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NOAA-TM-NMFS-SWFSC-233

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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# ABUNDANCE OF CETACEANS IN CALIFORNIA WATERS BASED ON 1991 AND 1993 SHIP SURVEYS

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## ABSTRACT

Ship surveys were conducted in summer/fall of 1991 and 1993 to estimate the abundance of cetaceans in the waters off California (between the coast and about 300nmi offshore). Line-transect methods were used from a 53 m research vessel. Approximately 8,800 nmi of transects were completed when sea states were Beaufort 5 or less. The estimated abundances and coefficients of variation (in parentheses) of the most common cetacean species are: 372,000 (0.22) short-beaked common dolphins (Delphinus delphis), 8,980 (0.64) long-beaked common dolphins (Delphinus capensis), 24,900 (0.31) striped dolphins (Stenella coeruleoalba), 11,200 (0.36) Pacific white-sided dolphins (Lagenorhynchus obliquidens), 8,980 (0.50) northern right whale dolphins (Lissodelphis borealis), 47,700 (0.40) Dall's porpoise (Phocoenoides dalli), 1,850 (0.50) bottlenose dolphins (Tursiops truncatus), 10,700 (0.41) Risso's dolphins (Grampus griseus), 1,000 (0.37) short-finned pilot whales, 747 (0.71) killer whales (Orcinus orca), 1,220 (0.39) sperm whales (Physeter macrocephalus), 380 (0.52) Baird's beaked whales (Berardius bairdii), 933 (0.27) fin whales (Balaenoptera physalus), 1,720 (0.22) blue whales (Balaenoptera musculus), 577 (0.31) humpback whales (Megaptera novaeangliae), 3,145 (0.54) pygmy sperm whales (Kogia breviceps), 9,160 (0.52) Cuvier's beaked whales (Ziphius cavirostris), 2,106 (0.79) mesoplodont beaked whales (Mesoplodon spp.) and 201 (0.65) minke whales (Balaenoptera acutorostrata). Estimates are also made for various other species which could only be identified to higher-level taxa.

## INTRODUCTION

The abundance of cetaceans in California waters has been estimated recently using ship and aerial line-transect surveys. The aerial surveys (Forney et al. 1995) covered waters out to 100-150 nmi in winter/spring of 1991 and 1992, and the ship surveys (Barlow 1995) covered waters out to 300 nmi in summer/fall 1991. Since those surveys, another cetacean ship survey was conducted off California out to 300 nmi offshore (in summer/fall 1993, Mangels and Gerrodette 1994). The 1993 survey also covered areas off Baja California and in the Gulf of California; however, the number of transect miles off California was less than in 1991. Given that the number of sightings in 1991 was only marginally adequate for estimating the California abundance of many species, data from 1993 alone are even less adequate. In this paper we combine the data from 1991 and 1993 to obtain better estimates of the summer/fall abundance of cetaceans in California waters between the coast and 300 nmi offshore.

## METHODS

### Field Methods

Similar line-transect methods were used to collect abundance data in both 1991 and 1993. During both years, scientists aboard the 53 m NOAA research vessel *McARTHUR* surveyed along uniformly placed, pre-determined transect lines (which differed between years). [In 1993 a small amount of survey effort was also conducted using a second vessel, the *DAVID STARR JORDAN*, of similar length and observation height.] The vessel traveled at 10 knots while a team of three observers searched for marine mammals: two using 25x pedestal-mounted binoculars and the third using unaided eyes and 7x binoculars. The third observer also recorded sighting and search-effort data on a computer system. Additional details about survey methods are given by Hill and Barlow (1992), Mangels and Gerrodette (1994), and Barlow (1995).

Small beaked whales of the genera Ziphius and Mesoplodon are notoriously difficult to differentiate in the field. Previous analyses of the 1991 survey used only those identifications that were certain, which left a large fraction (41%) of "unidentified beaked whales". In the present analyses, we prorate the "unidentified beaked whales" to one of these two genera if the written account of the sighting indicated that it was "probably" one genus or if the estimated lengths of the largest individuals in a group fell within the range of adults of one genus and not the other [we use 5.5m as the dividing point between the likely lengths of Ziphius (>5.5m) and Mesoplodon (<5.5m)]. Of the 18 sightings of "unidentified beaked whales" on surveys in 1991 and 1993, all but two provided sufficient information to assign them to probable categories of Ziphius or Mesoplodon and are treated as such in this report.

### Analytical Methods

To facilitate direct comparisons with the results of the 1991 survey (Barlow 1995), the same analytical approach is used here to estimate marine mammal abundance from the pooled 1991/93 data. Density is estimated separately in group-size strata to avoid size bias (Buckland et al. 1993, p. 77). The same group size strata are used as were used by Barlow (1995). The usual line-transect formula is used to estimate density, $D_{i,j}$, for species $j$ within group-size stratum $i$:

$$D_{ij} = \frac{n_{ij} \; S_{ij} \; f_{ik}(0)}{2 \; L \; g_{ik}(0)} \qquad (1),$$

where
- $n$ = 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,
- $k$ = species group to which species $j$ belongs.

To estimate $f(0)$ and $g(0)$, species are pooled into k=5 groups which share similar sighting characteristics: small delphinids, large delphinids, cryptic species, small whales, and large whales (Table 1). These are the same species groups used in analysis of 1991 survey data (Barlow 1995) except for two species that were seen only in 1993: the short-finned pilot whale was added to the large delphinid group and Blainville's beaked whale was added to the small whale group. Values of *g(0)* for these species groups are taken from Barlow (1995) and Barlow and Sexton (in press). The total abundance for species $j$ , ($N_j$), is estimated as the sum of the densities in all $s$ strata times the size of the study area, $A$ = 238,100 nmi$^2$,

$$N_j = A \sum_{i=1}^{s} D_{ij}$$

Because they are more difficult to detect in rough seas, abundance estimation for small whales and cryptic species are limited to transects that were completed in Beaufort sea states of 0 through 2; abundance estimates for small delphinids, large delphinids and large whales included data collected in Beaufort sea states of 0 through 5.

