The abundance of cetaceans in California waters. Part I: Ship surveys in summer and fall of 1991

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Abstract.—A ship survey was conducted in summer and fall of 1991 to estimate the abundance of cetaceans in California waters between the coast and approximately 555 km (300 nmi) offshore. Line-transect methods were used from a 53-m research vessel. Approximately 10,100 km were searched, and 515 groups of cetaceans were seen. The estimated abundances and coefficients of variation (in parentheses) of the most common small cetaceans are the following: 226,000 (0.28) short-beaked common dolphins, *Delphinus delphis*; 78,400 (0.35) Dall's porpoises, *Phocoenoides dalli*; 19,000 (0.41) striped dolphins, *Stenella coeruleoalba*; 12,300 (0.54) Pacific white-sided dolphins, *Lagenorhynchus obliquidens*; 9,470 (0.68) long-beaked common dolphins, *Delphinus capensis*; and 9,340 (0.57) northern right whale dolphins, *Lissodelphis borealis*. The estimated abundances (and CV's) of the most common large cetaceans are 2,250 (0.38) blue whales, *Balaenoptera musculus*; 935 (0.63) fin whales, *Balaenoptera physalus*; 756 (0.49) sperm whales, *Physeter macrocephalus*; and 626 (0.41) humpback whales, *Megaptera novaeangliae*. Estimates are also made for other species and for higher-level taxa that could not be identified to species.

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The abundance of cetaceans in California waters is poorly known for the majority of species found there. For small cetaceans, quantitative estimates of abundance with statistical confidence limits are available only for common dolphins, *Delphinus delphis* (Dohl et al., 1986) and for harbor porpoise, *Phocoena phocoena* (Barlow, 1988). For large cetaceans, such estimates are available for gray whales, *Eschrichtius robustus* (Reilly, 1984; Buckland et al., 1993a); humpback whales, *Megaptera novaeangliae* (Calambokidis et al., 1990a, 1993[1]), and blue whales, *Balaenoptera musculus*.[1] Estimates have been made for some of the other species (Dohl et al.[2,3]), but these estimates are more than 10 years old, and most lack information on statistical precision.

Many, and perhaps all, cetaceans in California waters are vulnerable to entanglement and death in gillnet fisheries. A program is now in place to estimate the incidental mortality of cetaceans in the California gillnet fisheries (Lennert et al., in press). It is difficult, however, to assess the impact of gillnet mortality on cetacean populations without knowing population sizes. Coordinated ship and aerial surveys were initiated recently to estimate the abundance of all cetacean species in the region of California gillnet fisheries. To evaluate the effect of seasonality on cetacean abundance, surveys were designed to cover both cold-water months (Feb–Apr) and warm-water months (Jul–Nov). A ship survey was conducted during the warm-water period of 1991; an aerial survey was conducted during the cold-water periods of both 1991 and 1992. Results from the ship survey are reported here; population estimates from the aerial surveys are reported in a companion paper (Forney et al., this issue).

Field methods

A line-transect survey was conducted from 28 July to 5 November 1991 with the 53-m National Oceanographic and Atmospheric Admin-

[1] Calambokidis, J., G. H. Steiger, and J. R. Evenson. 1993. Photographic identification and abundance estimates of humpback and blue whales off California in 1991–92. Final Contract Rep. 50ABNF100137, submitted to the Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038, 40 p.

[2] Dohl, T. P., K. S. Norris, R. C. Guess, J. D. Bryant, and M. W. Honig. 1978. Cetacea of the Southern California Bight. Part II of Summary of marine mammals and seabird surveys of the Southern California Bight area, 1975–78. Final Rep. to the Bureau of Land Management, 414 p. [NTIS Rep. No. PB81248189.]

[3] Dohl, T. P., R. C. Guess, M. L. Duman, and R. C. Helm. 1983. Cetaceans of central and northern California, 1980–83: status, abundance, and distribution. Final report to the Minerals Management Serv., Contract No. 14-12-0001-29090, 284 p.

istration (NOAA) vessel *McArthur* to assess the abundance of cetaceans in California waters. Primary cruise tracks were drawn for a unifirm survey of the 814,900 km^2 area between the 18-m (10-fathom) isobath and approximately 555 km (300 nmi) offshore (Fig. 1).

Primary observation team

The basic survey method was that which was developed and used to estimate the abundance of small cetaceans in the eastern tropical Pacific (Holt and Powers, 1982; Holt, 1987; Holt and Sexton, 1989; Wade and Gerrodette, 1993). The primary observation team consisted of three observers who searched from a viewing height of 10 m above the sea surface: two observers searched with 25× pedestal-mounted binoculars; the third observer searched with unaided eye, and (occasionally) 7× binoculars, and also served as data recorder. Observers rotated among these three duty stations every 1/2 hour, and two observer teams alternated work and rest periods every two hours. Sighting effort was maintained from dawn to dusk whenever weather conditions allowed, and searching covered the entire region from directly in front of the vessel to 90 degrees left and right and out to the horizon. Data were recorded on a lap-top computer that had direct input from the ship's GPS (Global Positioning System) navigation system. Recorded data included sighting conditions (sea state, cloud cover, sun position, etc.), observer positions, the beginning and end of effort, and information pertaining to sightings.

When a sighting was made, all observers were made aware of the animals' location. The perpendicular distance from the trackline to the center of the group was estimated from the initial bearing and distance. The initial bearing of a cue (a blow, a splash, or a sighting of animals) was measured relative to the bow of the vessel by means of a calibrated collar on the base of the yoke of the 25× binoculars. The initial distance was typically estimated from a calibrated reticle scale in the oculars of both the 25× and 7× binoculars with the formula derived by Smith (1982) and was calibrated by using radar-measured distances to inanimate objects (Barlow and Lee, 1994). If a shore horizon was closer than 11.1 km (6 nmi), distance was estimated by comparison with the radar-measured distance to shore. Occasionally, for very close animals seen only by the third observer, sighting distances and angles were estimated by eye. If a cue turned out to be a cetacean, effort was interrupted and the ship was typically diverted towards the animals in order to obtain estimates of species composition and group size. The vessel was not typically diverted for cetaceans that were greater than 5.55 km (3 nmi) perpendicular distance from the trackline.

Species identification was made collectively by the team, but quantitative estimates of species composition and group size were made independently by each observer. For estimation purposes, a group was defined as a collection of closely associated individuals (typically within several body lengths of each other) that exhibited cohesive behavior. In the field, however, a single distant sighting might prove to be two behaviorally distinct groups upon closer inspection. In such cases, when it was impossible to determine which was the original group sighted, both groups were pooled to estimate group size and species composition. For mixed-species groups, species composition was recorded as an observer's estimate of the percentage of each species present in the group. The observers recorded species composition and group-size data in confidential personal notebooks, and the data were transcribed at the end of the day into the computer data record by the cruise leader.

