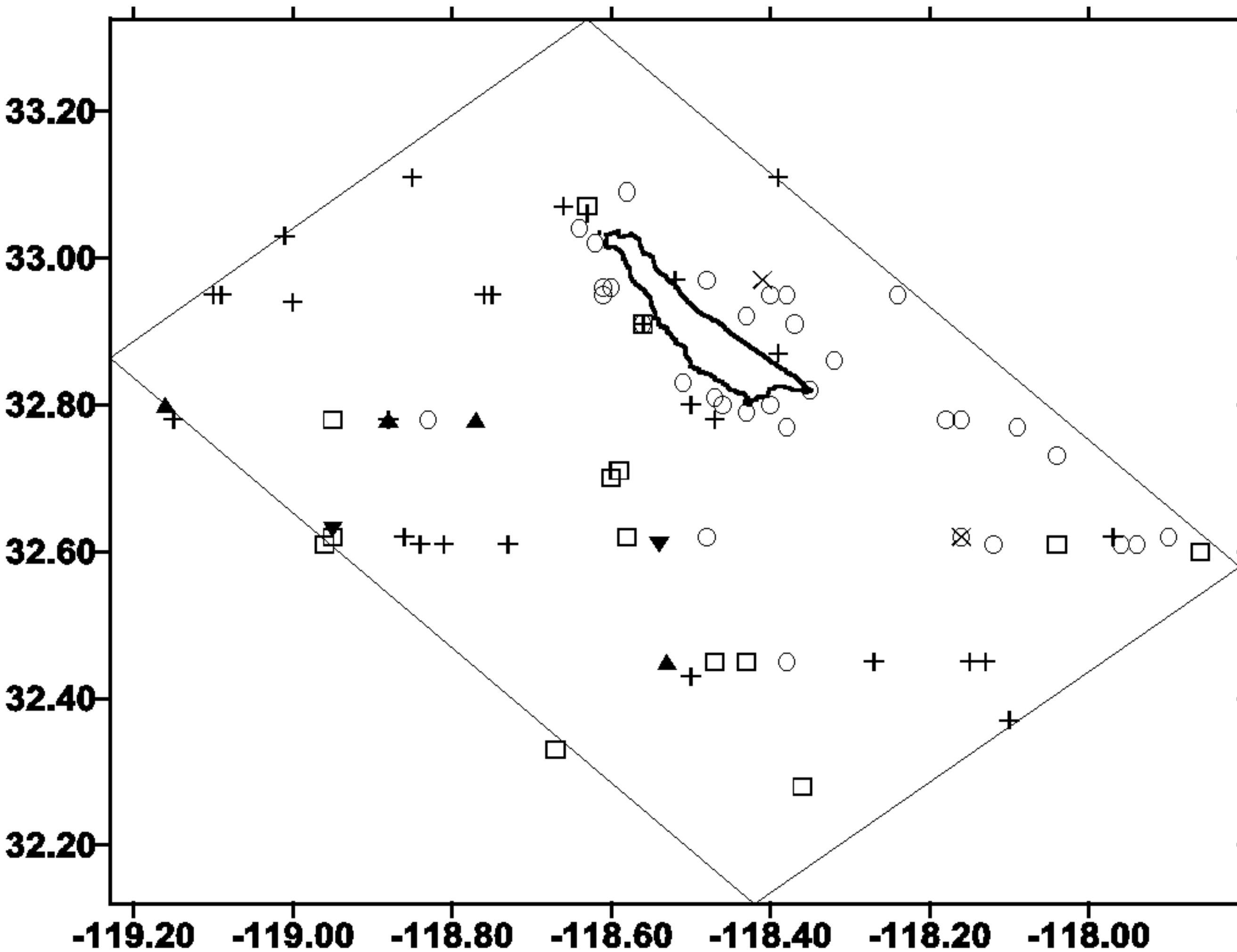


Figure 11. Sighting locations of all minke whales (*Balaenoptera acutorostrata* = X's), blue whales (*B. musculus* = squares), fin whales (*B. physalus* = cross hatches), humpback whales (*Megaptera novaeangliae*) (inverted triangles), gray whales (*Eschrichtius robustus*) (circles), and Cuvier's beaked whales (*Ziphius cavirostris*) (triangles) recorded during 1998-99 aerial line-transect surveys.

