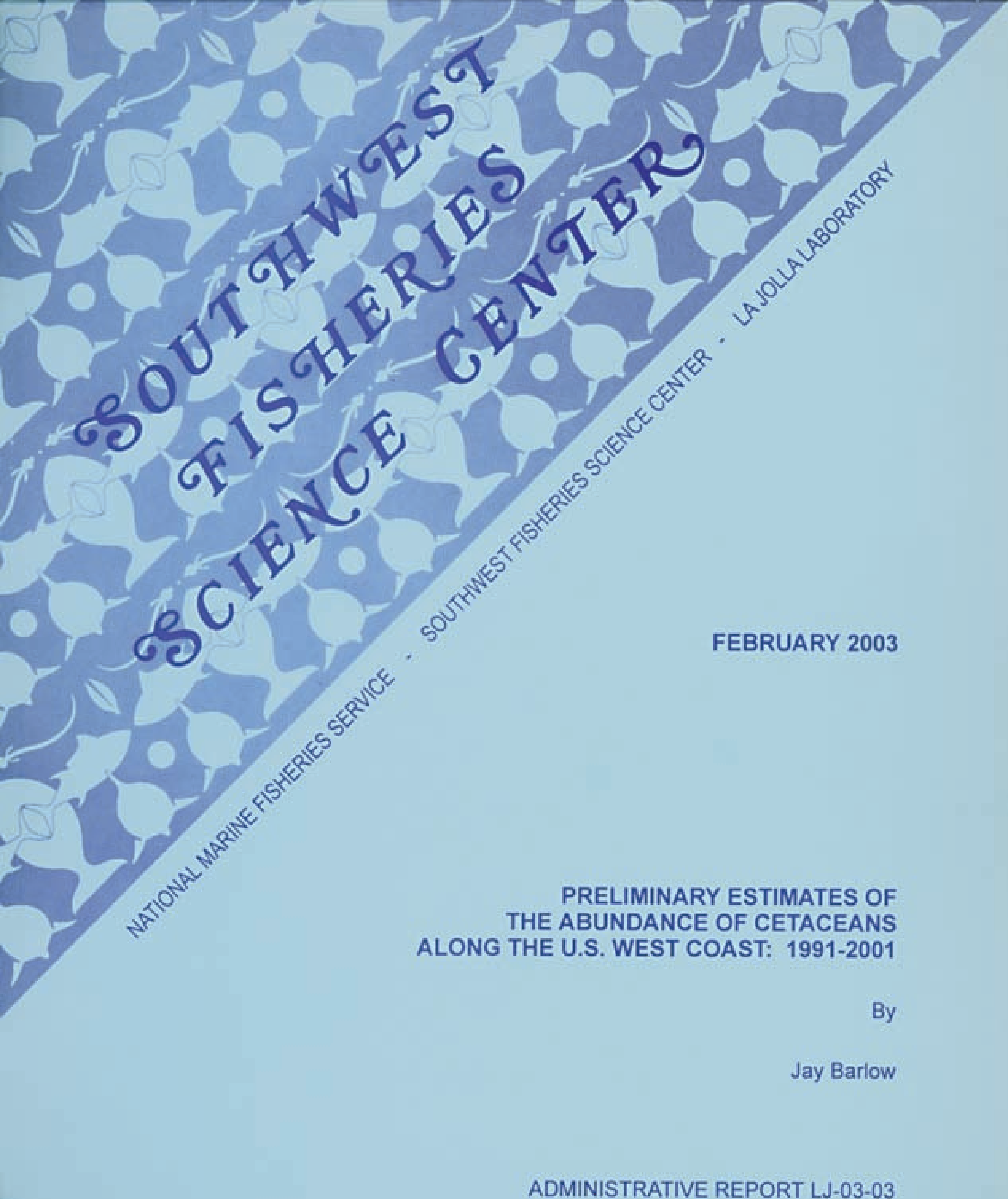

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PRELIMINARY ESTIMATES OF THE ABUNDANCE OF CETACEANS ALONG THE U.S. WEST COAST: 1991-2001

By

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Preliminary Estimates of the Abundance of Cetaceans along the U.S. West Coast: 1991-2001

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Abstract

The abundance of cetaceans along the U.S. west coast is estimated from ship line-transect surveys in 1991/1993, 1996, and 2001. The surveys were designed to uniformly cover waters from the coast to 300 nmi offshore in two geographic strata: California (surveyed in all years) and Oregon/Washington (surveyed in 1996 and 2001). Generalized additive models were used to identify factors that affect perpendicular sighting distance and to identify species groups with similar sighting characteristics. Data for all years and all surveys were pooled, and similar species were pooled into nine species groups for estimating the line-transect parameter f(0). Within a group, analyses were stratified by group size if that resulted in a lower AIC value for fitted detection functions. Detection probabilities on the transect line, g(0), were obtained from other studies that used the same survey methods. Abundance was estimated separately for each survey year and each geographic stratum using the pooled estimates of f(0) and g(0). Overall, the most abundant delphinid was the short-beaked common dolphin, with Risso's dolphins, Pacific white-sided dolphins, and northern right whale dolphins replacing this species as the most abundant in the OR/WA stratum. Dall's porpoises were also very abundant in colder waters. The most abundant baleen whales were fin whales, blue whales, and humpback whales. Sei whales and short-finned pilot whales, two species that were abundant in the 1960s and 1970s, were seldom seen during this survey period.