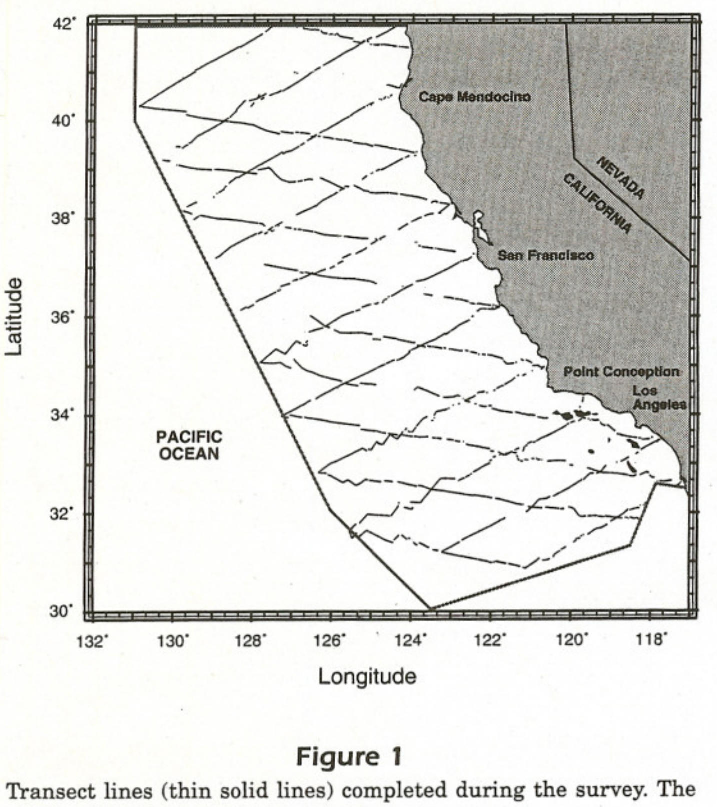

Figure 1

Transect lines (thin solid lines) completed during the survey. The bold polygon indicates the limit of the main study area.

Species identification

Observers attempted to classify all the species present in a group to the lowest possible taxonomic level (one member of each team was a cetacean identification expert with at least nine months of at-sea survey experience on prior marine mammal surveys). Several higher taxonomic groups were used in cases where species identification was not possible. These higher groups were beaked whales of the genus *Mesoplodon*; unidentified sei or Bryde's whales; unidentified beaked whales (including members of the genera *Mesoplodon* and *Ziphius*); unidentified large whales (including members of the species group "large whale" in Table 1 as well as the genera *Eschrichtius* and *Eubalaena*); unidentified baleen whales (including members of the genera *Balaenoptera*, *Megaptera*, *Eschrichtius*, and *Eubalaena*); unidentified small whales (including members of the species groups "small whales" and "large delphinids" in Table 1); unidentified delphinoids (including members of the species groups "small delphinids," "large delphinids," and "cryptic species" in Table 1); and unidentified cetaceans (which could include any of the species listed above or in Table 1). The number of sightings identified to these higher taxonomic levels is relatively small, and these animals were not included in the abundance estimates for individual species.

Conditionally independent observer

In addition to the primary observation team, a fourth observer was on duty 81% of the time and looked for cetaceans that were missed by the primary team. This conditionally independent observer was stationed immediately next to the other observers, searched with 7× binoculars and unaided eyes, and did not reveal the presence of cetaceans until after they were clearly missed by the primary observation team (i.e. after they had passed abeam of the vessel or were bow-riding). Nine different people served as independent observers during the survey, and all worked irregular schedules that overlapped with both primary teams. Independent observers did not work more than two consecutive hours. When a sighting was made by the independent observer, that person maintained their normal behavior so as to avoid drawing the attention of the primary observer team. Initial bearing and distance were estimated by eye or with the aid of reticles in the ocular of 7× binoculars and a hand-held protractor. After a group was clearly missed by the primary team, the independent observer announced the presence of the animals to the data recorder and gave the initial bearing and distance. Typically the vessel was diverted towards the group, and species composition and group size were estimated by the primary observation team.

Analytical methods

Cetacean abundance was estimated from survey data with line-transect methods (Buckland et al.,

Table 1

Number of groups of cetaceans which contained members of the indicated species and species groups. The sum of all species in a group may be greater than the total for that group because the latter contains mixed-species groups. Totals do not include off-effort sightings.

Species group and species	No. of sightings
Small delphinids	285
short-beaked common dolphin, *Delphinus delphis*	123
long-beaked common dolphin, *Delphinus capensis*	6
unclassified common dolphin, *Delphinus* spp.	8
striped dolphin, *Stenella coeruleoalba*	24
Pacific white-sided dolphin, *Lagenorhynchus obliquidens*	12
northern right whale dolphin, *Lissodelphis borealis*	16
unidentified delphinoid	21
Cryptic species	132
harbor porpoise, *Phocoena phocoena*	32
Dall's porpoise, *Phocoenoides dalli*	97
pygmy sperm whale, *Kogia breviceps*	3
Large delphinids	37
bottlenose dolphin, *Tursiops truncatus*	16
Risso's dolphin, *Grampus griseus*	29
killer whale, *Orcinus orca*	5
Large whales	127
sperm whale, *Physeter macrocephalus*	13
Baird's beaked whale, *Berardius bairdii*	1
Bryde's whale, *Balaenoptera edeni*	1
Bryde's or sei whale, *Balaenoptera edeni* or *B. borealis*	2
fin whale, *Balaenoptera physalus*	22
blue whale, *Balaenoptera musculus*	49
humpback whale, *Megaptera novaeangliae*	13
unidentified baleen whale	9
unidentified large whale	22
Small whales	48
unidentified beaked whale	7
mesoplodont beaked whale (*Mesoplodon* spp.)	5
Cuvier's beaked whale, *Ziphius cavirostris*	14
minke whale, *Balaenoptera acutorostrata*	4
unidentified small whale	11
unidentified cetacean	8

1993b). The basic equation for estimating abundance, N, for grouped animals with line transect is given by

$$N = \frac{AnSf(0)}{2Lg(0)}, \tag{1}$$

where A = size of the study area;
n = number of sightings;
S = mean group size;
$f(0)$ = sighting probability density at zero perpendicular distance;
L = length of transect line completed; and
$g(0)$ = probability of seeing a group directly on the trackline.

