Preliminary Winter Abundance Estimates for Cetaceans Along the California Coast Based on a 1991 Aerial Survey

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ABSTRACT

We present the results of an aerial line transect census of cetaceans along the California coast during March and April 1991. This survey was the first of two aerial surveys designed to estimate cetacean abundance within approximately 100-150 n.miles (185-278km) of the coast. A primary team of two observers searched through bubble windows which allowed an unobstructed view of the trackline directly underneath the aircraft. A third, semi-independent observer searched through a belly window and made observations of animals that were missed by the primary team. A total of 155 sightings were made of a minimum of 14 cetacean species (some animals could only be identified to higher taxa). Of those groups that were on the trackline, the fraction seen by at least one team, $g(0)$, was estimated to be at least 0.821 for groups of ≤10 small cetaceans, 0.956 for groups of >10 small cetaceans and 0.977 for medium and large cetaceans. Estimates of abundance using these correction factors are 277,783 common dolphins (CV=0.46), 10,506 Risso's dolphins (CV=0.48), 46,334 Pacific white-sided dolphins (CV=0.78), 13,362 northern right whale dolphins (CV=0.41), 1,236 harbor porpoise (CV=0.45), 5,832 Dall's porpoise (CV=0.28), 4,011 bottlenose dolphins (CV=0.62), 117 minke whales (CV=0.68), 1,720 gray whales (CV=0.42), 405 humpback whales (CV=0.42), 87 killer whales (CV=0.76), 56 sperm whales (CV=1.07), 505 beaked whales (CV=0.44) and 59 fin/sei/Bryde's whales (CV=1.00).

KEYWORDS: SURVEY-AERIAL; NORTH ATLANTIC; ASSESSMENT; COMMON DOLPHIN; RISSO'S DOLPHIN; WHITE-SIDED DOLPHIN; RIGHT WHALE DOLPHIN; HARBOUR PORPOISE; DALL'S PORPOISE; BOTTLENOSE DOLPHIN; MINKE WHALE; GRAY WHALE; HUMPBACK WHALE; KILLER WHALE; SPERM WHALE; BEAKED WHALE; FIN WHALE; SEI WHALE; BRYDE'S WHALE.

INTRODUCTION

Under the 1988 Amendment to the US Marine Mammal Protection Act, incidental mortality of marine mammals in commercial fishing operations was authorised for the five-year period 1988–93. During this period, additional data had to be collected on the affected marine mammal species in order to provide a basis for future management decisions. Recent estimates of incidental marine mammal mortality in US west coast gillnet fisheries have been obtained through the National Marine Fisheries Service (NMFS) observer program, which began in 1990 (Perkins *et al.*, 1992; Lennert *et al.*, 1993); however, recent estimates of cetacean abundance in the fishery area are lacking. For many of the common species of cetaceans in California, the only available population estimates are over 10 years old (Dohl *et al.*, 1978; 1983) and statistical confidence limits are available only for common dolphins, *Delphinus delphis* (Dohl *et al.*, 1986). For future management considerations, new abundance estimates, including statistical confidence limits, are necessary.

In 1991 and 1992, NMFS conducted a series of two aerial surveys (March-April 1991 and February-April 1992) and one ship survey (August-November 1991) along the California coast. Standard line transect methods were used from both platforms, and the surveys were designed to yield a target level of precision (coefficient of variation (CV) < 36%) in the abundance estimates of the most common species. Due to the pronounced seasonality in the California Current, and evidence of seasonality in the abundance of common dolphins (Dohl *et al.*, 1986), separate abundance estimates were deemed appropriate for winter (cold water) and summer (warm water) conditions. The survey periods were chosen based on climatic atlases of the California coast which show that, on average, March/April have the coldest sea surface temperatures, and September/October the warmest.

This paper presents the results of the 1991 aerial survey. Although the results are preliminary (the survey design indicated that two aerial surveys would be required to obtain an acceptable level of precision) we believe it is important to present them at this time given the lack of recent estimates for the majority of cetacean species in California. Final results will be presented for the two combined aerial surveys and for the ship survey when all data have been compiled and analysed.

SURVEY METHODS

Study area
The study area (Fig. 1) extends beyond the continental shelf edge along the California coast, to roughly the 3,000-4,000m depth isobath. This study area was defined on the basis of fisheries that are known to take marine mammals; the boundaries do not reflect the distributional boundaries of any known marine mammal populations. It encompasses all of the known coastal gillnet fishing area, based on effort data from the California Department of Fish and Game (CDFG). In central and northern California, this extends from the coast to approximately 100 n.miles (185km) perpendicular distance offshore. In the Southern California Bight, the study area is bounded by the US/Mexico border in the South and extends out to approximately 150 n.miles (278km) offshore. It then follows a straight line northwestward to a point 100 n.miles (185km) off Point Conception, connecting with the outer boundary of the central California area (see Fig. 1).