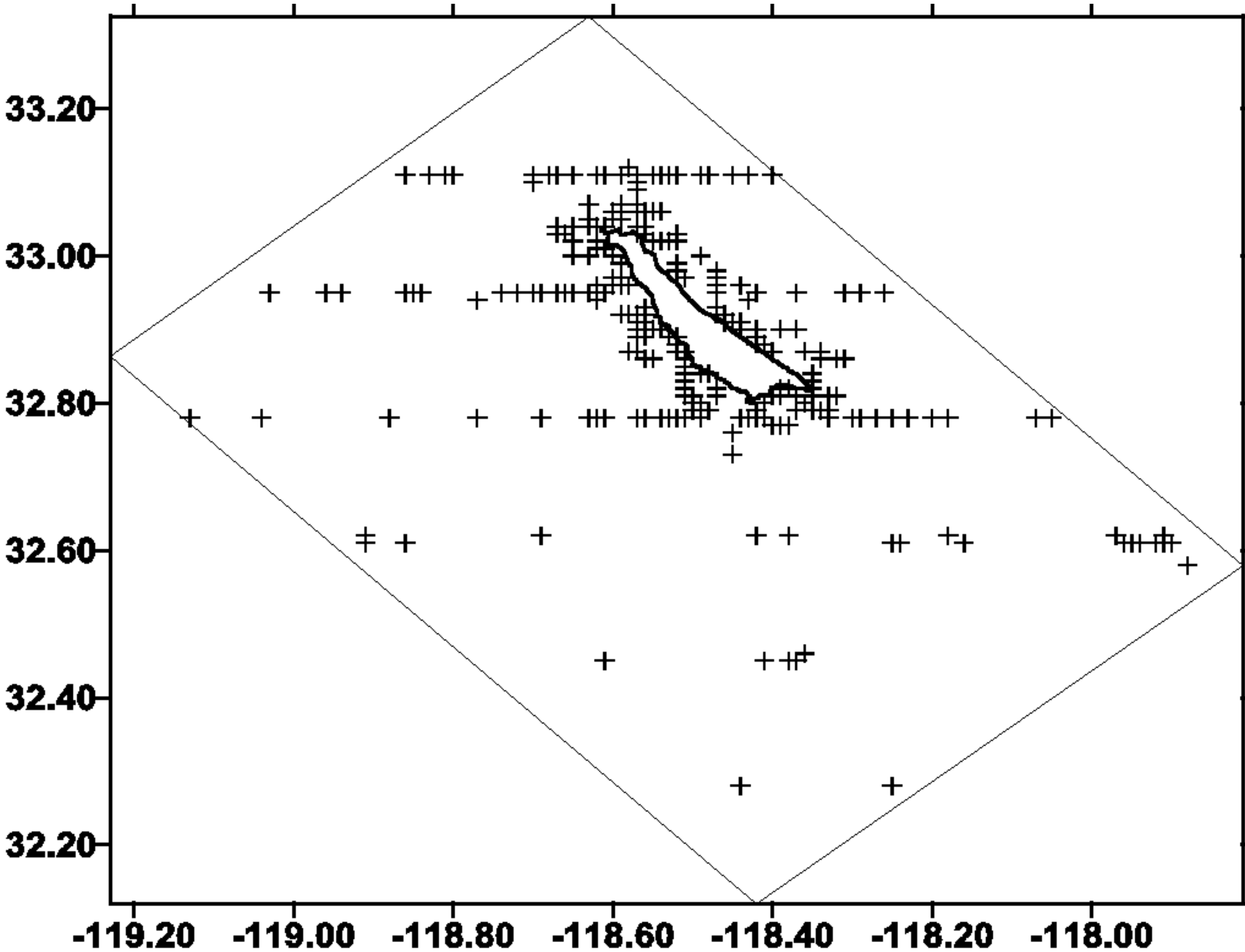


Figure 12. Sighting locations of all California sea lions (*Zalophus californianus*) (+) recorded during 1998-99 aerial line-transect surveys.