Ideally, S, $f(0)$, and $g(0)$ would be estimated separately for each species. However, the presence of mixed-species groups and small sample sizes required pooling for the estimation of $f(0)$ and $g(0)$. The parameter $f(0)$ was estimated with the Hazard rate model (Buckland, 1985). This model was fitted by maximum likelihood with ungrouped perpendicular distances. Perpendicular distances were estimated from bearing and radial distance estimates made by observers.

Pooling and stratification for estimating *f* (0)

Pooled $f(0)$'s were estimated for five species groups: "small delphinids," "large delphinids," "small whales," "large whales," and "cryptic species." The five species groups were defined to include all of the species seen on the survey (Table 1) and were based on patterns of species cooccurrence in groups and on similarities in the physical and behavioral attributes that affect sightability from a ship. As an example, bottlenose dolphins, *Tursiops truncatus*, were never seen in a single-species group but were seen with Risso's dolphins, *Grampus griseus*, 13 times, with striped dolphins, *Stenella coeruleoalba*, one time, and with sperm whales, *Physeter macrocephalus*, three times. Bottlenose dolphins were pooled together with Risso's dolphins because they were seen most frequently with that species and because their sighting characteristics are more similar to Risso's dolphins (medium body size, prominent dorsal fin, occasional low puffy blow, small to medium group size) than to the other two species with which they were seen. Because killer whales, *Orcinus orca*, were never seen with other species but share the same sighting characteristics, these were also included in the species group "large delphinids." The other four groups are "small delphinids" which are of small body size (2–3 m) and are found in medium to large groups; "small whales" which are of medium body size (4–10 m), typically show no blow, often surface inconspicuously, and are typically found in small groups; "large whales" which are of large body size (10–30 m), almost always show a conspicuous blow, and are found in small to medium groups; and "cryptic species" which are small (1.5–4.0 m), show no blow, typically surface inconspicuously, and are found in small groups. The assignment of higher-than-species taxa to species groups is given in Table 1.

In estimating $f(0)$ for each species group, I explored stratification by two factors that are likely to affect sightability: sea state and group size. To avoid estimating more parameters than are justified by the data, I chose the most parsimonious stratification model by minimizing Akaike's Information Criterion (AIC) (Akaike, 1973), defined as 2 multiplied by the number of parameters used to estimate $f(0)$ *minus* 2 multiplied by the sum of the log-likelihoods of the fitted values of $f(0)$. Sea state was subjectively stratified into calm (Beaufort 0–2) and rough (Beaufort 3–5), based on the obvious degradation in sighting conditions that occurs with the presence of whitecaps at Beaufort 3. I stratified by group size by first finding the group size that divided the data into two samples with approximately the same number of sightings in each. If this stratification resulted in a lower AIC, I explored further stratification into three samples of approximately equal size.

The above approach to stratification resulted in different strata for each species group. For small delphinids, AIC was minimized by stratifying group size into the categories 1–20, 21–100, and >100. For large delphinids, optimal stratification was with group size categories of 1–20 and >20. For large whales, AIC was minimized by using group size strata of 1–3 and >3. Because "cryptic species" and "small whales" were seldom seen in rough conditions, I estimated abundance for these species by using only data from calm conditions and did not explore stratification by sea state. Group size stratification resulted in higher AIC values for "cryptic species" and "small whales," so these groups were not stratified by group size. Sea-state stratification was not chosen on the basis of AIC values for any species group.

In stratification by group size, estimates of density in the various strata are added together to give an overall density. The equation for estimating abundance of each species k is therefore given by

$$N_k = \sum_{j=1}^{3} \frac{A n_{j,k} S_{j,k} f_{j,k}(0)}{2 L g_{j,k}(0)}, \tag{2}$$

where A = size of study area;

$n_{j,k}$ = number of sightings of species k in group size stratum j;
$S_{j,k}$ = mean group size of species k in group size stratum j;
$f_{j,k}(0)$ = sighting probability density at zero perpendicular distance for group size stratum j of the species group to which species k belongs;
L = length of transect line completed; and
$g_{j,k}(0)$ = probability of detecting a group directly on the trackline for group size stratum j of the species group to which species k belongs.

Perpendicular distance truncation

Sightings of distant groups add little to the estimation of trackline density and can introduce bias. Buckland et al. (1993b) recommend truncating to eliminate at least the most distant 5% of all sightings. In the current study, groups of cetaceans were typically not pursued for species identification and group size estimation if they were farther than 5.5 km (3 nmi) from the trackline. Therefore, by survey design, perpendicular distances must be truncated at no more than 5.5 km. I used a truncation distance of 3.7 km (2 nmi) for "small delphinids," "cryptic species," "large delphinids," and "small whales," which eliminated 8.8%, 2.4%, 4.6%, and 12.8% of all groups (respectively). A truncation distance of 5.5 km was used for "large whales," which eliminated 10.9% of groups.

Group-size estimation

The estimation of group size for cetaceans is difficult and can lead to bias in the estimation of abundance. To avoid bias, correction factors were developed for individual observers. The estimates of four of the six primary observers on the present survey had been previously calibrated by means of aerial photographic estimates to represent "true" group size.[4] The "best" estimates of two of these four were found to indicate group size with accuracy and did not require any correction factors. The other two required correction factors, and, for one, correction factors varied significantly from one year to the next. A helicopter was not available to make aerial photographic estimates of group size on the present survey, so correction factors for individual observers were estimated indirectly by comparison with the two observers who, in the previous study, did not require correction.

Linear regression was used to compare one observer's estimates of group size to another's for the subset of groups that were estimated by both. Group sizes were $\log_{10}$-transformed to normalize variances. For the two observers who did not require a correction factor in the previous study,[4] the slope of the regression was 1.009 (SE=0.017), indicating that, relative to each other, the observers were still estimating group size consistently. Correction factors for the other four observers were based on the slope and intercept of the regression of their "best" estimates against the mean of "best" estimates of the two who did not need calibration.

The group size for each species in a group was estimated as the average of all observers' corrected estimates of the size of the group multiplied by the average of all observers' estimates of the percentage of that species present (if in a mixed-species group).