There are several differences in the analytical methods used in this paper compared to Barlow et al. (1995). A major difference is that a variety of line-transect models were investigated for estimating *f(0)* and the best model was chosen using the Akaike Information Criterion in program DISTANCE (Laake et al. 1994). These models included hazard-rate and half-normal key functions with cosine adjustments (Buckland et al. 1993). Barlow (1995) only used the hazard-rate model. Another difference is that the coefficients of variation (CVs) in densities are estimated as the square root of the sum of the squared CVs of the variable components in Equation 1. The CVs of the encounter rate ($n \cdot S / L$) are estimated by breaking the effort into 75 nmi segments of effort and empirically estimating the variance among segments. The CVs of *f(0)* are estimated analytically using the information matrix approach. The CVs of *g(0)* are taken from Barlow (1995) and Barlow and Sexton (in press). The bootstrap approach used by Barlow (1995) produced similar estimates but was unnecessarily computer-intensive and time-consuming. Another difference is that Barlow (1995) used bias-corrected group size estimates for some observers (who were calibrated against relatively unbiased observers); these bias-correction factors have not been developed yet for the 1993 survey and are not used for the analyses presented here. Finally, a new approach has been developed for estimating *g(0)* for long-diving whales (Barlow and Sexton, in press), and values of *g(0)* for sperm whales, dwarf and pygmy sperm whales, Cuvier's beaked whales, mesoplodont beaked whales are taken from that paper.

## RESULTS

Both the 1991 and 1993 surveys uniformly covered the study area (Figs. 1 and 2, respectively). A total of 8,826 nmi was surveyed in Beaufort sea states of 5 or less, and 2,039 nmi were surveyed in Beaufort 2 or less. For most species, the encounter rates (numbers of groups seen per 1000 nmi and numbers of individuals seen per 1000 nmi) were quite similar between years (Table 2). The most notable change during this time period was an apparent increase in the encounter rates of warm-temperate and tropical delphinoids (short-beaked and long-beaked common dolphins and striped dolphins) and an apparent decrease in cold-temperate delphinoids (Dall's porpoise, northern right whale dolphins, and Pacific white-sided dolphins). The encounter rates of many large whales (sperm whales, Baird's beaked whales, fin whales, blue whales, and humpback whales) also increased from 1991 to 1993.

The estimated effective search widths (ESW, $1/f(0)$) were also quite similar when comparing previous estimates for 1991 (Barlow 1995) with new estimates for 1991 and 1993 pooled (Table 3). The best fits were obtained with the hazard-rate model (with no cosine terms) for cryptic species and small delphinids and with the half-normal/cosine model for small whales, large whales, and large delphinids. The most notable changes were a decrease in ESW for large groups of small delphinids (from 3.4km to 1.9km), a decrease in ESW for small groups of large delphinids (from 2.0km to 1.1km), and an increase in ESW for small whale species (from 1.6km to 2.7km). Although the magnitude of some of these changes is large, none of these changes can be viewed as unexpected given the estimation error (coefficients of variation) for these parameters (Table 3).

Overall estimates of cetacean abundance based on 1991 and 1993 pooled (Table 4) are generally similar to estimates based on 1991 alone (Barlow 1995). The most notable changes are a greater estimated abundance of short-beaked common dolphins (226,000 vs. 372,000), a lesser abundance of Dall's porpoise (78,000 vs. 48,000), and a greater abundance of Baird's beaked whales (38 vs. 380). Also, there were no short-finned pilot whales or Blainville's beaked whales identified during the 1991 survey, but their 1991/93 abundances are now estimated as approximately 1,000 and 728 (respectively) based only on sightings made in 1993.

## DISCUSSION

With the addition of 1993 data, the new cetacean abundance estimates for California (Table 4) differ from previous estimates. These differences are, in some cases, substantial. Short-beaked common dolphin abundance is now 1.6 times more than previously estimated (Barlow 1995). Dall's porpoise abundance is now 1.6 times less than previously estimated. The new Baird's beaked whale abundance estimate is 10 times greater than the previous estimate. Short-finned pilot whales were not seen at all in 1991 (making a de facto estimate of zero) and are now estimated to include 1,000 individuals. Although some of these differences are large, with the exception of Baird's beaked whales and short-finned pilot whales, all the new estimates are within the 95% confidence intervals of the previous estimates. Because the new estimates are based on data which were also used to make the old estimates, a rigorous statistical comparison is not possible; however, the wide confidence intervals do indicate that such large difference can be expected given the statistical sampling and estimation errors that would be expected from these types of data. Nonetheless, it may be informative to look for the reasons why some of the differences are as large as they are.

Estimates of $f(0)$ changed substantially for several of the species groups. The increase in $f(0)$ for large groups of small delphinids (Table 3) certainly contributed to the increase in the estimated abundance of short-beaked common dolphins and striped dolphins, both of which commonly occur in large groups. However, this does not explain all of the increase. Encounter rates for short-beaked common dolphins and striped dolphins also increased from 1991 to 1993 (Table 2). The apparent decrease in the estimated abundance of cold-temperate delphinoids was also reflected in decreased encounter rates of these species (Pacific white-sided dolphins, northern right whale dolphins, and Dall's porpoise). Because there were correlated increases in warm-temperate/tropical delphinoids and correlated decreases in cold-temperate delphinoids, part of the difference between the pooled 1991/93 estimates and the 1991 estimates could be explained by shifts in the distributions of these species cause by year-to-year variation in oceanographic conditions.

Similarly, the increase in the apparent abundance of short-finned pilot whales may also have been the result of a real increase in their abundance caused by a shift in their distribution. An increase was also seen in the frequency that short-finned pilot whales were caught in drift gillnets off California; only one was observed caught in gillnets in 1991 and 1992 combined, but 11 were observed in 1993 alone (Barlow et al. 1994). This provides additional evidence that pilot whale abundance may have increased. The actual number of sightings is, however, so low (0 in 1991 and 4 in 1993) that the apparent change could be explained entirely as a statistical artifact.