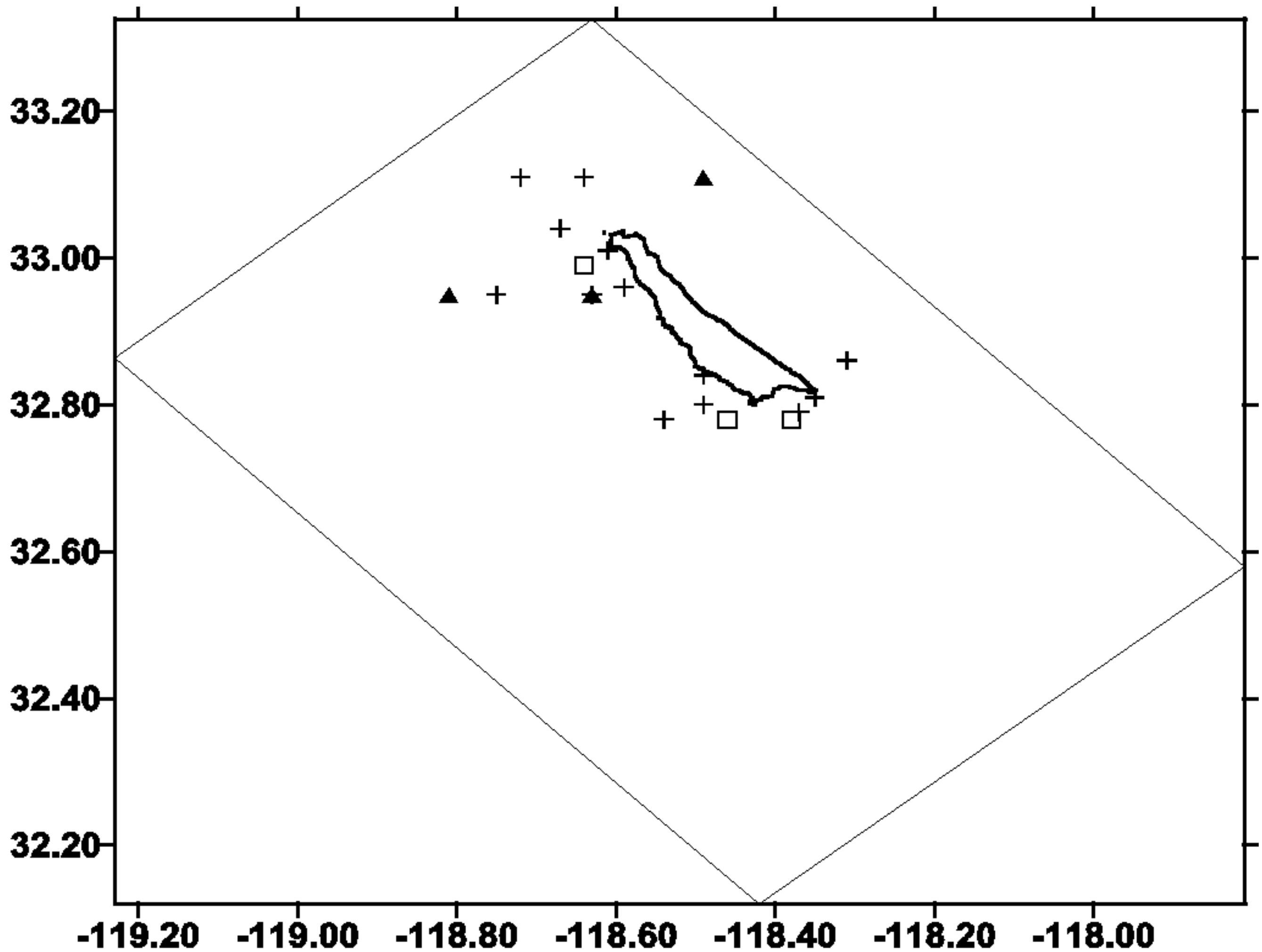


Figure 13. Sighting locations of all harbor seals (*Phoca vitulina*) (cross hatches), northern elephant seals (*Mirounga angustirostris*) (triangles), and sea otters (*Enhydra lutris*) (squares) recorded during 1998-99 aerial line-transect surveys.

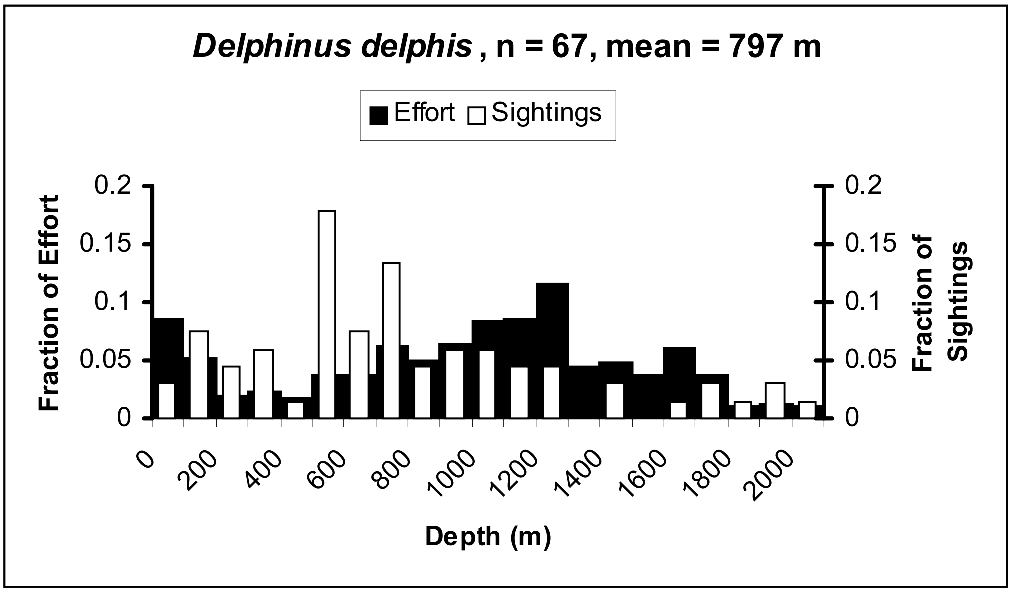


Figure 14. Distribution of seafloor depths and common dolphin sighting depths during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. Distributions of seafloor and sighting depths were significantly different ($p < 0.001$), as determined by a Kolmogorov-Smirnov goodness of fit test.

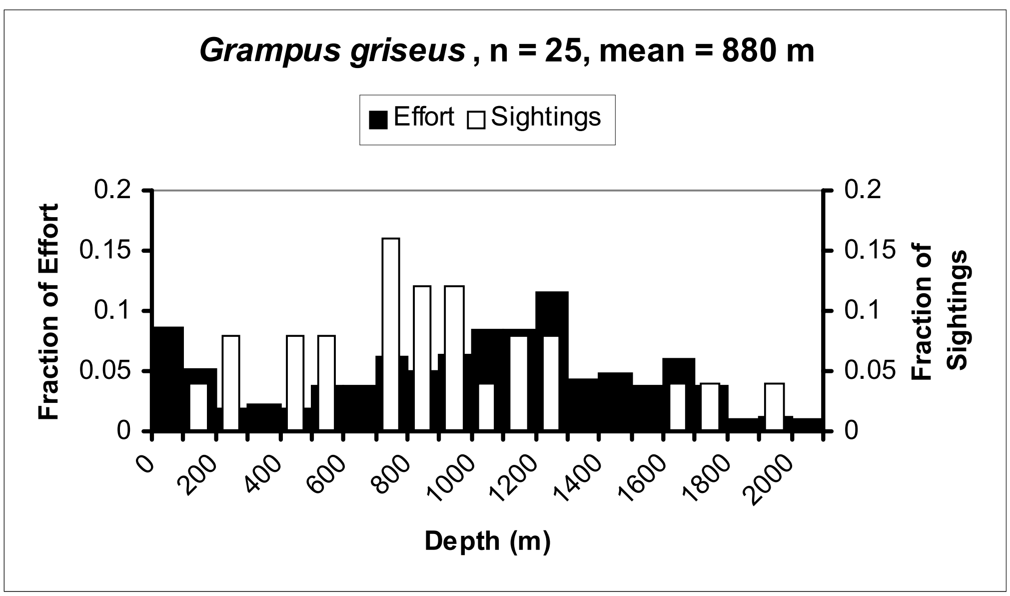


Figure 15. Distribution of seafloor depths and sighting depths for Risso's dolphins during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. Distributions of seafloor and sighting depths were significantly different ($0.02 < p < 0.05$), as determined by a Kolmogorov-Smirnov goodness of fit test.