Probability of detecting trackline groups

Estimating the probability that a group on the transect line will be seen, $g(0)$, is fraught with difficulties (see Buckland et al. [1993b] for a review of previous attempts). In the context of bias from missed groups of marine mammals, it is useful to think in terms of the dichotomy proposed by Marsh and Sinclair (1989): bias can result from groups that were available to be seen but were not (perception bias) and from groups that were not available to be seen either because they did not surface or because they surfaced behind a swell (availability bias). I will make a minimum estimate of perception bias based on data collected by the conditionally independent observer and on the approach given in the Appendix. Because the sample of sightings made by independent observers is small (only 37 cetacean groups), $f_2(0)$ in Equation 7 was estimated for all cetaceans pooled without stratification by group size or sea state. Perpendicular distance data were fitted with the Hazard rate model to estimate $f_2(0)$. (Groups are only available to the independent observer if they were missed by the other observers; therefore the distribution of perpendicular distances need not be monotonically decreasing. In this case, however, it was, and a more general model is not likely to have performed better than the Hazard rate model.) The analytical variances of $f_1(0)$ and $f_2(0)$ (from the information matrix method) were used in estimating the coefficient of variation of $g_1(0)$ from Equation 8, and the variances of n_1 and n_2 were estimated by assuming a Poisson distribution. Consideration of availability bias is deferred to the Discussion section.

[4] Gerrodette, T. D., and C. Perrin. 1991. Calibration of shipboard estimates of dolphin school size from aerial photographs. Admin. Rep. LJ-91-36, available from Southwest Fish. Sci. Cent., P.O. 271, La Jolla, CA 92038, 73 p.

Coefficients of variation and confidence intervals

Coefficients of variation (CV) and confidence intervals (CI) of the abundance estimates are based on the bootstrap method (Efron, 1977; Buckland et al., 1993b). The sightings associated with consecutive segments of search effort were combined to form a set of subsamples of 139 km (75 nmi) of search effort (corresponding to approximately one day of survey effort).[5] I drew subsamples randomly with replacement from this set of effort segments, and a pseudo-population size was estimated by using the same group size stratification as was used for the actual abundance estimates. For each bootstrap sample, the probability of detecting trackline groups, $g(0)$, was estimated as a random number between 0 and 1 drawn from the probability distribution of a binomial ratio with a mean and coefficient of variation equal to the estimated values. This process was repeated 1,000 times, and the CV of the estimated population size was calculated as the standard error of the 1,000 pseudo-population sizes divided by the estimated population size. Bootstrap 95% confidence intervals on the population estimates were based on the 25th and 976th ranked estimates from the bootstrap samples. Log-normal 95% confidence intervals were based on the method given by Buckland et al. (1993b) and used the bootstrap estimate of CV.

Results

During the survey approximately 10,100 km of searching effort were completed (Fig. 1), and 515 cetacean groups were seen during the sampling effort. Tracklines included 2,386 km in calm sea states (Beaufort 2 or less) and 7,696 km in rough sea states (Beaufort 3–5). During the survey, 18 cetacean species were identified (as well as at least one species that could only be identified to genus) (Table 1). More detailed data summaries for this survey are presented by Hill and Barlow (1992), including the positions and school sizes of all on- and off-effort sightings of cetaceans and pinnipeds, maps showing the distribution of sightings for each species, distributions of perpendicular distances for each species, patterns of association in mixed-species groups, summaries of searching effort completed under various conditions, and sighting rates of individual observers. The fit of the probability density functions to the distributions of perpendicular distances are illustrated by Barlow.[5]

[5] Barlow, J. 1993. The abundance of cetaceans in California waters estimated from ship surveys in summer/fall 1991. Admin. Rep. LJ-93-09, available from Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038, 39 p.

Group-size estimation

Group-size correction parameters, the slopes and intercepts (in parentheses) of $\log_{10}$-transformed regressions, were 0.922 (0.03), 1.022 (–0.03), 0.886 (0.07), and 0.777 (0.11) for the four observers who required correction. Three of these observers appear to have underestimated group size, in some cases by a large amount (a group of 500 would have been, on average, estimated as 328, 534, 283, and 152 by these four observers, respectively).

Probability of detecting trackline groups

Independent observers searched a total of 8,190 km. Approximately 7% of groups were detected only by the independent observer; however, all groups that were detected only by the independent observer were groups of less than 20 individuals and accounted for only 0.7% of the individuals that were seen on the survey. Of all groups that had less than 20 animals and were seen while the independent observer was on duty, 347 were seen by the primary observers, and 40 were seen by the independent observer.

Abundance estimation

With estimated values of $f(0)$ and $g(0)$ (Table 2), density and abundance were calculated for 19 cetacean species and 9 higher taxonomic categories (Table 3). Common dolphins were the most abundant cetaceans by a large margin. Of the two recently recognized common dolphin species (Heyning and Perrin, 1994), the short-beaked variety was much more abundant than the long-beaked variety. Blue whales were the most abundant species of large whale.

Discussion

Distribution

The distributions of cetaceans seen during this survey (Figs. 2–6) are in general agreement with the results of other studies in this area (Leatherwood et al., 1982; Dohl et al., 1986; Smith et al., 1986; Barlow, 1988; Forney et al., this issue; Dohl et al.[2,3]). However, the observed distribution of some species contradicted results of previous studies. Striped dolphins were seen rather commonly in mixed groups with short-beaked common dolphins in southern and central California between 185 and 555 km (100–300

Table 2

Estimated values of $f(0)$ and $g(0)$ for each of the species group stratifications which were chosen on the basis of Akaike's Information Criterion (AIC) minimization. Truncation distances for estimating $f(0)$ are 5.5 km for large whales and 3.7 km for all other species. Sample sizes include the total number of groups seen by the primary team, n, the number of groups seen by the primary team when an independent observer was on duty, n_1, and the number of groups seen by the independent observers but not by the primary team, n_2. NA indicates information that is not available because it could not be estimated. CV is the coefficient of variation.