The general increase in the estimated abundance of small beaked whales is the net result of increases in some parameters and decreases in others. The effective search width for small whales increased from 1.6 to 2.7km (Table 3) with the addition of more sightings. The new estimate of *f(0)* is considerably more precise (CV=0.16) than the previous estimate (CV=0.48), consequently the abundance estimates for these species are also more precise (Table 4). The values of *g(0)* used in the present analysis are much lower than previous values because previous values only include perception bias (Marsh and Sinclair 1989) and the more recent values also include availability bias (which is a particular concern for long-diving species). Encounter rates did not change much between 1991 and 1993; therefore the increase in estimated abundance is probably not real but, rather, is caused by changes (improvements) in methods of analyses.

The large change in the estimated abundance of Baird's beaked whales from 38 based on 1991 data to 380 based on 1991/93 data, is almost entirely due to changes in the observed encounter rate. Only one group was seen in 1991 (although 2 other groups were seen while "off-effort") compared to 4 groups in 1993. Clearly, this difference could be explained by sampling error. Most groups of Baird's beaked whales are greater than 3 individuals, and the estimates of *f(0)* for such large groups of large whales did not change appreciable from previous estimates (Table 3).

In general, the differences between abundance estimates presented here (Table 4) and those presented earlier (Barlow 1995) can be explained entirely by sampling variability and estimation error. It is likely, however, that some of these differences are caused by real changes in abundance between 1991 and 1993. By pooling abundance between these years, we do not mean to imply that abundance was the same in both years or that differences were not real; rather, we are simply estimating the mean number present over the period from 1991 to 1993. Another survey planned for summer/fall 1996 may help resolve whether the patterns of changes observer here have continued since 1993.

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Table 1. Species groups used in estimating $f(0)$ and $g(0)$.

| Species Group<br>Species |
|---|
| **Small Delphinids** |
| short-beaked common dolphin (Delphinus delphis) |
| long-beaked common dolphin (Delphinus capensis) |
| unclassified common dolphin (Delphinus delphis) |
| striped dolphin (Stenella coeruleoalba) |
| Pacific white-sided dolphin (Lagenorhynchus obliquidens) |
| northern right whale dolphin (Lissodelphis borealis) |
| unidentified delphinoid |
| **Cryptic Species** |
| harbor porpoise (Phocoena phocoena) |
| Dall's porpoise (Phocoenoides dalli) |
| pygmy sperm whale (Kogia breviceps) |
| Pygmy or dwarf sperm whale (Kogia breviceps or simus) |
| **Large Delphinids** |
| bottlenose dolphin (Tursiops truncatus) |
| Risso's dolphin (Grampus griseus) |
| Short-finned pilot whale (Globicephala macrorhynchus) |
| killer whale (Orcinus orca) |
| **Small Whales** |
| unidentified beaked whale |
| mesoplodont beaked whale (Mesoplodon spp.) |
| Blainville's beaked whale (Mesoplodon densirostris) |
| Cuvier's beaked whale (Ziphius cavirostris) |
| minke whale (Balaenoptera acutorostrata) |
| unidentified small whale |
| unidentified cetacean |
| **Large Whales** |
| sperm whale (Physeter macrocephalus) |
| Baird's beaked whale (Berardius bairdii) |
| Bryde's whale (Balaenoptera edeni) |
| Bryde's or sei whale (Balaenoptera edeni/borealis) |
| fin whale (Balaenoptera physalus) |
| blue whale (Balaenoptera musculus) |
| humpback whale (Megaptera novaeangliae) |
| unidentified baleen whale |
| unidentified large whale |

Table 2. Comparison of encounter rates of groups *(n/L)* and individuals *(n·S/L)* for species seen during 1991 and 1993 surveys of California waters. Coefficients of variation (CVs) are based on the variance in encounter rates measured in consecutive 75 nmi segments of survey effort.

| | Number Groups n | Groups per 1000nmi | CV Groups per 1000nmi | Animals per 1000nmi | CV Animals per 1000nmi |
|---|---|---|---|---|---|
| short-beaked common dolphin | | | | | |
| 1991 Survey | 122 | 22.5 | 0.166 | 2136 | 0.214 |
| 1993 Survey | 106 | 31.1 | 0.181 | 5015 | 0.232 |
| long-beaked common dolphin | | | | | |
| 1991 Survey | 6 | 1.1 | 0.698 | 181 | 0.798 |
| 1993 Survey | 2 | 0.6 | 0.999 | 129 | 1.064 |
| striped dolphin | | | | | |
| 1991 Survey | 24 | 4.4 | 0.252 | 193 | 0.359 |
| 1993 Survey | 18 | 5.3 | 0.286 | 304 | 0.470 |
| Pacific white-sided dolphin | | | | | |
| 1991 Survey | 12 | 2.2 | 0.439 | 54 | 0.516 |
| 1993 Survey | 8 | 2.3 | 0.448 | 32 | 0.579 |
| northern right whale dolphin | | | | | |
| 1991 Survey | 16 | 3.0 | 0.399 | 47 | 0.553 |
| 1993 Survey | 8 | 2.3 | 0.369 | 33 | 0.477 |
| unidentified delphinoid | | | | | |
| 1991 Survey | 21 | 3.9 | 0.261 | 13 | 0.312 |
| 1993 Survey | 24 | 7.0 | 0.266 | 229 | 0.456 |
| bottlenose dolphin | | | | | |
| 1991 Survey | 16 | 3.0 | 0.427 | 23 | 0.478 |
| 1993 Survey | 5 | 1.5 | 0.513 | 25 | 0.687 |
| Risso's dolphin | | | | | |
| 1991 Survey | 28 | 5.2 | 0.279 | 100 | 0.352 |
| 1993 Survey | 17 | 5.0 | 0.328 | 91 | 0.441 |
| short-finned pilot whale | | | | | |
| 1991 Survey | 0 | 0.0 | - | 0 | - |
| 1993 Survey | 4 | 1.2 | 0.601 | 16 | 0.641 |
| killer whale | | | | | |
| 1991 Survey | 5 | 0.9 | 0.488 | 4 | 0.526 |
| 1993 Survey | 2 | 0.6 | 0.700 | 4 | 0.771 |
| harbor porpoise | | | | | |
| 1991 Survey | 32 | 5.9 | 0.544 | 26 | 0.716 |
| 1993 Survey | 3 | 0.9 | 0.561 | 1 | 0.596 |
| Dall's porpoise | | | | | |
| 1991 Survey | 96 | 17.7 | 0.316 | 65 | 0.331 |
| 1993 Survey | 13 | 3.8 | 0.404 | 16 | 0.469 |
| pygmy or dwarf sperm whale | | | | | |
| 1991 Survey | 3 | 0.6 | 0.697 | 1 | 0.716 |
| 1993 Survey | 2 | 0.6 | 1.000 | 1 | 1.000 |
| unidentified beaked whale | | | | | |
| 1991 Survey | 0 | 0.0 | - | 0 | - |
| 1993 Survey | 2 | 0.6 | 0.992 | 1 | 1.046 |
| mesoplodont beaked whales | | | | | |
| 1991 Survey | 6 | 1.1 | 0.394 | 2 | 0.420 |
| 1993 Survey | 6 | 1.5 | 0.409 | 5 | 0.499 |
| Cuvier's beaked whale | | | | | |
| 1991 Survey | 18 | 3.3 | 0.321 | 7 | 0.332 |
| 1993 Survey | 12 | 3.5 | 0.310 | 6 | 0.340 |