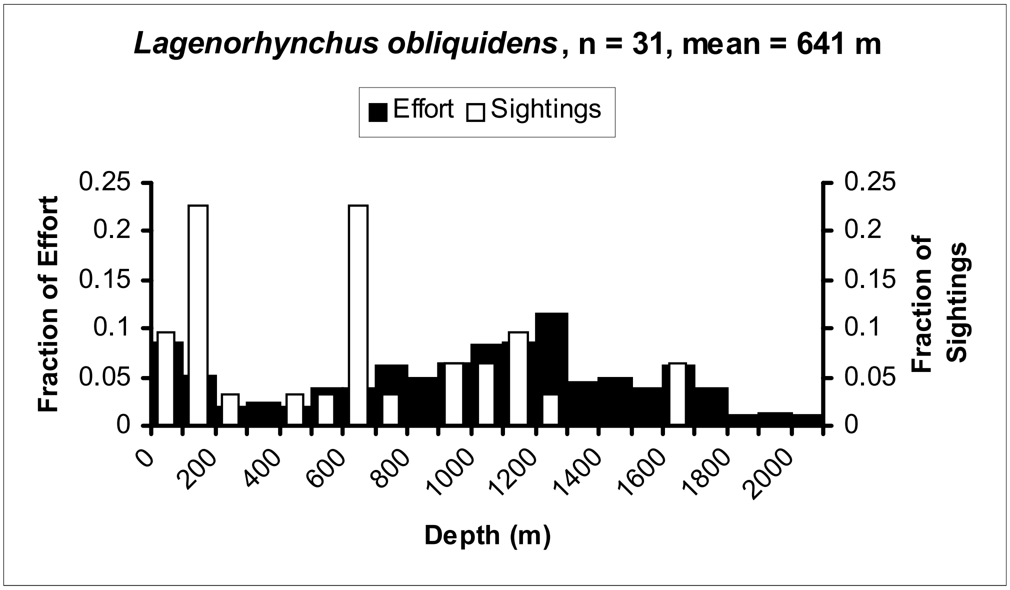


Figure 16. Distribution of seafloor depths and sighting depths for Pacific white-sided dolphins during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. Distributions of seafloor and sighting depths were significantly different ($p < 0.001$), as determined by a Kolmogorov-Smirnov goodness of fit test.

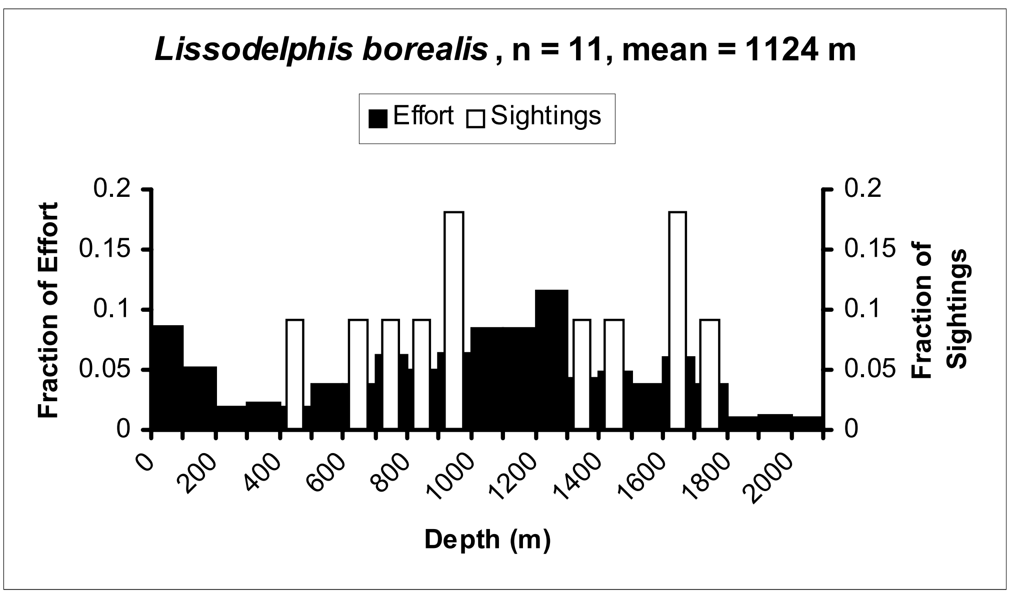


Figure 17. Distribution of seafloor depths and sighting depths for northern right whale dolphins during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. Distributions of seafloor and sighting depths were not significantly different ($p > 0.50$), as determined by a Kolmogorov-Smirnov goodness of fit test.