Transects
A total of 154 transects form two approximately uniform, overlapping grids with lines spaced roughly 45–50 n.miles (83–93km) apart. This yields an overall grid with lines spaced approximately 22–25 n.miles (41-46km) apart (Fig. 1). The location of the grid was chosen without reference to
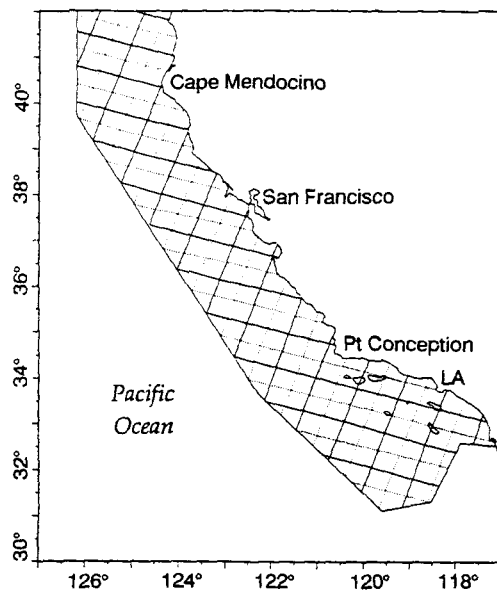
Fig. 1. Study area with two overlapping transects grids. The solid line represents Grid 1, the dotted line Grid 2.

specific areas or topographical features. They are oriented to reduce sun glare during the surveys while providing approximately uniform coverage of the study area and minimising non-survey travel time. Survey direction along transects was chosen to minimise glare, generally in a northeast or northwest direction. To avoid potential differences in regional coverage, an attempt was made to complete all transects of the first grid, providing coarse coverage of the entire study area, before beginning the second grid.

Equipment and procedures

The survey platform was a twin-engine turbo-prop *DeHavilland* Twin Otter, with capacity for five scientists and two pilots. Surveys were conducted at approximately 700ft (213m) altitude and 100 knots (167–185km/hr) airspeed. The surveys were designed to obtain abundance estimates for cetaceans, but pinnipeds were recorded when seen farther than 10km from land to provide information on their offshore distribution. Turtle sightings were also recorded. Two 'primary' observers searched through bubble windows on the left and right sides of the aircraft. These windows allowed viewing to the side and directly beneath the aircraft with at least 10° of overlap between sides. To achieve higher sighting efficiency near the trackline, observers searched for cetaceans only out to 1,000m perpendicular distance (12° declination angle).

A round 18in (46cm) viewing hole in the belly of the aircraft was used for monitoring of the trackline by a 'secondary' observer. This viewing port provided visibility of the trackline between 55° left and 55° right declination, overlapping considerably with the primary observers. The secondary observer reported cetaceans missed by the primary team, so that the fraction of animals missed on the trackline could later be estimated. A fourth person recorded all sighting, effort and environmental data.

Approximately every 30 minutes, the five scientists rotated between these four active positions and one resting position. All observers had previous experience in identifying cetacean species from aerial and/or shipboard surveys.

Data recording

A laptop computer connected to a *LORAN* navigational receiver was used to record survey data. During the survey, a continuous record of position (updated every few seconds), altitude, airspeed and survey conditions was maintained. Conversation in the aircraft was recorded on a central cassette recorder to provide a complete record of activities. In addition, observers recorded individual sighting information into personal notebooks.

Environmental conditions

Environmental conditions were recorded throughout the survey whenever changes occurred. Sea state was recorded using the Beaufort scale; surveys were conducted only in sea states 0–4. Sky condition was recorded as a percentage of cloud cover between the viewing area and the sun. Glare (due to sun or cloud reflections) was recorded separately by each observer as a percentage of the viewing area obscured. Water colour was categorised as dark blue, light blue, or green, based on comparison with colour plates of known hue and intensity. Presence/absence data was recorded for haze below the aircraft and for kelp on the water surface.

Sighting procedures

When sightings were made, the aircraft's position was recorded along with information on species identification, the observer who made the sighting and the declination angle to the center of the school (measured with a clinometer). All observers then concentrated on identifying the sighted species and estimating school size while the aircraft circled over the animals. School size was defined to include the animal(s) initially sighted as well as any additional subgroups judged to belong to the same school (i.e. travelling in the same direction or belonging to the same feeding aggregation). Fluorescein dye markers were dropped as necessary to aid in the relocation of animals. Navigation and position features in the data entry program were also used to relocate animals, and to return to the same location on the trackline after all sighting information had been collected. Any additional schools sighted while diverted from the transect were recorded as 'off effort' sightings and were not used for abundance estimation.

Species identification was discussed and agreed upon by all observers. When it was not possible to identify animals with certainty, a code or combination of codes reflecting the possible identification of the animals was entered. A flowchart of the species codes used is shown in Fig. 2. High, low and best estimates of school size were recorded separately by all observers who were able to obtain an estimate. To avoid influencing each other, the observers wrote their estimates into personal notebooks without discussing them. At the end of the day, the survey leader entered all estimates into the data files.