| | Number Groups n | Groups per 1000nmi | CV Groups per 1000nmi | Animals per 1000nmi | CV Animals per 1000nmi |
|---|---|---|---|---|---|
| minke whale | | | | | |
| 1991 Survey | 4 | 0.7 | 0.601 | 1 | 0.604 |
| 1993 Survey | 0 | 0.0 | - | 0 | - |
| unidentified small whale | | | | | |
| 1991 Survey | 11 | 2.0 | 0.306 | 2 | 0.317 |
| 1993 Survey | 8 | 2.3 | 0.327 | 3 | 0.364 |
| unidentified cetacean | | | | | |
| 1991 Survey | 8 | 1.5 | 0.378 | 2 | 0.437 |
| 1993 Survey | 5 | 1.5 | 0.422 | 5 | 0.511 |
| sperm whale | | | | | |
| 1991 Survey | 13 | 2.4 | 0.398 | 11 | 0.460 |
| 1993 Survey | 15 | 4.4 | 0.401 | 38 | 0.448 |
| Baird's beaked whale | | | | | |
| 1991 Survey | 1 | 0.2 | 2.000 | 1 | 2.000 |
| 1993 Survey | 4 | 1.2 | 0.600 | 18 | 0.622 |
| Bryde's or sei whale | | | | | |
| 1991 Survey | 3 | 0.6 | 0.740 | 1 | 0.740 |
| 1993 Survey | 2 | 0.6 | 0.999 | 1 | 0.999 |
| fin whale | | | | | |
| 1991 Survey | 23 | 4.2 | 0.471 | 8 | 0.502 |
| 1993 Survey | 32 | 9.4 | 0.375 | 18 | 0.384 |
| blue whale | | | | | |
| 1991 Survey | 50 | 9.2 | 0.251 | 18 | 0.261 |
| 1993 Survey | 46 | 13.5 | 0.263 | 22 | 0.269 |
| humpback whale | | | | | |
| 1991 Survey | 13 | 2.4 | 0.314 | 7 | 0.452 |
| 1993 Survey | 17 | 5.0 | 0.445 | 8 | 0.457 |
| unidentified baleen whale | | | | | |
| 1991 Survey | 9 | 1.7 | 0.444 | 2 | 0.460 |
| 1993 Survey | 15 | 4.4 | 0.368 | 6 | 0.379 |
| unidentified large whale | | | | | |
| 1991 Survey | 22 | 4.1 | 0.285 | 5 | 0.303 |
| 1993 Survey | 11 | 3.2 | 0.321 | 16 | 0.645 |
| unidentified whale | | | | | |
| 1991 Survey | 1 | 0.2 | 2 | 0.2 | 2 |
| 1993 Survey | 1 | 0.3 | 2 | 0.3 | 2 |
| baleen whale total | | | | | |
| 1991 Survey | 98 | 18.1 | 0.180 | 36 | 0.195 |
| 1993 Survey | 112 | 32.9 | 0.175 | 54 | 0.185 |
| tropical delphinoids | | | | | |
| 1991 Survey | 162 | 29.9 | 0.137 | 2352 | 0.197 |
| 1993 Survey | 133 | 39.1 | 0.151 | 5360 | 0.219 |
| temperate delphinoids | | | | | |
| 1991 Survey | 124 | 22.9 | 0.254 | 166 | 0.263 |
| 1993 Survey | 29 | 8.5 | 0.242 | 81 | 0.315 |
| baleen whales w/ minke's | | | | | |
| 1991 Survey | 102 | 18.8 | 0.1702 | 37 | 0.1707 |
| 1993 Survey | 112 | 32.9 | 0.1661 | 54 | 0.1787 |

Table 3. Maximum likelihood estimates of line-transect parameters for species groups and associated strata from 1991 surveys and from 1991 and 1993 surveys pooled. Effective search widths (ESW) are the inverse of *f(0)*. Coefficients of variation are the same for both and are based on analytical estimates of the standard error of *f(0)* using the information matrix approach.