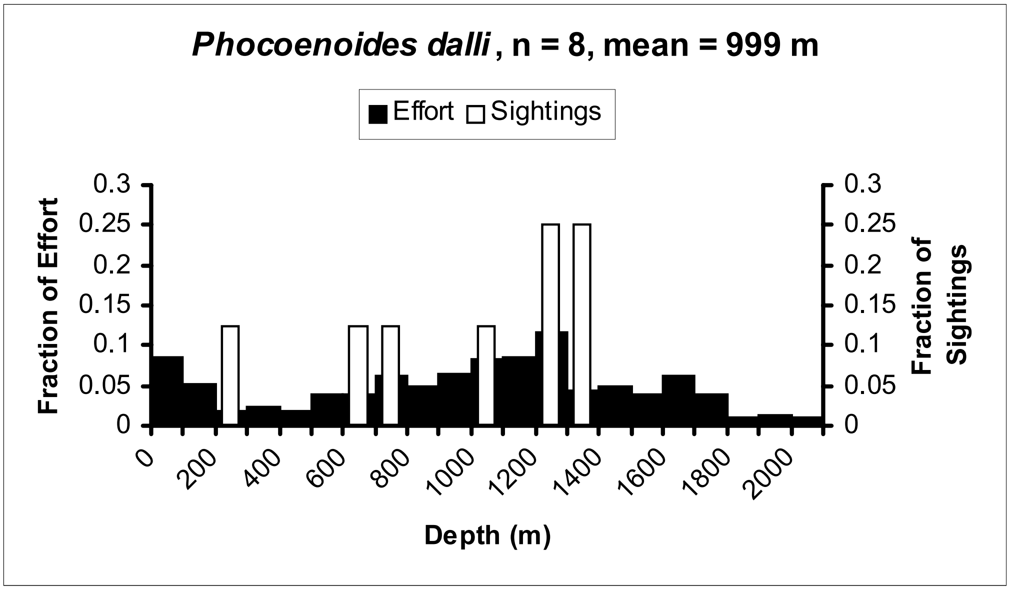


Figure 18. Distribution of seafloor depths and sighting depths for Dall's porpoise during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were not significantly different ($p > 0.50$), as determined by a Kolmogorov-Smirnov goodness of fit test.

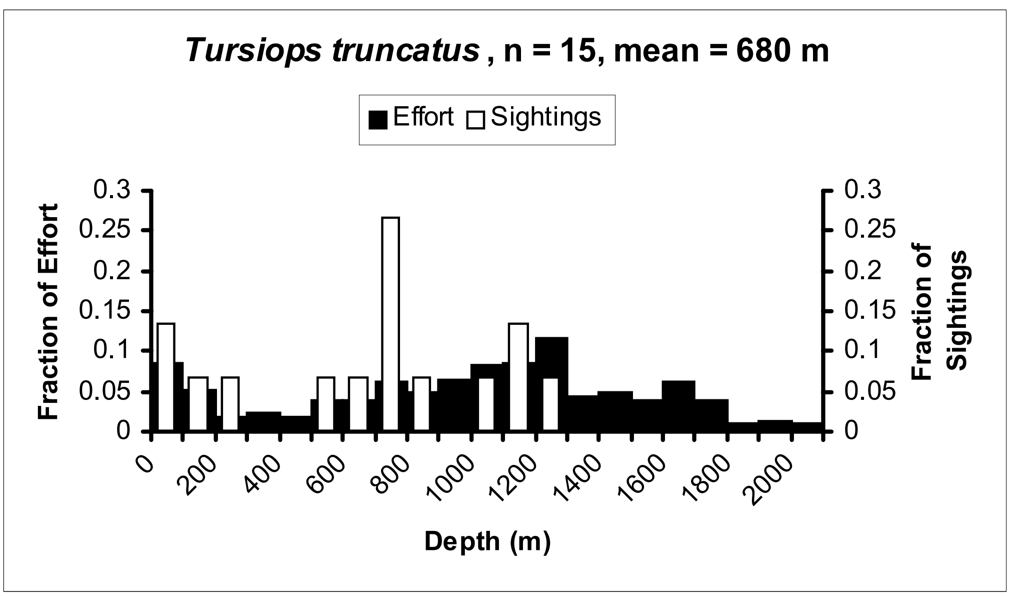


Figure 19. Distribution of seafloor depths and sighting depths for bottlenose dolphins during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were significantly different ($0.01 < p < 0.02$), as determined by a Kolmogorov-Smirnov goodness of fit test.