Sighting procedures were essentially the same for the primary and secondary observers, except that the secondary observer waited approximately 10 seconds after sighting animals before announcing them, in order to ensure that they had passed the field of view and were missed by the primary team. Additionally, due to space

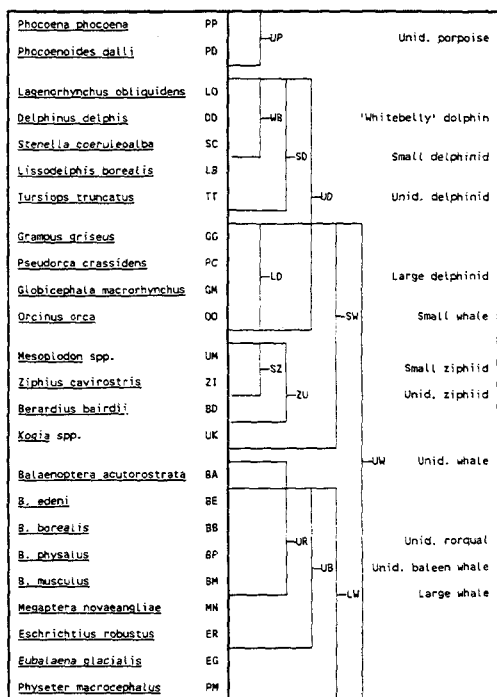| Phocoena phocoena | PP | |
Phocoenoides dalli	PD	—UP Unid. porpoise
Lagenorhynchus obliquidens	LO	
Delphinus delphis	DD	—WB 'Whitebelly' dolphin
Stenella coeruleoalba	SC	—SD Small delphinid
Lissodelphis borealis	LB	
Tursiops truncatus	TT	—UD Unid. delphinid
Grampus griseus	GG	
Pseudorca crassidens	PC	—LD Large delphinid
Globicephala macrorhynchus	GM	
Orcinus orca	OO	—SW Small whale
Mesoplodon spp.	UM	—SZ Small ziphiid
Ziphius cavirostris	ZI	—ZU Unid. ziphiid
Berardius bairdii	BD	
Kogia spp.	UK	
Balaenoptera acutorostrata	BA	—UW Unid. whale
B. edeni	BE	
B. borealis	BB	
B. physalus	BP	—UR Unid. rorqual
B. musculus	BM	—UB Unid. baleen whale
Megaptera novaeangliae	MN	—LW Large whale
Eschrichtius robustus	ER	
Eubalaena glacialis	EG	
Physeter macrocephalus	PM	

Fig. 2. Flowchart of species identification codes used during the 1991 aerial survey. Not all species were seen.

limitations in the belly viewing port, the secondary observer estimated sighting angles from marks previously applied to the window, rather than using a clinometer.

ANALYTICAL METHODS

Data stratification

The study area was divided into four *a posteriori* geographic areas based on survey coverage and species distributions. This was necessary because we were not able to complete both grids in all areas and the resulting coverage was not uniform throughout the study area. As species distributions were also not uniform, it was inappropriate to estimate abundances over the entire region.

Although environmental conditions such as sea state and percentage of cloud cover were recorded throughout the survey and have been shown to influence cetacean sighting rates (Holt and Cologne, 1987; Forney *et al.*, 1991), it was not possible to stratify the data by these criteria due to insufficient sample sizes. It is expected that addition of data from the second survey year will provide sufficient information to evaluate the effects of environmental conditions.

Sightings of unidentified species have either been excluded from abundance calculations (Wade and Gerrodette, 1992), or they have been assigned to individual species based on the proportion of sightings of each species (Holt and Sexton, 1989; Wade and Gerrodette, 1993). Neither approach is satisfactory for this analysis due to the small number of sightings made during

the survey and the non-uniform distribution of some species throughout the study area. To maximise sample sizes without relying on imprecise estimates of species proportions, sightings of unidentified species were assigned a species code based on the geographically closest identified sighting of a candidate species (see Fig. 2). For example, a school of dolphins identified as 'whitebellies' (indicating they were either Pacific white-sided (*Lagenorhynchus obliquidens*), striped (*Stenella coeruleoalba*) or common dolphins), was assigned to one of these three based on the identity of the species which had the closest identified sighting. Due to the rarity of beaked whale sightings, and the general difficulty in resighting and identifying them to the species level during surveys, only a combined abundance estimate was obtained for this group.

The small number of sightings also made it necessary to pool distributions of perpendicular sighting distances to estimate the detection probability density function for line transect calculations. Other researchers have pooled across species or species stocks with similar sighting characteristics (Holt and Sexton, 1989; Wade and Gerrodette, 1992). Sighting characteristics are generally evaluated based on body size, group size, behaviour, associated animals and other sighting cues. In particular, group size is known to influence detectability of groups (Drummer, 1985; Holt and Sexton, 1989), so only species with similar group sizes should be pooled.

Preliminary groups were created based on considerations of school size, body size and behaviour. These groups were then evaluated using a Kolmogorov-Smirnov test, and only if distributions of perpendicular distance were not significantly different from one another were the groups pooled. This resulted in the following three species/group size categories for abundance estimation: (1) small cetacean groups with 1–10 animals; (2) small cetacean groups with more than 10 animals; and (3) medium and large cetaceans. The species in these groups are given in Table 1.

Table 1

Assignment of species to three species/group size categories for estimation of f(0) and g(0). N = number of sightings in each category.