| Main Stratum | 1991 Data | | | 1991+1993 Data | | |
|---|---|---|---|---|---|---|
| Sub-strata | f(0) /km | ESW km | C.V. f(0) | f(0) /km | ESW km | C.V. f(0) |
| Small Delphinids (2.0 nmi Truncation) | | | | | | |
| Group size 1-20 | 1.258 | 0.79 | 0.249 | 1.724 | 0.58 | 0.255 |
| Group size 21-100 | 0.944 | 1.06 | 0.336 | 0.905 | 1.10 | 0.240 |
| Group size 101+ | 0.283 | 3.54 | 0.193 | 0.528 | 1.89 | 0.239 |
| Large Delphinids (2.0 nmi Truncation) | | | | | | |
| Group size 1-20 | 0.504 | 1.98 | 0.306 | 0.912 | 1.10 | 0.395 |
| Group size 21+ | 0.352 | 2.84 | N.A. | 0.383 | 2.61 | 0.232 |
| Cryptic Species (2.0 nmi Truncation) | | | | | | |
| Calm seas | 1.574 | 0.64 | 0.199 | 1.568 | 0.64 | 0.200 |
| Small Whales (2.0 nmi Truncation) | | | | | | |
| Calm seas | 0.614 | 1.63 | 0.488 | 0.369 | 2.71 | 0.160 |
| Large Whales (3.0 nmi Truncation) | | | | | | |
| Group size 1-3 | 0.696 | 1.44 | 0.278 | 0.437 | 2.29 | 0.100 |
| Group size 4+ | 0.256 | 3.90 | N.A. | 0.238 | 4.20 | 0.147 |

Table 4. Line-transect estimates of cetacean abundance in California waters based on 1991 and 1993 ship surveys. Estimates of density for each strata were based on Eq. 1. Log-normal 95% confidence intervals (CIs) were based on the approach given by Buckland et al. (1994). Most unidentified beaked whales were prorated as Cuvier's beaked whales or mesoplodont beaked whales based on sighting descriptions.

| Species Group<br>Species<br>Strata | Number Groups<br>n | Mean Size of Groups<br>S | f(0)<br>/km | g(0) | Animal Density<br>/sq km | Pop. Size<br>N | C.V.<br>N | Log-Normal Lower 95%<br>C.I. | Log-Normal Upper 95%<br>C.I. | CV<br>n*S/L | CV<br>f(0) | CV<br>g(0) | CV<br>Density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Small delphinids** | | | | | | | | | | | | | |
| short-beaked common dolphin | | | | | 0.4570 | 372,425 | 0.222 | 242,215 | 572,634 | | | | |
| Group size 1-20 | 42 | 11.81 | 1.724 | 0.77 | 0.0340 | | | | | 0.221 | 0.255 | 0.137 | 0.364 |
| Group size 21-100 | 93 | 44.34 | 0.905 | 1.00 | 0.1143 | | | | | 0.160 | 0.240 | 0.000 | 0.288 |
| Group size 101+ | 70 | 272.73 | 0.528 | 1.00 | 0.3087 | | | | | 0.195 | 0.239 | 0.000 | 0.308 |
| long-beaked common dolphin | | | | | 0.0110 | 8,980 | 0.636 | 2,866 | 28,138 | | | | |
| Group size 1-20 | 1 | 11.56 | 1.724 | 0.770 | 0.0008 | | | | | 2.000 | 0.255 | 0.137 | 2.021 |
| Group size 21-100 | 1 | 5.63 | 0.905 | 1.000 | 0.0002 | | | | | 2.000 | 0.240 | 0.000 | 2.014 |
| Group size 101+ | 3 | 207.58 | 0.528 | 1.000 | 0.0101 | | | | | 0.633 | 0.239 | 0.000 | 0.677 |
| common dolphin (unclassified) | | | | | 0.0124 | 10,120 | 1.420 | 1,291 | 79,347 | | | | |
| Group size 1-20 | 8 | 4.94 | 1.724 | 0.770 | 0.0027 | | | | | 0.439 | 0.255 | 0.137 | 0.526 |
| Group size 21-100 | 2 | 17.92 | 0.905 | 1.000 | 0.0010 | | | | | 0.804 | 0.240 | 0.000 | 0.839 |
| Group size 101+ | 1 | 538.93 | 0.528 | 1.000 | 0.0087 | | | | | 2.000 | 0.239 | 0.000 | 2.014 |
| striped dolphin | | | | | 0.0306 | 24,910 | 0.314 | 13,647 | 45,466 | | | | |
| Group size 1-20 | 3 | 9.81 | 1.724 | 0.770 | 0.0020 | | | | | 0.725 | 0.255 | 0.137 | 0.781 |
| Group size 21-100 | 12 | 27.81 | 0.905 | 1.000 | 0.0092 | | | | | 0.472 | 0.240 | 0.000 | 0.530 |
| Group size 101+ | 19 | 62.82 | 0.528 | 1.000 | 0.0193 | | | | | 0.346 | 0.239 | 0.000 | 0.421 |
| Pacific white-sided dolphin | | | | | 0.0137 | 11,187 | 0.358 | 5,661 | 22,108 | | | | |
| Group size 1-20 | 10 | 7.78 | 1.724 | 0.770 | 0.0053 | | | | | 0.407 | 0.255 | 0.137 | 0.499 |
| Group size 21-100 | 8 | 35.16 | 0.905 | 1.000 | 0.0078 | | | | | 0.447 | 0.240 | 0.000 | 0.507 |
| Group size 101+ | 1 | 37.05 | 0.528 | 1.000 | 0.0006 | | | | | 2.000 | 0.239 | 0.000 | 2.014 |
| northern right whale dolphin | | | | | 0.0110 | 8,977 | 0.497 | 3,576 | 22,534 | | | | |
| Group size 1-20 | 11 | 8.61 | 1.724 | 0.770 | 0.0065 | | | | | 0.701 | 0.255 | 0.137 | 0.758 |
| Group size 21-100 | 8 | 11.68 | 0.905 | 1.000 | 0.0026 | | | | | 0.397 | 0.240 | 0.000 | 0.464 |
| Group size 101+ | 2 | 59.72 | 0.528 | 1.000 | 0.0019 | | | | | 1.038 | 0.239 | 0.000 | 1.065 |
| unidentified delphinoid | | | | | 0.0130 | 10,585 | 0.572 | 3,732 | 30,024 | | | | |
| Group size 1-20 | 31 | 4.33 | 1.724 | 0.770 | 0.0092 | | | | | 0.228 | 0.255 | 0.137 | 0.368 |
| Group size 21-100 | 1 | 19.85 | 0.905 | 1.000 | 0.0006 | | | | | 2.000 | 0.240 | 0.000 | 2.014 |
| Group size 101+ | 1 | 200.00 | 0.528 | 1.000 | 0.0032 | | | | | 2.000 | 0.239 | 0.000 | 2.014 |