Main stratum and substrata	Number of sightings			Primary observers		Secondary observers		Primary observers	
	n	n_1	n_2	$f(0)$ km^{-1}	CV $f(0)$	$f(0)$ km^{-1}	CV $f(0)$	$g(0)$	CV $g(0)$
Small delphinids (3.7 km truncation)									
group size 1–20	67	58	9	1.258	0.249	1.864	0.147	0.770	0.137
group size 21–100	58	51	0	0.944	0.336	1.864	0.147	1.000	NA
group size 101+	47	44	0	0.283	0.193	1.864	0.147	1.000	NA
Cryptic species (3.7 km truncation)									
calm seas	102	78	14	1.574	0.199	1.864	0.147	0.787	0.103
Large delphinids (3.7 km truncation)									
group size 1–20	15	14	1	0.504	0.306	1.864	0.147	0.736	0.391
group size 21+	17	17	0	0.352	NA	1.864	0.147	1.000	NA
Large whales (5.5 km truncation)									
group size 1–3	87	81	3	0.696	0.278	1.863	0.146	0.901	0.073
group size 4+	26	22	0	0.256	NA	1.863	0.146	1.000	NA
Small whales (3.7 km truncation)									
calm seas	23	19	1	0.614	0.488	1.864	0.147	0.840	0.218

nmi) from shore. Although striped dolphins were known to inhabit this area (Leatherwood et al., 1982), their frequency of occurrence was much greater than expected. Blue whales were seen primarily in southern California between 92 and 370 km (50–200 nmi) offshore. In previous years, this species was seen commonly in central California between the coast and 92 km (50 nmi) offshore (Calambokidis et al., 1990b). One species was surprising in its absence: short-finned pilot whales, *Globicephala macrorhynchus*, were previously common in southern California, especially around the Channel Islands in winter (Leatherwood et al., 1982). (Note: one group of pilot whales was seen and photographed by independent researchers between San Francisco and Monterey on 2 November 1991.[6])

Abundance

Abundance estimates from this study are also in general agreement with previous esti-

[6] Jones, P. A., and I. D. Szczepaniak. 1992. Report on the seabird and marine mammal censuses conducted for the long-term management strategy (LTMS), August 1990 through November 1991, for the U.S. Environmental Protection Agency, Region IX, San Francisco. July 1992.

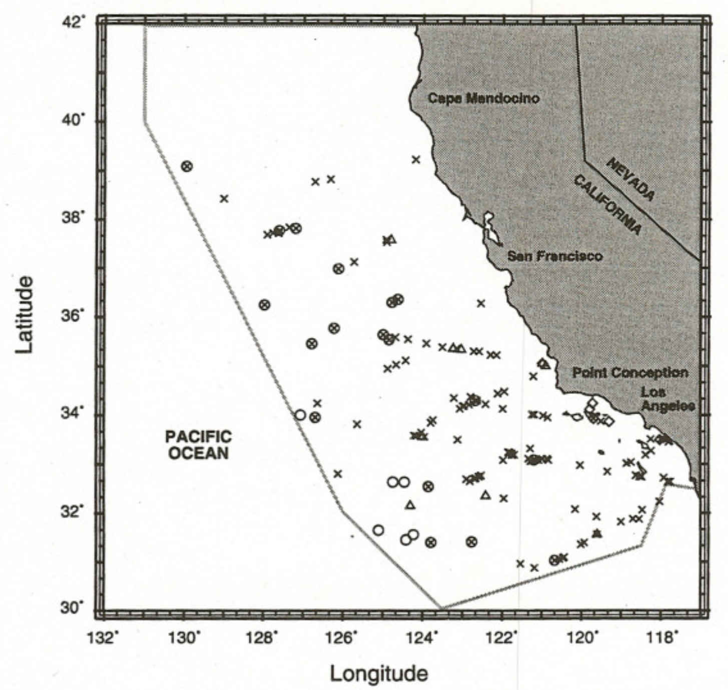

Figure 2

Locations of on-effort sightings of short-beaked common dolphins (×), long-beaked common dolphins (◇), unidentified common dolphins (△), and striped dolphins (○). Scientific names are given in Table 1.

Table 3

Number of groups seen (n), mean group size (S), density of individuals, abundance estimates (N), 95% confidence intervals (CI) on those estimates, and coefficients of variation (CV) for all species and higher taxa that were identified. Density estimates are based on lengths of transect given in the text and estimates of $f(0)$ and $g(0)$ given in Table 2. Mean group size includes only the indicated species and can therefore be less than the minimum of the group size category (which is defined based on the total number of all species present). Scientific names are given in Table 1.

						Boot strap		Log-normal	
Species strata	Number of groups n	Mean group size S	Animal density km^{-2}	Pop. size N	CV	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
Small delphinids									
short-beaked common dolphin			3.248	225,821	0.279	143,026	419,911	132,139	385,918
group size 1–20	25	11.0	0.261						
group size 21–100	52	44.7	1.274						
group size 101+	39	267.3	1.713						
long-beaked common dolphin			0.136	9,472	0.683	0	27,029	2,817	31,842
group size 1–20	1	11.8	0.011						
group size 21–100	0	0.0	0.000						
group size 101+	4	190.2	0.125						
common dolphin (unclassified)			0.148	10,286	0.815	573	37,007	2,539	41,664
group size 1–20	6	5.4	0.031						
group size 21–100	1	15.1	0.008						
group size 101+	1	661.5	0.109						
striped dolphin			0.273	19,008	0.412	8,234	45,864	8,755	41,267
group size 1–20	2	7.7	0.015						
group size 21–100	5	29.3	0.080						
group size 101+	14	77.6	0.178						
Pacific white-sided dolphin			0.177	12,310	0.537	1,888	27,965	4,590	33,010
group size 1–20	7	11.5	0.076						
group size 21–100	3	46.2	0.076						
group size 101+	2	75.4	0.025						
northern right whale dolphin			0.134	9,342	0.567	2,125	21,488	3,322	26,272
group size 1–20	10	9.9	0.094						
group size 21–100	3	9.4	0.015						
group size 101+	2	75.7	0.025						
unidentified delphinoid			0.052	3,603	0.462	1,180	6,197	1,521	8,536
group size 1–20	17	3.2	0.052						
group size 21–100	0	0.0	0.000						
group size 101+	0	0.0	0.000						
Cryptic species									
harbor porpoise[1]	31	5.0	0.758	52,743	0.682	0	147,905	15,714	177,026
Dall's porpoise	69	3.3	1.127	78,422	0.354	33,462	150,487	40,026	153,649
pygmy sperm whale	2	1.3	0.013	870	0.796	0	2,741	220	3,433
Large delphinids									
bottlenose dolphin			0.022	1,503	0.481	499	3,819	615	3,674
group size 1–20	4	2.8	0.004						
group size 21+	10	8.3	0.017						
Risso's dolphin			0.122	8,496	0.415	4,236	21,676	3,890	18,555
group size 1–20	12	8.3	0.039						
group size 21+	16	25.2	0.082						
killer whale			0.004	307	1.196	0	2,340	48	1,947
group size 1–20	3	3.7	0.004						
group size 21+	0	0.0	0.000						
Large whales									
sperm whale			0.011	756	0.493	211	1,537	303	1,886
group size 1–3	4	1.2	0.002						
group size 4+	9	6.6	0.009						

Table 3 (Continued)