Species	Group size	N	f(0)	g(0)
Small cetaceans				
Delphinus delphis				
Grampus griseus	1-10	63	4.15	0.821
Lagenorhynchus obliquidens				
Lissodelphis borealis				
Phocoena phocoena	>10	26	2.37	0.956
Phocoenoides dalli				
Tursiops truncatus				
Large cetaceans				
Balaenoptera acutorostrata				
Eschrichtius robustus				
Megaptera novaeangliae	1-10	37	2.32	0.977
Orcinus orca				
Physeter macrocephalus				
Balaenoptera sp.				
Ziphiid whales				

In summary, the data for each species were divided into either four or eight strata, defined by four areas and one or two group size categories. Species-specific abundances were calculated separately for each stratum and then combined to obtain overall population estimates.

Abundance estimation

Line transect methods (Burnham *et al.*, 1980) were applied to estimate abundances separately for each stratum. A modification of the standard formula used to estimate the density of animals, corrected for the probability of missing animals on the trackline (Buckland *et al.*, 1993), was used here to estimate the abundance of each species:

$$N = \sum_{j=1}^{3} \sum_{i=1}^{4} \frac{n_{i,j} s_{i,j} f_j(0)}{2 L_i g_j(0)} A_i, \tag{1}$$

where

N = estimate of the total number of animals of the species in the study area;

$n_{i,j}$ = number of sightings of the species in Area i and species/group size category j;

$s_{i,j}$ = average group size of the species in Area i and species/group size category j, calculated as the total number of animals in all groups divided by the number of groups sighted;

$f_j(0)$ = the probability density function evaluated at zero perpendicular distance for species/group size category j;

$g_j(0)$ = the probability of detecting a group of animals on the trackline for species/group size category j;

L_i = the length of transect surveyed in Area i (in km);

A_i = the size of Area i (in km^2).

Values for $f(0)$ were obtained for each species/group size category by fitting the distribution of all perpendicular sighting distances (primary and secondary) to the Hazard rate model with the program *HAZARD* (Buckland, 1985).

Correction for missed animals, $g(0)$

Standard line transect theory generally sets $g(0) = 1$, assuming that all animals on the trackline are seen. However, in aerial surveys for cetaceans, animals on the trackline are likely to be missed due to two factors: (1) animals at the surface may not be seen by the observers; and (2) animals which are submerged when the aircraft passes cannot be seen by observers. These two types of visibility bias have been called perception bias and availability bias, respectively (Marsh and Sinclair, 1989).

Availability bias has been corrected in the analysis of harbor porpoise line transect data, based on studies of dive patterns of individual animals (Barlow *et al.*, 1988; Calambokidis *et al.*, 1992). However, the proportion of time a school is visible will depend not only on dive patterns of individuals, but also on the size of the group (Holt and Cologne, 1987). Separate correction factors for different species and/or school sizes are difficult and expensive to obtain, and are not currently available. In this analysis, no correction for availability bias could be made.

Perception bias in line transect surveys has been addressed through independent observer experiments, which use additional observers on secondary platforms, such as additional aircraft, vessels or land-based observation points (Hiby and Hammond, 1989; Calambokidis, 1990), or add a second observer team on a single survey platform (Butterworth and Borchers, 1988; Hiby and Hammond, 1989; Øien, 1990).

In this study, the first approach was not feasible due to the high cost and logistic problems involved in having a second aircraft or vessel nearby to identify missed animals. Furthermore, the need to circle over each group of animals sighted for identification and enumeration made it impossible to have two fully independent observer teams within the aircraft. For these reasons, we opted for a partially independent observer design, wherein the secondary observer called out sightings only after they had been missed by the primary team. This enables estimation of a maximum correction factor for the fraction of animals missed by both teams.

The fraction of animals seen on the trackline by both teams combined, $g_{Tot}(0)$, can be expressed as:

$$g_{Tot}(0) = g_P(0) + g_S(0)(1 - g_P(0)) \tag{2}$$

where the subscripts P and S represent the primary and secondary teams, respectively. Although both $g_{Tot}(0)$ and $g_S(0)$ are unknown, the ratio $g_{Tot}(0)/g_P(0)$ can be estimated as:

$$\frac{g_{Tot}(0)}{g_P(0)} = \frac{n_{Tot} f_{Tot}(0)}{n_P f_P(0)} \tag{3}$$

where

n_{Tot} = number of sightings made by the primary and secondary teams combined;

n_P = number of sightings made by the primary team;

$f_{Tot}(0)$ = probability density function evaluated at zero perpendicular distance for primary and secondary sightings combined;

$f_P(0)$ = probability density function evaluated at zero perpendicular distance for primary sightings.

We assume that the secondary observer misses no more than the primary observers on the trackline ($g_S(0) \geq g_P(0)$). Therefore, the following inequality, in terms of the known ratio $g_{Tot}(0)/g_P(0)$, can be derived from Equation (2) for the expected fraction of animals on the trackline seen by at least one observer team:

$$g_{Tot}(0) \geq \left(2 - \frac{g_{Tot}(0)}{g_P(0)}\right) \frac{g_{Tot}(0)}{g_P(0)} \tag{4}$$

The two sides are equal when $g_S(0) = g_P(0)$. Using the above equations, the overall probability of detecting a group of animals on the trackline, $g_{Tot}(0)$, was estimated for each of the three species/group size categories. Because the view of the trackline from the belly (secondary) observer position is better than from the side (primary) positions, $g_{Tot}(0)$ is expected to represent the minimum proportion seen.