Table 4. (Cont.)

| Species Group<br>Species<br>Strata | Number Groups n | Mean Size of Groups S | f(0) /km | g(0) | Animal Density /sq km | Pop. Size N | C.V. N | Log-Normal Lower 95% C.I. | Log-Normal Upper 95% C.I. | CV n*S/L | CV f(0) | CV g(0) | CV Density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Large delphinids** | | | | | | | | | | | | | |
| bottlenose dolphin | | | | | 0.0023 | 1,850 | 0.504 | 728 | 4,696 | | | | |
| Group size 1-20 | 7 | 4.70 | 0.912 | 0.74 | 0.0012 | | | | | 0.590 | 0.395 | 0.391 | 0.811 |
| Group size 21+ | 9 | 9.67 | 0.383 | 1.00 | 0.0010 | | | | | 0.466 | 0.232 | 0.000 | 0.521 |
| Risso's dolphin | | | | | 0.0132 | 10,720 | 0.413 | 4,927 | 23,327 | | | | |
| Group size 1-20 | 26 | 8.45 | 0.912 | 0.736 | 0.0083 | | | | | 0.249 | 0.395 | 0.391 | 0.609 |
| Group size 21+ | 15 | 27.38 | 0.383 | 1.000 | 0.0048 | | | | | 0.326 | 0.232 | 0.000 | 0.400 |
| short-finned pilot whale | | | | | 0.0012 | 1,004 | 0.372 | 495 | 2,033 | | | | |
| Group size 1-20 | 2 | 11.10 | 0.912 | 0.736 | 0.0008 | | | | | 0.710 | 0.395 | 0.391 | 0.902 |
| Group size 21+ | 2 | 16.58 | 0.383 | 1.000 | 0.0004 | | | | | 0.800 | 0.232 | 0.000 | 0.833 |
| killer whale | | | | | 0.0009 | 747 | 0.711 | 213 | 2,615 | | | | |
| Group size 1-20 | 5 | 4.83 | 0.912 | 0.736 | 0.0009 | | | | | 0.443 | 0.395 | 0.391 | 0.711 |
| Group size 21+ | 0 | 0.00 | 0.383 | 1.000 | 0.0000 | | | | | 0.000 | 0.232 | 0.000 | 0.232 |
| **Cryptic species** | | | | | | | | | | | | | |
| harbor porpoise (see footnote) | 34 | 4.21 | 1.568 | 0.787 | 0.0378 | 30,801 | 0.871 | 7,067 | 134,245 | 0.841 | 0.200 | 0.103 | 0.871 |
| Dall's porpoise | 69 | 3.21 | 1.568 | 0.787 | 0.0585 | 47,661 | 0.404 | 22,261 | 102,043 | 0.335 | 0.200 | 0.103 | 0.404 |
| pygmy sperm whale | 3 | 1.17 | 1.568 | 0.189 | 0.0039 | 3,145 | 0.538 | 1,170 | 8,453 | 0.489 | 0.200 | 0.103 | 0.538 |
| pygmy or dwarf sperm whale | 1 | 1.00 | 1.568 | 0.190 | 0.0011 | 891 | 2.037 | 73 | 10,958 | 2.000 | 0.200 | 0.330 | 2.037 |
| **Small whales** | | | | | | | | | | | | | |
| unidentified beaked whale | 1 | 2.00 | 0.369 | 0.260 | 0.0004 | 307 | 0.541 | 114 | 827 | 0.436 | 0.154 | 0.280 | 0.541 |
| mesoplodont beaked whale | 5 | 1.80 | 0.369 | 0.260 | 0.0017 | 1,378 | 0.577 | 482 | 3,937 | 0.480 | 0.154 | 0.280 | 0.577 |
| Blainville's Beaked whale | 1 | 4.75 | 0.369 | 0.260 | 0.0009 | 728 | 2.025 | 60 | 8,891 | 2.000 | 0.154 | 0.280 | 2.025 |
| Cuvier's beaked whale | 12 | 2.49 | 0.369 | 0.130 | 0.0112 | 9,163 | 0.521 | 3,506 | 23,946 | 0.354 | 0.154 | 0.350 | 0.521 |
| minke whale | 4 | 1.06 | 0.369 | 0.840 | 0.0002 | 201 | 0.652 | 63 | 646 | 0.595 | 0.154 | 0.218 | 0.652 |
| unidentified small whale | 5 | 1.00 | 0.369 | 0.840 | 0.0003 | 237 | 0.451 | 102 | 552 | 0.364 | 0.154 | 0.218 | 0.451 |
| unidentified cetacean | 4 | 1.50 | 0.369 | 0.840 | 0.0003 | 285 | 0.592 | 97 | 833 | 0.528 | 0.154 | 0.218 | 0.592 |

Table 4. (Cont.)