Species strata	Number of groups n	Mean group size S	Animal density km^{-2}	Pop. size N	CV	Boot strap Lower 95% CI	Boot strap Upper 95% CI	Log-normal Lower 95% CI	Log-normal Upper 95% CI
Baird's beaked whale			0.001	38	1.025	0	127	7	203
group size 1–3	0	0.0	0.000						
group size 4+	1	3.7	0.001						
Bryde's whale			0.001	61	1.078	0	242	11	339
group size 1–3	1	1.9	0.001						
group size 4+	0	0.0	0.000						
Bryde's or sei whale			0.001	63	1.093	0	232	11	355
group size 1–3	2	1.0	0.001						
group size 4+	0	0.0	0.000						
fin whale			0.013	935	0.635	130	2,607	299	2,925
group size 1–3	17	1.4	0.011						
group size 4+	4	4.7	0.003						
blue whale			0.033	2,250	0.381	899	4,131	1,093	4,632
group size 1–3	36	1.6	0.026						
group size 4+	13	3.3	0.007						
humpback whale			0.009	626	0.411	196	1,133	289	1,359
group size 1–3	7	1.8	0.006						
group size 4+	3	7.3	0.003						
unidentified baleen whale			0.003	214	0.631	26	530	69	665
group size 1–3	5	1.2	0.003						
group size 4+	1	2.1	0.001						
unidentified large whale			0.009	629	0.470	167	1,306	262	1,508
group size 1–3	15	1.3	0.009						
group size 4+	0	0.0	0.000						
Small whales									
unidentified beaked whale	3	3.5	0.019	1,322	0.892	0	4,541	295	5,921
mesoplodont beaked whale	2	1.0	0.004	250	0.834	0	746	60	1,040
Cuvier's beaked whale	7	1.9	0.023	1,621	0.823	186	5,555	396	6,637
minke whale	4	1.1	0.008	526	0.971	0	2,244	106	2,596
unidentified small whale	5	1.0	0.009	645	0.767	127	2,061	170	2,446
unidentified cetacean	3	1.7	0.009	620	0.879	0	2,026	141	2,731

[1] More precise estimates for harbor porpoise are recently available in Barlow and Forney (1994).

mates (Dohl et al., 1986; Barlow, 1988; Calambokidis et al., 1990a; Dohl et al.[2,3]). This is the first cetacean survey in California waters to include the region between 277 and 555 km (150–300 nmi) offshore. The studies of Dohl et al.[2,3] included only the inshore 185 km (100 nmi) of the present study area, making direct abundance comparisons difficult. The mark-recapture population estimates of blue and humpback whales by Calambokidis et al. (1990, a and b) were based on individuals sighted near the coast. Furthermore, the estimates of Dohl et al.[2,3] do not have associated statistical confidence intervals. Hence, accurate comparisons with previous studies can be made only for the more coastal species and meaningful statistical tests of differences can be made for even fewer species. Direct comparisons with the 1991 and 1992 aerial surveys (Forney et al., this issue) are planned for future publications.

The abundance of harbor porpoise estimated for 1984 and 1985 was approximately 9,576 (CV=0.51) (Barlow [1988] his regions 1–4), which is smaller than the present estimate of 52,700 (CV=0.68). This discrepancy may be due to the inappropriate design of the present survey for a coastal species such as harbor porpoise.

Humpback whale abundance in central California was estimated as 338 based on aerial surveys from August to November of 1980–83 (Dohl et al.[3]); however, this estimate does not include a correction factor for submerged whales. Based on mark-recapture methods, the abundance of humpback whales in 1991 and 1992 was estimated to be 581 (CV=0.03).[1] This estimate is

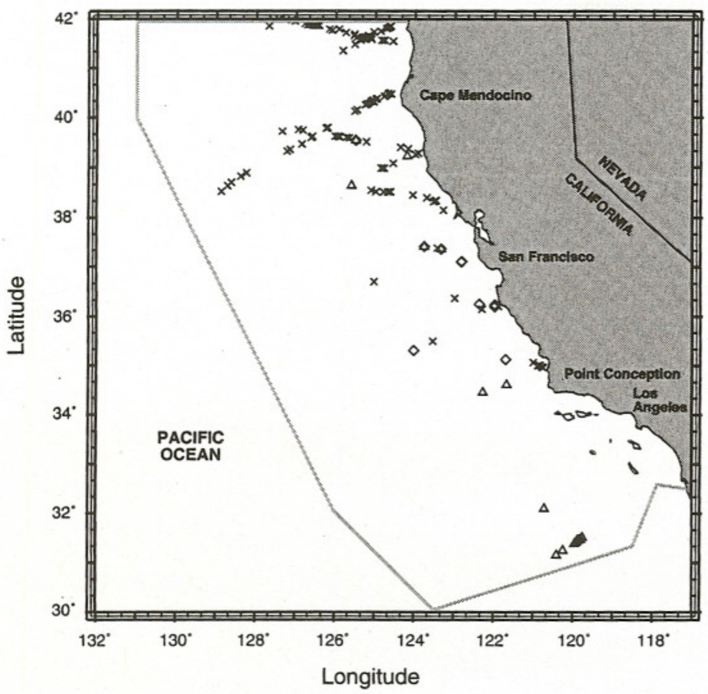

Figure 3

Locations of on-effort sightings of Dall's porpoise (×), northern right whale dolphins (△), and Pacific white-sided dolphins (◇). Scientific names are given in Table 1.

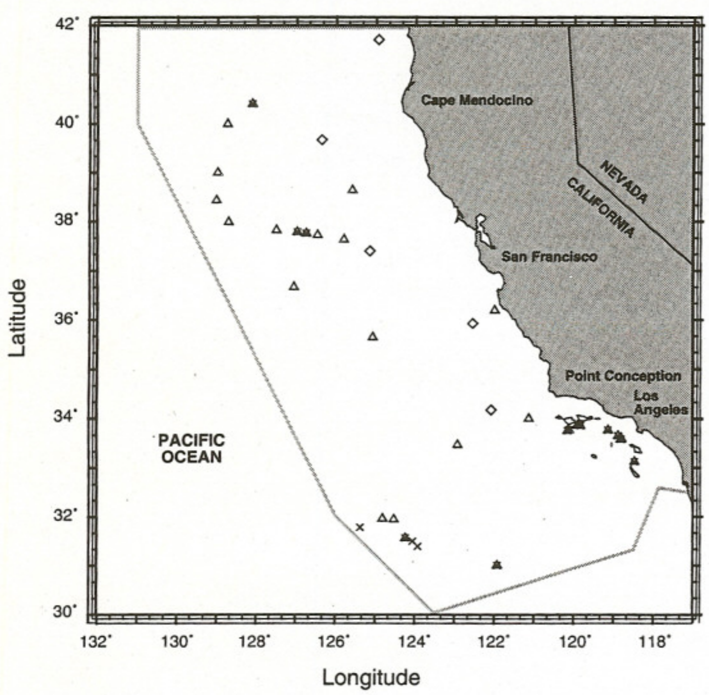

Figure 4

Locations of on-effort sightings of killer whales (◇), Risso's dolphins (△), and bottlenose dolphins (×). Scientific names are given in Table 1.

very close to the present estimate of 626 and is well within its 95% confidence interval.