Variance estimation

Variance in the abundance estimates was calculated using bootstrap techniques applied to the complete data set. The data were subdivided by area into segments of effort of equal length. To investigate possible effects of the choice of segment length on estimates of variance, values of 5km, 10km, 15km and 20km were tested. The segments were drawn randomly with replacement until the total number of kilometers actually surveyed in each area was reached. This process was repeated 1,000 times for each segment length.

Each replicate was treated and analysed as a separate survey. Sightings were first stratified into the three above species/group size categories. Individual values for n and s were calculated, and $f(0)$ was estimated with the program *HAZARD*. The correction factor $g(0)$ estimated for the actual survey data was used for all bootstrap calculations, and was assumed to be known without error. Uncorrected (assuming $g(0)=1$) and corrected (using the estimated correction factor $g(0)$) abundance estimates for each species were then calculated for each replicate. The variance, coefficient of variation and percentile confidence limits (Buckland, 1984) were obtained from the distribution of the 1,000 bootstrap abundance estimates using standard formulae.

RESULTS

A summary of all completed survey effort, stratified by Beaufort sea state and percentage cloud cover, is shown in Table 2. Due to unusually stormy weather during the survey period, only approximately 85% (5,309km) of transect Grid 1 and 27% (1,724km) of Grid 2 were completed, for a total of 7,033km. Fig. 3 shows the completed transects and the four *a posteriori* areas used for stratification. Approximately uniform effort was achieved within each area stratum. A total of 126 cetacean sightings were made while on effort (actively searching), and an additional 29 sightings were made while off effort (in transit or circling). The locations of all 155 cetacean sightings made during the survey are plotted in Fig. 4. Sighting information stratified by area and species is summarised in Table 3.

Positive species identification was not possible for 21 of the 126 'on effort' sightings. Four of these sightings were identified as ziphiid whales, for which a combined abundance estimate will be obtained, and no individual species assignment is required. For the remaining 17

Table 2

Survey effort (in kilometers) stratified by sea state and % cloud cover.

	Beaufort sea state				
% Cloud cover	0&1	2	3	4	Total
0-24	211	911	1,917	1,339	4,378
25-49	26	66	96	85	273
50-74	45	58	326	241	670
75-100	76	129	978	529	1,712
Total	358	1,164	3,317	2,194	7,033

Fig. 4. Locations of all 155 cetacean sightings made during the survey. The 126 'on effort' sightings (used in the abundance estimation) are shown by squares, and the 29 'off effort' sightings (made while circling or in transit) are shown with plus signs.

sightings, assignments to individual species are shown in Table 4. In one case, the animals were identified as belonging to the genus *Balaenoptera* and could be narrowed down to one of three species: fin whale (*B. physalus*), sei whale (*B. edeni*) or Bryde's whale (*B. borealis*). However, none of these three species were otherwise sighted during the survey, and no individual species could be assigned.

Distributions of perpendicular distance from the trackline for individual species (based on both primary and secondary sightings) were combined into the three species/group size categories defined above (Analytical Methods section), based on similarities in the distributions. The Hazard model fit to the perpendicular distance distributions for each of the three categories is shown in Fig. 5. The probability of detecting a group of animals on the trackline, $g(0)$, was estimated separately for the three species/group size categories. Table 1 shows the assignment of individual species to the three groups, along with the estimates of $f(0)$ and $g(0)$.

Corrected and uncorrected abundance estimates along with estimates of precision are shown in Table 5. The chosen length of the sampling unit (5, 10, 15 or 20km) for the bootstrap simulation did not appear to influence the estimates of precision (Fig. 6), although for two species, the smallest segment length produced slightly different values than the other three. The percentile confidence limits and the CVs shown in Table 5 are taken from the bootstrap with a segment length of 20km.

DISCUSSION

The estimates of abundance obtained from this survey are preliminary. They represent data from the first of two surveys which were designed to yield a combined level of
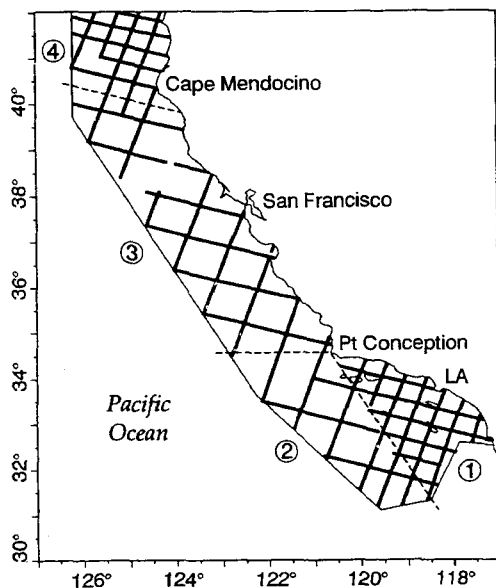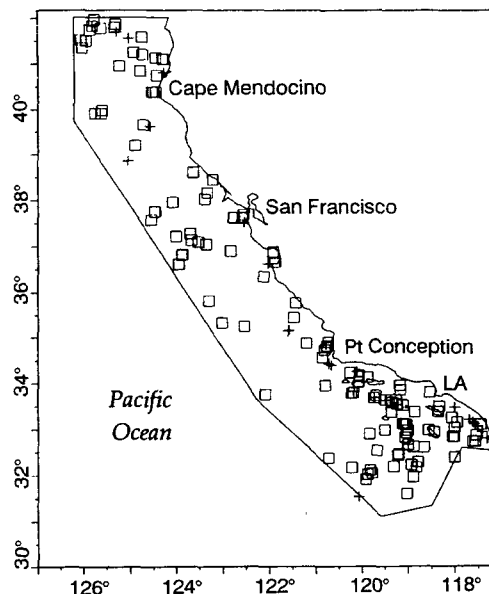