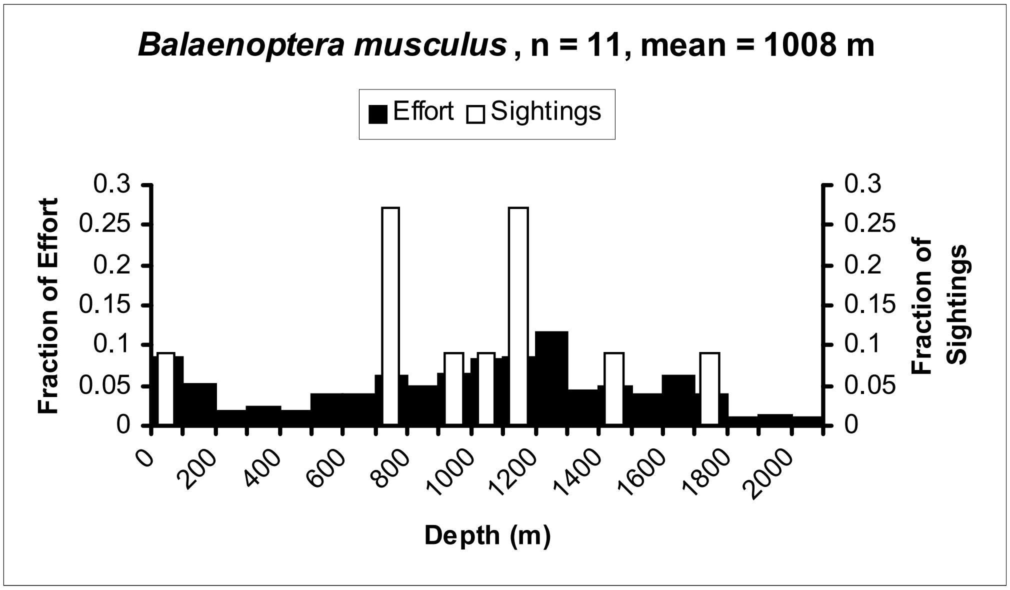


Figure 20. Distribution of seafloor depths and sighting depths for blue whales during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distribution of seafloor and sighting depths were not significantly different ($0.20 < p < 0.50$), as determined by a Kolmogorov-Smirnov goodness of fit test.

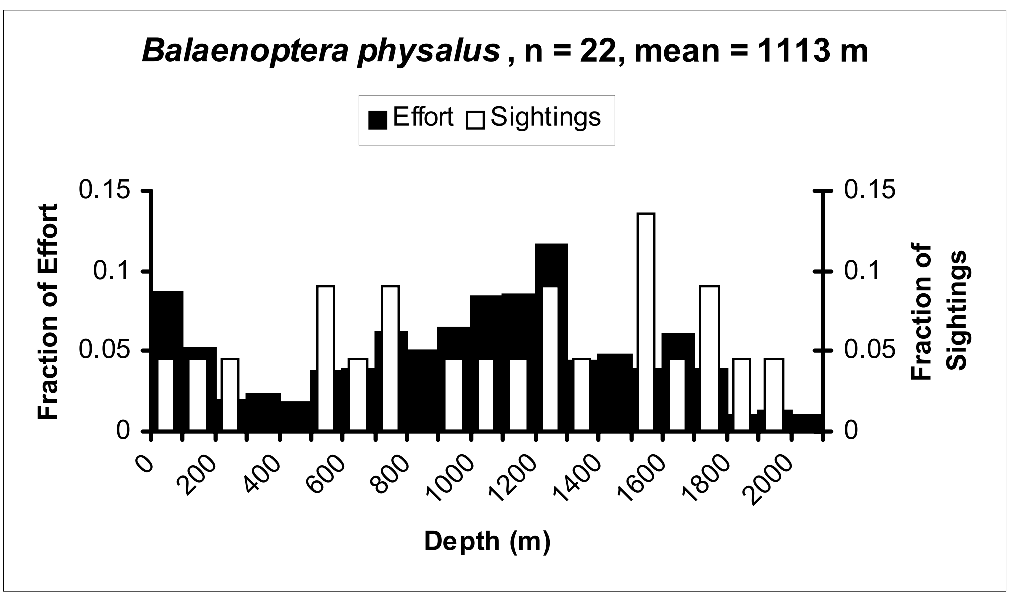


Figure 21. Distribution of seafloor depths and sighting depths for fin whales during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were not significantly different ($0.20 < p < 0.50$), as determined by Kolmogorov-Smirnov goodness of fit test.

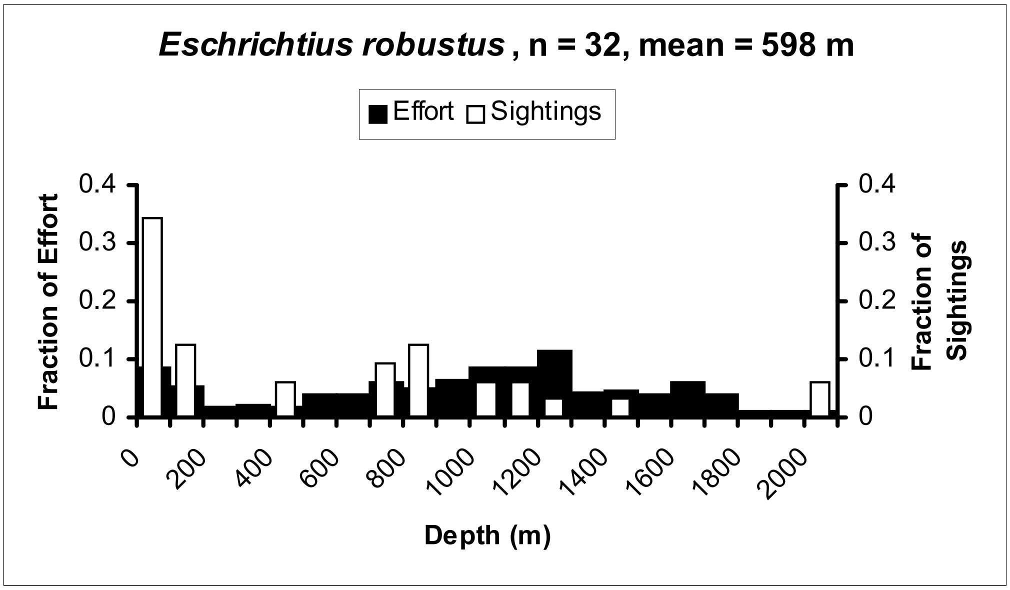


Figure 22. Distribution of seafloor depths and sighting depths for gray whales during on-effort transect segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were significantly different ($p < 0.001$), as determined by a Kolmogorov-Smirnov goodness of fit test.