| Species Group / Species | Strata | Number Groups n | Mean Size of Groups S | f(0) /km | g(0) | Animal Density /sq km | Pop. Size N | C.V. N | Log-Normal Lower 95% C.I. | Log-Normal Upper 95% C.I. | CV n*S/L | CV f(0) | CV g(0) | CV Density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Large whales** | | | | | | | | | | | | | | |
| sperm whale | | | | | | 0.0015 | 1,231 | 0.392 | 586 | 2,583 | | | | |
| | Group size 1-3 | 7 | 1.78 | 0.437 | 0.870 | 0.0002 | | | | | 0.456 | 0.100 | 0.090 | 0.475 |
| | Group size 4+ | 18 | 8.75 | 0.238 | 0.870 | 0.0013 | | | | | 0.409 | 0.147 | 0.090 | 0.444 |
| Baird's beaked whale | | | | | | 0.0005 | 380 | 0.526 | 144 | 1,002 | | | | |
| | Group size 1-3 | 0 | 0.00 | 0.437 | 0.901 | 0.0000 | | | | | 0.000 | 0.100 | 0.090 | 0.135 |
| | Group size 4+ | 5 | 12.81 | 0.238 | 1.000 | 0.0005 | | | | | 0.497 | 0.147 | 0.090 | 0.526 |
| Bryde's whale | | | | | | 0.0000 | 24 | 2.005 | 2 | 292 | | | | |
| | Group size 1-3 | 1 | 2.00 | 0.437 | 0.901 | 0.0000 | | | | | 2.000 | 0.100 | 0.090 | 2.005 |
| | Group size 4+ | 0 | 0.00 | 0.238 | 1.000 | 0.0000 | | | | | 0.000 | 0.147 | 0.090 | 0.172 |
| Bryde's or sei whale | | | | | | 0.0000 | 36 | 0.713 | 10 | 128 | | | | |
| | Group size 1-3 | 3 | 1.00 | 0.437 | 0.901 | 0.0000 | | | | | 0.700 | 0.100 | 0.090 | 0.713 |
| | Group size 4+ | 0 | 0.00 | 0.238 | 1.000 | 0.0000 | | | | | 0.000 | 0.147 | 0.090 | 0.172 |
| fin whale | | | | | | 0.0011 | 933 | 0.270 | 555 | 1,569 | | | | |
| | Group size 1-3 | 40 | 1.51 | 0.437 | 0.901 | 0.0009 | | | | | 0.287 | 0.100 | 0.090 | 0.317 |
| | Group size 4+ | 11 | 3.09 | 0.238 | 1.000 | 0.0002 | | | | | 0.453 | 0.147 | 0.090 | 0.485 |
| blue whale | | | | | | 0.0021 | 1,723 | 0.226 | 1,112 | 2,667 | | | | |
| | Group size 1-3 | 75 | 1.59 | 0.437 | 0.901 | 0.0018 | | | | | 0.224 | 0.100 | 0.090 | 0.261 |
| | Group size 4+ | 16 | 2.93 | 0.238 | 1.000 | 0.0003 | | | | | 0.293 | 0.147 | 0.090 | 0.340 |
| humpback whale | | | | | | 0.0007 | 577 | 0.315 | 316 | 1,054 | | | | |
| | Group size 1-3 | 23 | 1.61 | 0.437 | 0.901 | 0.0006 | | | | | 0.313 | 0.100 | 0.090 | 0.341 |
| | Group size 4+ | 4 | 5.40 | 0.238 | 1.000 | 0.0002 | | | | | 0.748 | 0.147 | 0.090 | 0.768 |
| unidentified baleen whale | | | | | | 0.0002 | 194 | 0.295 | 110 | 341 | | | | |
| | Group size 1-3 | 11 | 1.32 | 0.437 | 0.901 | 0.0002 | | | | | 0.284 | 0.100 | 0.090 | 0.314 |
| | Group size 4+ | 2 | 1.50 | 0.238 | 1.000 | 0.0000 | | | | | 0.777 | 0.147 | 0.090 | 0.796 |
| unidentified large whale | | | | | | 0.0004 | 303 | 0.293 | 173 | 531 | | | | |
| | Group size 1-3 | 20 | 1.25 | 0.437 | 0.901 | 0.0004 | | | | | 0.260 | 0.100 | 0.090 | 0.293 |
| | Group size 4+ | 0 | 0.00 | 0.238 | 1.000 | 0.0000 | | | | | 0.000 | 0.147 | 0.090 | 0.172 |

Footnote: More precise estimates for harbor porpoise are recently available in Barlow and Forney (1993).

Figure 1. Transect lines (fine lines) covered in the "California" study area (bold lines) during the 1991 survey.