Fig. 3. Completed transects (solid lines) and *a posteriori* geographic strata (separated by dashed lines) used in the analysis. Area numbers are shown in circles.

Table 3

Summary of on effort sighting information for all species seen by area. Survey effort is 1,862km for Area 1, 1,362km for Area 2, 2,552km for Area 3 and 1,290km for Area 4. Multi-species sightings are listed once for each species, so the totals are higher than the actual number of sightings.

	No. of sightings by Area					Group size range		No. of sightings by Area					Group size range
	1	2	3	4	All			1	2	3	4	All	
Common dolphin (D. delphis)	11	3	-	-	14	9-2,525	Minke whale (B. acutorostrata)	1	-	1	1	3	1
Risso's dolphin (G. griseus)	8	1	1	-	10	4-59	Gray whale (E. robustus)	7	-	6	2	15	1-10
Pacific white-sided dolphin (L. obliquidens)	2	2	3	1	8	1-848	Humpback whale (M. novaeangliae)	-	-	2	3	5	1-2
							Killer whale (O. orca)	-	1	-	1	2	1
Northern right whale dolphin (L. borealis)	14	2	4	2	22	1-83	Sperm whale (P. macrocephalus)	-	-	1	-	1	1
Harbor porpoise (P. phocoena)	-	-	7	5	12	1-2	Ziphiid whales Mesoplodon sp.	-	-	1	1	2	1-2
Dall's porpoise (P. dalli)	4	1	11	4	20	1-6	Z. cavirostris	-	1	-	1	2	1-5
							Unid. Ziphiid	-	1	-	1	2	1-2
Bottlenose dolphin (T. truncatus)	4	-	1	-	5	1-51	Unid. whale	1	1	3	1	6	1-2
Unid. dolphin/porpoise	3	3	4	1	11	1-9							
All small cetaceans:	46	12	31	13	102	1-2,525	**All large cetaceans:**	9	4	14	11	38	1-10

Table 4

List of unidentified sighting locations and assignment to individual species for the analysis. Assignment was selected from all species which could not be ruled out based on characteristics seen. See Fig. 2 for key to codes. In two cases, it was not possible to assign the sighting to a single species (see Results).

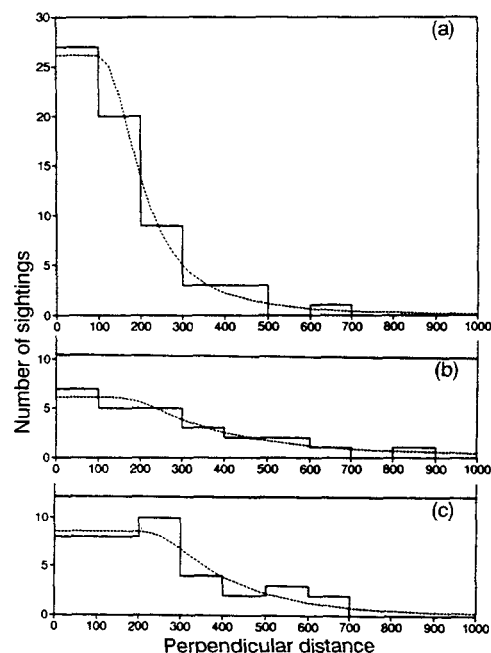| Latitude	Longitude	No. animals	Code(s)	Assigned species
Small Cetaceans				
31°36.24'N	118°59.65'W	4	DD/LO	L. obliquidens
32°16.94'N	118°44.93'W	2	WB/PD/TT	P. dalli
32°39.63'N	118°58.22'W	1	TT/SZ	T. truncatus
32°06.05'N	119°47.09'W	6	SD/PD	L. obliquidens
33°57.13'N	120°45.68'W	1	WB	D. delphis
33°38.31'N	119°12.92'W	1	SD	D. delphis
36°20.16'N	122°04.96'W	1	WB	L. obliquidens
37°05.32'N	123°29.94'W	2	SD/UP	P. dalli
38°36.19'N	123°35.73'W	9	SD	L. obliquidens
39°58.25'N	125°33.18'W	8	WB	L. obliquidens
41°51.96'N	125°15.15'W	2	LO/PD	P. dalli
Large Cetaceans				
31°57.84'N	118°51.04'W	2	BB/BE/BP	Balaenoptera sp.
31°54.71'N	119°52.73'W	1	SZ/UK	Unid. Ziphiid
34°52.49'N	121°09.66'W	1	LW	E. robustus
36°48.22'N	123°50.91'W	1	LW	M. novaeangliae
39°11.46'N	124°51.43'W	1	UB	M. novaeangliae
40°22.90'N	124°24.18'W	1	LW	E. robustus