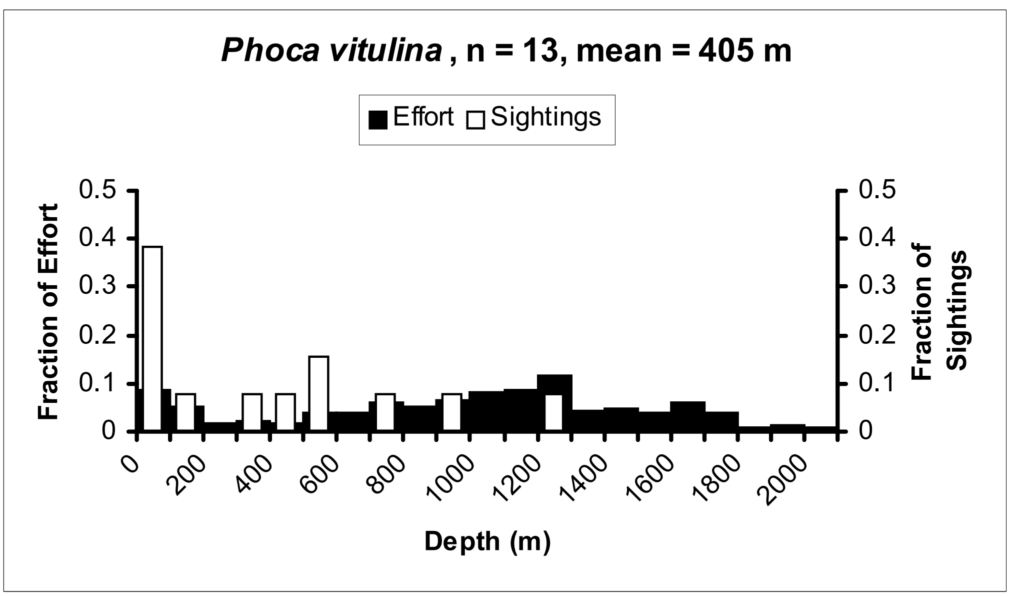


Figure 23. Distribution of seafloor depths and sighting depths for harbor seals during on-effort transect segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were significantly different ($p < 0.001$), as determined by a Kolmogorov-Smirnov goodness of fit test.

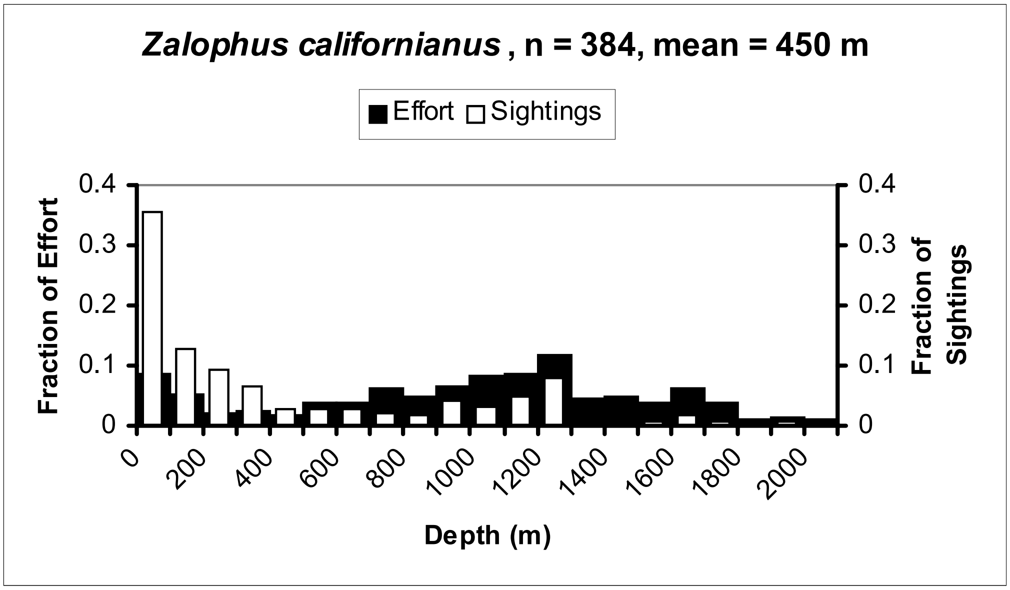
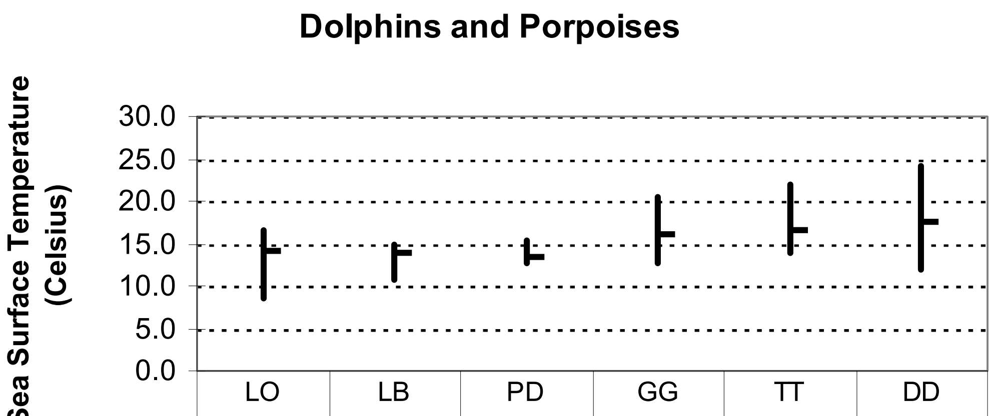
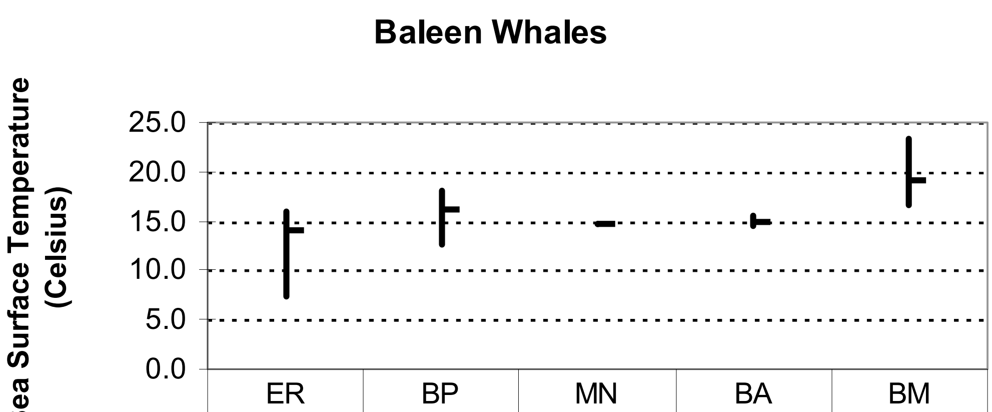