For two species, new estimates of abundance appear to be substantially different from previous estimates. For the late 1970's, the combined summer and fall estimate of common dolphin abundance was 57,270 (CV=0.17) (Dohl et al., 1986). Although the methods used were very different and the area surveyed was smaller in that study, estimates for other small cetaceans are similar in the two studies. A large increase in common dolphin abundance is likely. This could have resulted as an effect of the 1991–92 El Niño. Although there were no surface temperature manifestations of El Niño in the study area at the time of the survey, it is possible that common dolphins were moving into California waters from farther south as a result of El Niño changes there. Since 1980, a decline has been noted in the abundance of the northern stock of common dolphins south of 30°N (Anganuzzi et al., 1993), and those authors hypothesize that this could have been caused by a general northward movement of that stock. This interpretation is consistent with the increases noted here, but the magnitude of the decrease in the south (from approximately 500,000 in 1980 to approximately 100,000 in 1991 [Anganuzzi et al. 1993]) is greater than the entire estimated population in California waters.

The abundance of blue whales, based on the current line-transect data (2,250), is also much higher than recent estimates made from individual-identification mark-recapture techniques (904 based on left-side photographs and 1,112 based on right-side photographs).[1] Although some mark-recapture estimates may be biased low because of geographic heterogeneity in habitat use by individual whales (Hammond, 1990), the methods used for mark-recapture should have minimized those effects.[1] South of the present study area, the abundance of blue whales was estimated to be 1,415 (CV=0.24) based on line-transect ship surveys in the eastern tropical Pacific from 1986 to 1990 (Wade and Gerrodette, 1993). The latter study included sightings made along the coast of Baja California (which probably belong to the California feeding population) as well as sightings made near the Costa Rica Dome and along the Equator (which are likely to be part of a different population; Reilly and Thayer [1990]).

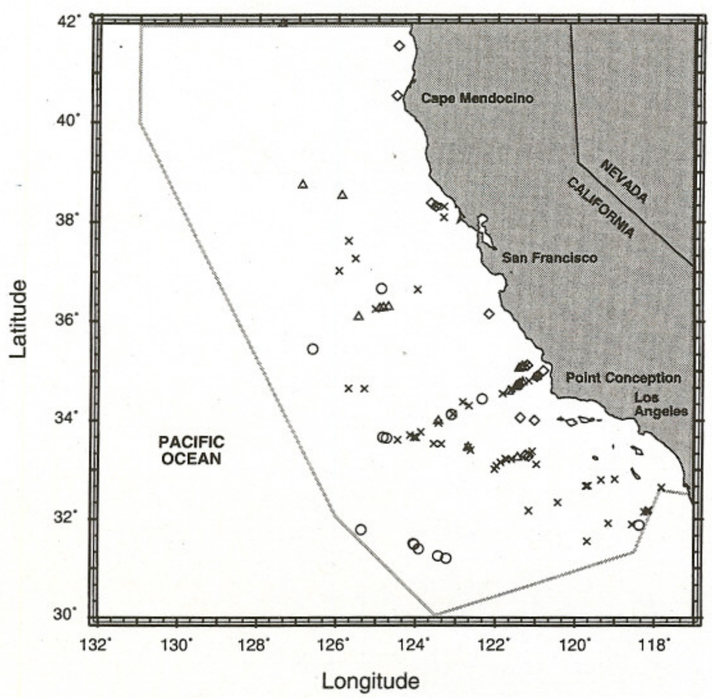

Figure 5

Locations of on-effort sightings of fin whales (△), humpback whales (◇), blue whales (×), and sperm whales (○). Scientific names are given in Table 1.

Probability of detecting trackline groups

The probability of detecting a trackline group of animals, $g(0)$, varied between 0.74 and 1.0 (Table 2). The data clearly indicated that small groups are much more likely to be missed than are large groups. This is intuitively obvious and justifies stratifying by group size when estimating $g(0)$ values. The fraction of trackline harbor porpoise seen in calm seas has been estimated previously to be 0.78 (with five observers on a similar platform in California, Barlow [1988] and 0.70 (with six observers in the Gulf of Maine, Palka [1993]). The higher value of $g(0)$ estimated here for "cryptic species" with only three observers (0.81) may be due to the inclusion of Dall's porpoise which may be easier to see or may simply be an artifact of small sample size.

These estimates of the fraction of animals seen include only animals that were available to be seen. Availability bias is likely to be large for species such as beaked whales, which have extremely long dive times, and harbor porpoise and Dall's porpoise, which have shorter dive times but seldom are seen more than 0.5 km from the ship and may therefore remain submerged during the entire time they are within visual range. Correcting for availability bias is more difficult than for perception bias. Attempts that have been made so far have involved detailed modeling of the surfacing behavior of the animal and the searching behavior of the researchers (Doi, 1971, 1974; Barlow et al., 1988; Stern, 1992; Kasamatsu and Joyce[7]). In addition, there are still problems with estimating perception bias because the methods used here assume that all animals are equally available to be seen if they surface. Heterogeneity in sightability (e.g. animals that splash vs. animals that do not) generally will result in an underestimate of the fraction missed. Additional work is needed to obtain complete estimates of the fraction of trackline animals seen for all species.

Previous studies of Dall's porpoise have shown that attraction to the vessel is a greater problem for estimating the abundance of this species than are missing trackline animals (Turnock and Boucher[8]). Turnock and Quinn (1991) estimated a correction factor of 0.2378 (CV=0.3391) to adjust Dall's porpoise abundance estimates for ship surveys (effectively then, g_0=4.2). That study was based, however, on a design that used only one observer who searched with 7× binoculars and unaided eyes. In the present study, very few Dall's porpoise appeared to be attracted to the vessel; of those sighted in calm conditions and used for abundance estimation, only 10% (9 of 88) of the Dall's porpoise groups approached the vessel to "ride the bow wave," and 89% (78 of 88) were exhibiting a "slow roll" surfacing behavior at the time they were first sighted. Because attraction to the vessel was less than in other studies and because most Dall's porpoise were sighted before showing any apparent reaction to the vessel (perhaps because 25× binoculars were used), the magnitude of bias is probably less than that estimated by Turnock and Quinn (1991).