Fig. 5. Distribution of perpendicular sighting distances (100m intervals; solid line) and Hazard model fit (dotted line) for (A) small cetaceans in groups ≤10, (B) small cetaceans in groups >10, and (C) medium and large cetaceans.

precision in the abundance estimate corresponding roughly to a coefficient of variation of 0.36 for the common species. As expected, precision is lower than this after just one survey. However, these new abundance estimates are believed to be superior to other currently available estimates (Dohl et al., 1978; 1983) for two reasons: (1) previous estimates do not include levels of precision; and (2) previous estimates are based on data which were collected over 10 years ago, and species distributions and abundances may have changed. For example, short-finned pilot whales, Globicephala macrorhynchus, which formerly were seen regularly along the California coast, were not sighted at all during this survey. Both of these

factors introduce uncertainty which makes these previous estimates less useful for management purposes.

Although the variability in the presented estimates is quite large (CVs ranging from 0.28 to 1.07), it is likely to decrease considerably with data from the second survey,

Table 5

Uncorrected (U) and corrected (C) abundance estimates (N) for all cetacean species sighted during the 1991 aerial survey in California. Bootstrap estimates of precision are presented in terms of the 95% confidence limits and the coefficients of variation (CV) for the bootstrap simulations with segments of 20km length. The correction factor is assumed to be known without error.

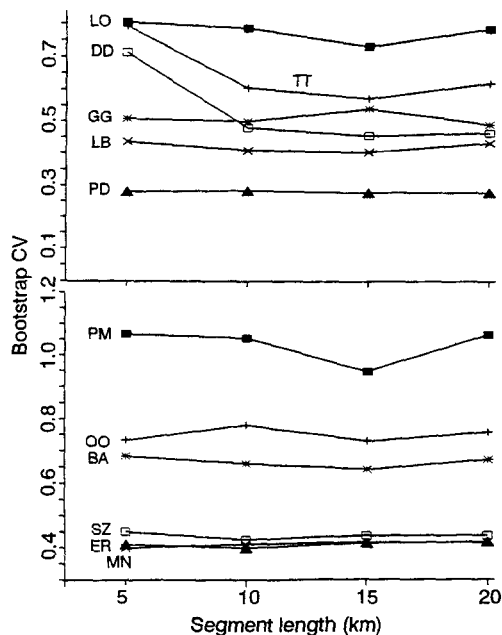| Species		N	L95%	U95%	CV
D. delphis	U	265,446	84,626	581,711	0.46
	C	277,783	88,837	608,516	0.46
G. griseus	U	9,807	3,109	23,564	0.49
	C	10,506	3,488	25,074	0.48
L. obliquidens	U	43,905	4,386	143,361	0.78
	C	46,334	5,228	150,241	0.78
L. borealis	U	11,820	5,130	26,659	0.43
	C	13,362	6,138	29,396	0.41
P. phocoena	U	1,014	290	2,092	0.45
	C	1,236	353	2,549	0.45
P. dalli	U	4,786	2,659	7,786	0.28
	C	5,832	3,240	9,487	0.28
T. truncatus	U	3,811	161	9,578	0.62
	C	4,011	196	10,038	0.62
B. acutorostrata	U	114	0	278	0.68
	C	117	0	285	0.68
E. robustus	U	1,680	507	3,324	0.42
	C	1,720	519	3,404	0.42
M. novaeangliae	U	395	110	776	0.42
	C	405	113	795	0.42
O. orca	U	85	0	222	0.76
	C	87	0	227	0.76
P. macrocephalus	U	55	0	210	1.07
	C	56	0	215	1.07
Beaked whales	U	493	147	1,017	0.44
	C	505	151	1,041	0.44
Fin/Sei/Bryde's whale	U	58	0	210	1.00
	C	59	0	215	1.00

Fig. 6. Coefficients of variation (based on 1.000 replicates) for simulations using bootstrap segment lengths of 5km, 10km, 15km and 20km. See Fig. 2 for key to species codes.

particularly for the small cetaceans. The precision of estimates for some of the larger whales is expected to remain low due to the small numbers of sightings. However, abundance estimates for several species of the larger whales have been obtained with other, more efficient methods, such as photo-identification studies (blue and humpback whales: Calambokidis et al., 1991) or land-based census techniques (gray whales: Reilly, 1984; Buckland, 1993).

Several sources of potential bias must be addressed. In this analysis, we have attempted to assess the magnitude of perception bias and correct for it in the abundance estimates. The estimated maximum proportion of animals missed ranges from 0.024 to 0.218 of all sightings, depending on group size and body size of the animals. If no other biases were occurring, the best point estimate would lie between the uncorrected and corrected values in Table 5. However, availability bias could not be corrected for in this analysis. This should produce a downward bias in the abundance estimate, whose magnitude will vary between species. The bias is expected to be smallest for species which tend to occur in large groups, and largest for species which spend relatively less time at the surface.