Figure 24. Distribution of seafloor depths and sighting depths for California sea lions during on-effort segments of aerial line-transect surveys. Distribution of seafloor depths was determined from 2,347 depths taken at 60-second time intervals along each on-effort transect segment. The distributions of seafloor and sighting depths were significantly different ($p < 0.001$), as determined by Kolmogorov-Smirnov goodness of fit test.



	LO	LB	PD	GG	TT	DD
High	16.7	14.9	15.3	20.6	21.9	24.2
Low	8.6	10.7	12.8	12.8	13.8	12.0
Mean	14.0	13.8	13.5	16.0	16.5	17.5

Figure 25. Range of sea-surface temperatures over which dolphin and porpoise species were encountered during aerial line-transect surveys. Species key: LO = Pacific white-sided dolphin, LB = northern right whale dolphin, PD = Dall's porpoise, GG = Risso's dolphin, TT = bottlenose dolphin, and DD = short-beaked common dolphin.



	ER	BP	MN	BA	BM
High	15.9	18.2	14.7	15.5	23.4
Low	7.4	12.6	14.7	14.4	16.7
Mean	14.0	16.1	14.7	14.9	19.2

Figure 26. Range of sea-surface temperatures over which baleen whale species were encountered during aerial line-transect surveys. Species key: ER = gray whale, BP = fin whale, MN = humpback whale, BA = minke whale, and BM = blue whale.

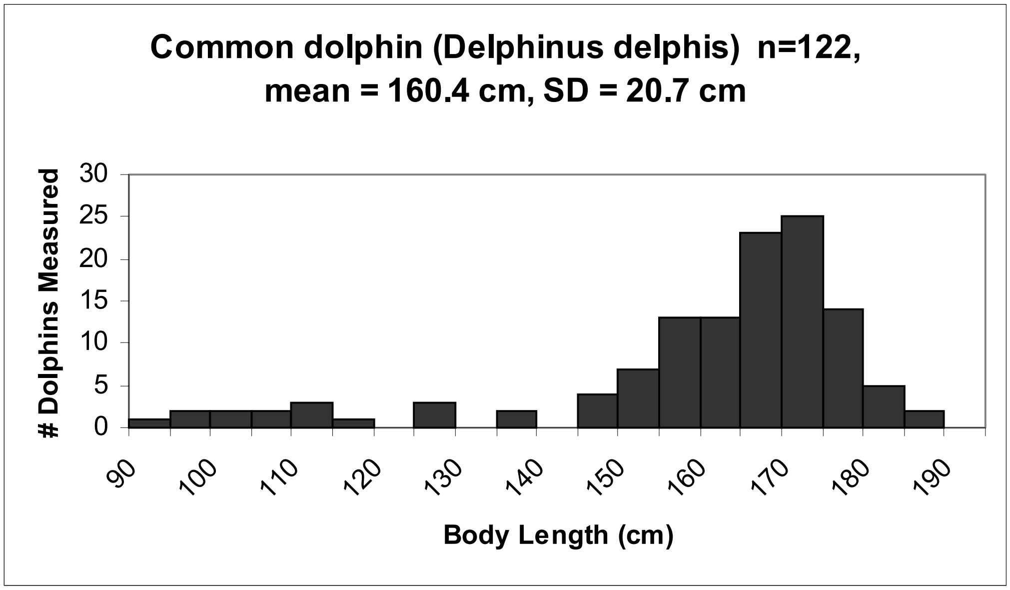


Figure 27. Histogram of dolphin lengths obtained with aerial photogrammetry from two common dolphin schools photographed near San Clemente Island in January 1999. Schools were photographed at N32º 51.90 / W118º 15.42 and N32º 44.91 / W118º 10.39.