Statistical precision

An attempt was made to account for most sources of sampling error in the bootstrap estimates of confidence intervals and coefficients of variation. However, several sources of variation could not be easily included. The process of selecting a stratification

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[7] Kasamatsu, F., and G. G. Joyce. 1991. Abundance of beaked whales in the Antarctic. Int. Whaling Comm. working paper SC/43/O12.

[8] Turnock, B. J., and G. C. Boucher. 1990. Population abundance of Dall's porpoise, *Phocoenoides dalli*, in the western North Pacific Ocean. Int. Whaling Comm. working paper SC/42/SM10.

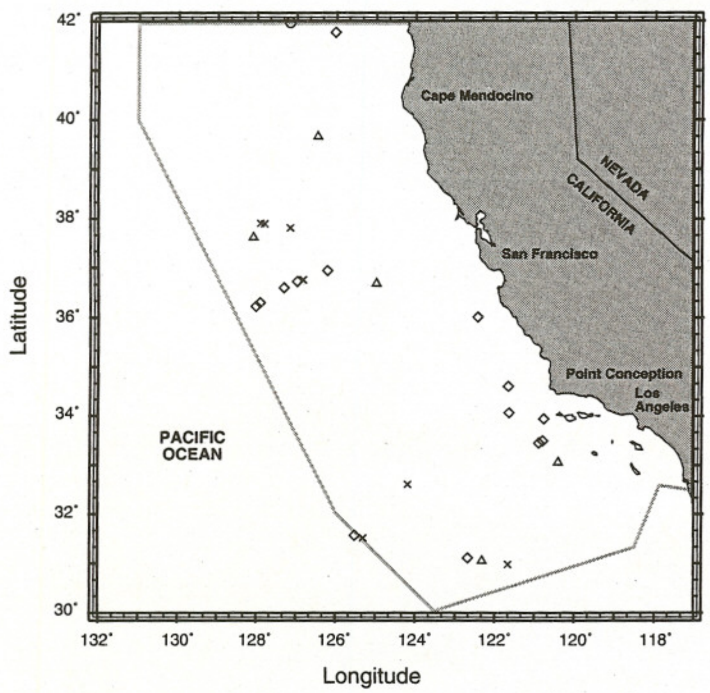

Figure 6

Locations of on-effort sightings of beaked whales of the genus *Mesoplodon* (△), Cuvier's beaked whales (◇), Baird's beaked whales (○), and unidentified beaked whales (×). Scientific names are given in Table 1.

model by minimizing AIC would have been too time consuming to include in the bootstrap procedure; hence, precision estimates are contingent on the chosen models being approximately correct. Variability in estimating mean group size was included implicitly in the Monte Carlo sampling, but it was assumed that the group size estimate for any given group was accurate. Pooling of data to estimate $f(0)$ and $g(0)$ introduces a bias (to the extent that individuals differ within a pooled group) which is not accounted for in precision estimates. All of these factors would tend to result in precision being overestimated. Overall, coefficients of variation are likely to be too small and true confidence intervals are probably wider than those reported.

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Appendix

To estimate the total fraction of trackline groups missed owing to perception bias requires that the survey be designed with two teams of completely independent observers. To be independent, both teams would have to search simultaneously, not notifying or cueing each other until a group of animals had passed abeam of the vessel and were clearly missed by the other team. This approach was deemed infeasible because of the need to approach groups to estimate group size and species composition. If the vessel was not turned until after all groups had passed abeam, a very large percentage of those groups would not be relocated. The probability of relocation would depend on group size and species composition. These factors would add considerably to the difficulty in interpreting such survey data.

Instead, the survey was designed to use a single, conditionally independent observer who was aware of sightings made by the primary team, but who did not reveal the presence of a group until that group was clearly missed by the primary team. Data from the conditionally independent observer are used to make an estimate of the probability that the primary survey team detected a trackline group.

The expected number of groups, n, seen very close to the transect line, say within distance δ, can be estimated as

$$n_\delta = \frac{n_\omega \int_0^\delta g(x)h(x)dx}{\int_0^\omega g(x)h(x)dx}, \tag{3}$$

where n_ω is the total number of groups seen within the truncation distance ω, $g(x)$ is the probability of seeing a group that is at perpendicular distance x, and $h(x)$ is the probability that a group will be at perpendicular distance x (usually assumed to be 1.0 for primary observers at all x). As δ approaches zero distance, the above equation can be reexpressed as

$$n_\delta = \frac{n_\omega g(0)h(0)\delta}{\int_0^\omega g(x)h(x)dx}, \tag{4}$$

which, from the line-transect definition of $f(0)$ (Burnham et al., 1980), can be simplified to

$$n_\delta = n_\omega f(0)\delta. \tag{5}$$

The probability of a trackline group being seen by the primary observers can be expressed as

$$g_1(0) = \frac{n_{1\delta}}{n_{1\delta} + n_{2\delta} / g_2(0)}, \tag{6}$$

where the subscript 1 refers to sightings made by the primary observers and subscript 2 refers to sightings missed by the primary observers but seen by the independent observer. Combining Equations 5 and 6 and simplifying results in

$$g_1(0) = \frac{n_{1\omega} f_1(0)}{n_{1\omega} f_1(0) + n_{2\omega} f_2(0) / g_2(0)}. \tag{7}$$

Because there were three primary observers and only one independent observer, $g_1(0)$ should be greater than or equal to $g_2(0)$. Thus

$$g_1(0) \le 1 - \frac{n_{2\omega} f_2(0)}{n_{1\omega} f_1(0)}. \tag{8}$$

This equation was applied (substituting = for ≤) to the subset of data collected while an independent observer was on duty to estimate the probability that a group on the trackline would have been seen by the primary observer team. This quantity will be biased and overestimated to the extent that $g_1(0)$ is greater than $g_2(0)$.

The coefficient of variation for $g_1(0)$ can be approximated as

$$CV(g_1(0)) = \frac{mCV(m)}{1-m}, \tag{9}$$

given

$$m = \frac{n_{2\omega} f_2(0)}{n_{1\omega} f_1(0)}, \tag{10}$$

and

$$CV(m) = \sqrt{CV^2(n_{1\omega}) + CV^2(n_{2\omega}) + CV^2(f_1(0)) + CV^2(f_2(0))}. \tag{11}$$