Although line transect methods are robust to pooling different distributions (Burnham et al., 1980), the pooling of all environmental conditions is likely to introduce a downward bias in the abundance estimation due to the

lower probability of sighting animals on the trackline under poor conditions (Holt, 1987; Barlow et al., 1988; Forney et al., 1991). The magnitude of this bias is unknown, and is likely to vary between species. Our method of correcting for missed groups may account for some of this bias, but may not be robust to heterogeneity in the fraction missed due to environmental conditions.

Potential upward bias in line transect analysis can result if factors other than distance to the trackline affect the probability of seeing a school. School size has been shown to affect the probability of detection (Drummer, 1985; Holt and Sexton, 1989), and this can lead to an upward bias in the abundance estimate (Quinn, 1985; Drummer and McDonald, 1987). To counteract this effect, we have stratified small cetacean sightings by group size and estimated abundances separately for small and large groups of the same species. This is an artificial separation, but it reduces potential biases due to large variation in group size within a single species.

In summary, three sources of downward bias and one source of upward bias in the abundance estimates have been identified. We have corrected for one of the sources of downward bias (perception bias), and attempted to minimise the upward bias by a post-stratification by school size range. Overall, our estimates may still be biased downward.

When comparing the current abundance estimates with those made previously by other researchers, the differences vary between species. Estimates for Pacific white-sided dolphins and Dall's porpoise, for example, are similar to previous values of approximately 26,000–86,000 and 3,000–9,000, respectively (Dohl et al., 1978; 1983). The corrected estimate of 405 humpback whales is also

similar to recent estimates based on photo-identification work (Calambokidis et al., 1991), despite differences in seasonal timing of these studies. Other species previously recorded were not seen at all during this aerial survey (e.g. short-finned pilot whales) and some were seen in greater numbers than before. The most notable disagreement is for common dolphins, with the current corrected winter estimate (277,783) being more than an order of magnitude larger than the previous value of 15,488 (CV=0.36; Dohl et al., 1986). The validity of the new estimate is supported by the 1991 summer/fall estimate from a ship survey, which is also in the hundreds of thousands of animals (Barlow, 1993).

Two of the species for which abundance estimates were made occur in two distinct forms in California waters. The two forms of common dolphins (offshore and neritic) are currently undergoing a taxonomic review and may be divided into two distinct species (Heyning and Perrin, 1991; Rosel, 1992; Dizon et al., In press). Although clear differences in color pattern, size and beak length exist between these two forms, it is not always possible to differentiate them from the air, and the abundance estimate here is a combined estimate. If future assessments require separate estimates for the two forms, aerial surveys may not be adequate.

The second species which occurs in two forms is the bottlenose dolphin, which is divided into a coastal population found very close to shore along portions of the California mainland (Hansen, 1990; Maldini, 1991), and an offshore population, which is distributed more widely in offshore waters (Hansen, 1990). All of the animals seen during this survey were at least several miles from the mainland, so the estimate presented here is assumed to represent the population of offshore animals. Separate aerial surveys are currently being conducted by NMFS to assess year-round abundance of the coastal bottlenose dolphin.

Estimates for harbor porpoise and gray whales are substantially lower than previous estimates (Reilly, 1984; Barlow, 1988; Barlow et al., 1988; Buckland, 1993). This is likely to be due to the fact that the defined study area is not appropriate for the range of these animals. Gray whales have a much larger range and migrate through California waters (southward and then northward) from roughly November to May. The current estimate can be thought of as that portion of the population which was migrating through California in March and early April. Harbor porpoise are limited to a narrow coastal band, and our tracklines only overlapped with this region at specific points. The overall sighting rates are therefore not representative of the total area in which harbor porpoise occur.

The estimates presented for the beaked whales as a group can be viewed as a combined estimate for whales of the genus Mesoplodon and Ziphius cavirostris. All unidentified beaked whale sightings could be narrowed down to these two genera. The only other beaked whale species known to occur in this region, Berardius bairdii, can be readily distinguished based on its size and was not sighted during this survey.

In summary, although we were not able to complete the two full survey grids as planned, sightings were sufficient for most of the small cetacean species and for the beaked whales as a group to obtain reasonable estimates with confidence limits. The analysis indicates that precision is likely to reach acceptable levels when data from the 1992 aerial survey are included. Coupled with the summer/fall

ship survey estimates, these studies will provide valuable insights into seasonal changes in distribution of cetaceans along the California coast, as well as potential historical changes. Given the uncertainty in abundance estimates, we stress the importance of presenting confidence limits. Bootstrap percentile confidence limits may be improved upon in the future with more advanced bootstrap procedures (Efron, 1987). Sensitivity of the estimates to our method of assigning 'unknown' sightings to species also requires examination. Furthermore, surveys must be designed with a target level of precision in mind to ensure that an appropriate level of survey effort is completed.

ACKNOWLEDGEMENTS

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