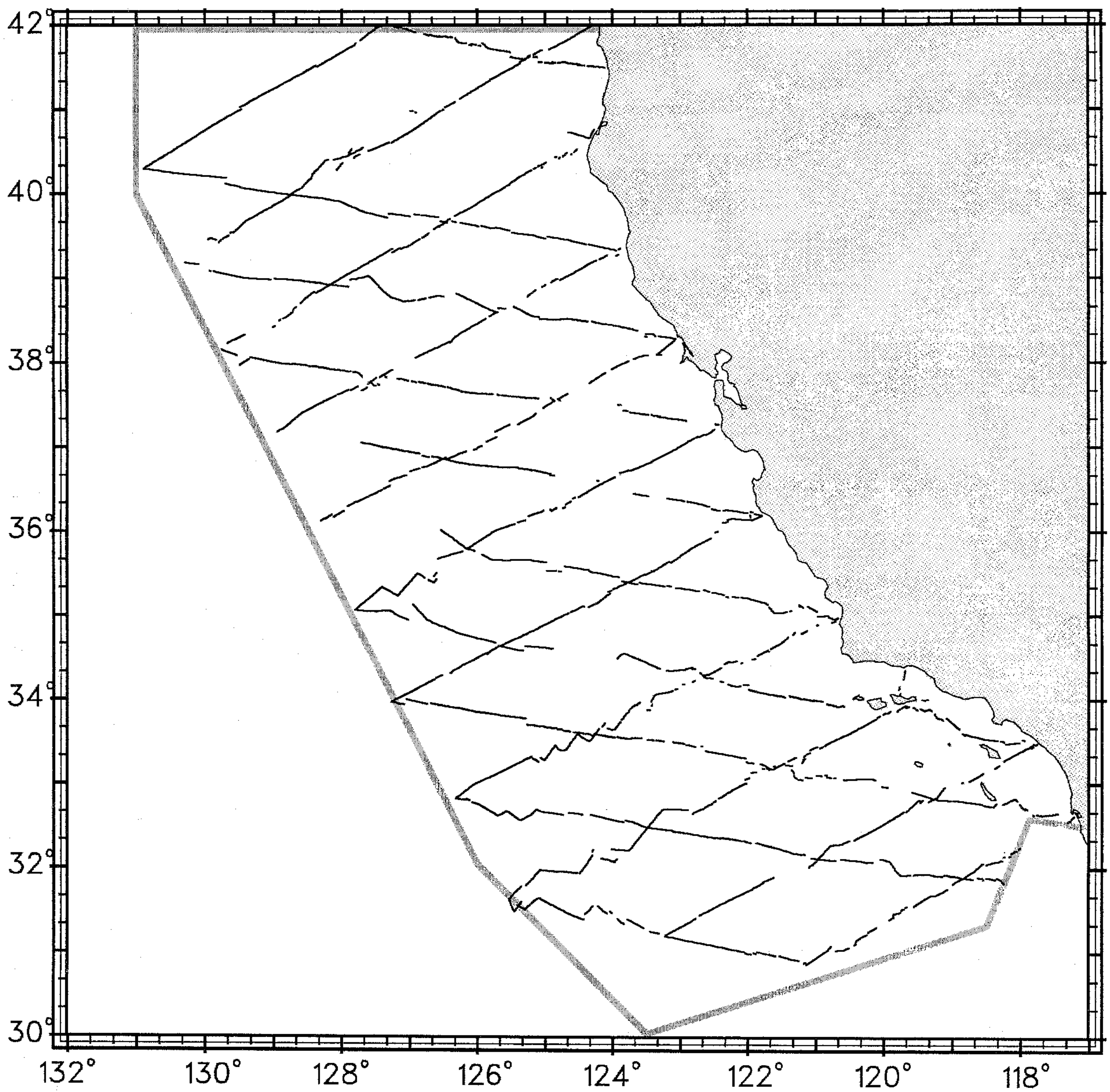
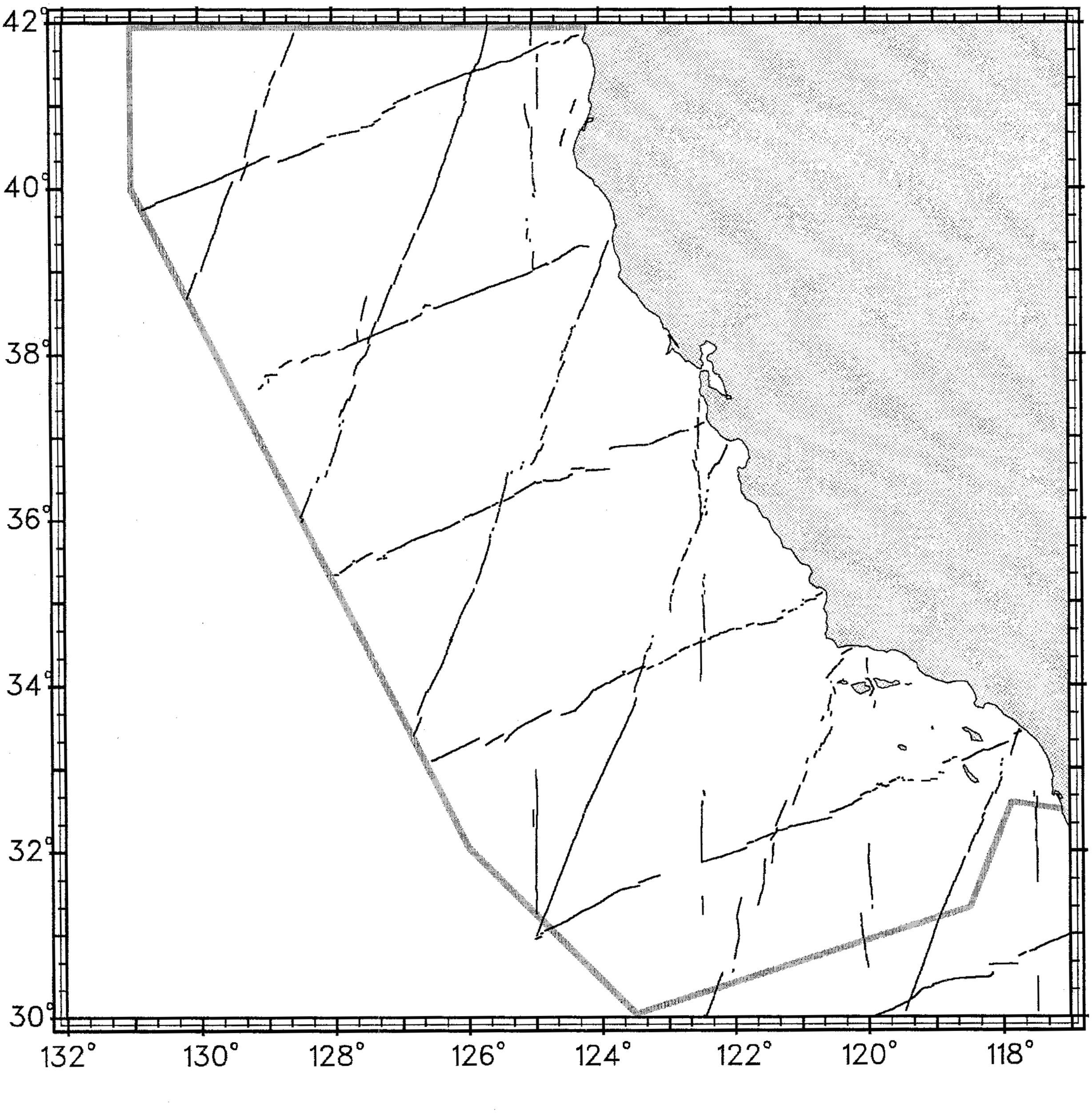


Figure 2. Transect lines (fine lines) covered in the "California" study area (bold lines) during the 1993 survey.



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