Introduction

The abundance of cetaceans along the U.S. west coast has been estimated for some species in some areas. The U.S. Minerals Management Service contracted aerial line-transect surveys off California, Oregon and Washington in the late 1970s and the 1980s, and estimates of abundance were made for some of the more common cetacean species (Dohl et al. 1980; Dohl et al. 1983; Dohl et al. 1986; Brueggeman et al. 1990). Harbor porpoise abundance along the coast of California has been estimated from ship surveys in 1984-95 (Barlow 1988) and from aerial surveys in 1984-85 (Barlow et al. 1988) and 1988-93 (Barlow and Forney 1994). Harbor porpoise abundance off Oregon and Washington was estimated by aerial surveys in 1989-91 (Calambokidis et al. 1993). The abundance of most whale and dolphin species off California was estimated from ship-based surveys in summer/fall of 1991 (Barlow 1995) and aerial surveys in winter/spring of 1991 and 1992 (Forney et al. 1995). The abundance of migrating gray whales has been estimated from shore counts in 1967-80 (Reilly 1984) and 1987-88 (Buckland et al. 1993b). For the coastal population of bottlenose dolphins in California, abundance was estimated from aerial surveys in 1991-94 (Carretta et al. 1998). The abundance of blue whales and humpback whales that feed off the west coast in summer and fall has been estimated by mark-recapture methods using photo-identification (Calambokidis et al. 2002).

Despite all this cetacean survey work along the U.S. west coast, there remain significant gaps in our knowledge. The aerial surveys described above were mostly within 100 nmi of the coastline. Only the 1991 ship survey included areas between 100 and 300 nmi from the coast, and that study was limited to waters off California (south of 42° N). No cetacean abundance estimates have been published for waters that are further than 100 nmi off the coasts of Oregon and Washington. Many of the published abundance estimates are based on surveys that were conducted more than a decade ago and might not reflect current conditions or population levels.

Since 1991, additional cetacean surveys have been conducted by the Southwest Fisheries Science Center (SWFSC) in summer/fall of 1993 (California) and in summer/fall of 1996 and 2001 (California, Oregon, and Washington). Interim results from those more recent surveys are available in unpublished reports (Barlow 1994; Barlow and Gerrodette 1996; Barlow 1997; Barlow and Taylor 2001; Hill and Barlow 1992; Mangels and Gerrodette 1994; Von Saunder and Barlow 1999). In this paper, line-transect methods are used to analyze data collected from SWFSC ship surveys in 1991, 1993, 1996, and 2001 off the U.S. west coast. Effort during the 1993 survey was not sufficient to stand alone, so I pooled 1991 and 1993 survey efforts for all analyses. I used a non-linear regression technique to examine variation in the estimation of perpendicular sighting distance over this time period. I determined that data from different years could be pooled and that some species could be combined when estimating the effective strip widths for these surveys. I used previous estimates of trackline sighting probabilities (g(0)) for each species and conventional line-transect methods (Buckland et al. 1993a) to estimate the abundance for most species, stratified by year (1991/93, 1996, and 2001). I also calculated a pooled 1996-2001 estimate of abundance to best approximate the current abundance of cetaceans along the U.S. west coast. These results represent significant improvements in analyses of the 1991-96 surveys and completely new estimates from the 2001 survey.

Field Methods

All four surveys were conducted using the same line-transect survey methods from two National Oceanographic and Atmospheric Administration (NOAA) research vessels: the *R/V McArthur* and the *R/V David Starr Jordan* (Table 1). Surveys were conducted from late July through early November, with the 2001 survey extending to early December. Transect lines followed a uniform grid that was established prior to each survey. Ships traveled at 9-10 kts (16.7-18.5 km/hr) through the water. The actual transect lines surveyed each year are shown in Fig. 1.

Observers searched from the flying bridge deck of these ships (observation height 10.5 m). Typically, six observers rotated among three observation stations (left 25X binocular, recorder, and right 25X binocular) during their 2-hour watches and then rested for 2 hours. The recorder searched with naked eyes (and occasionally 7X binoculars) and entered effort and sighting data using a data entry program on a laptop computer. Observers were selected on the basis of previous experience searching and identifying marine mammals at sea; at least four observers on each ship had previous line-transect experience with cetaceans and at least two of these were considered to be experts in marine mammal identification at sea. Prior to each survey, observers were given a refresher course in marine mammal identification and were given instruction on how to best estimate group sizes. Group size and the percentage of each species in a group was estimated and recorded independently by each on-duty observer. Generally, observers were given as much time as they felt was necessary to estimate group size and species composition. Starting in 1996, at least one hour was allocated to group size estimation for sperm whales to provide reasonable confidence that all members of the group surfaced at least once. Species determinations were recorded as certain only if observers were very sure of their species identification; otherwise, "species" were identified to the lowest taxonomic level or general category (e.g., "large whale" or " baleen whale") that an observer could determine with certainty. Observers were also encouraged to separately record the most probable species if the actual species could not be determined with certainty. In this paper, I use both probable and certain species identifications rather than pro-rating the unidentified sightings into species categories.

Most surveys were conducted in closing mode during which the ship diverted from the trackline as necessary to allow closer estimation of group size and species composition. The ship was not diverted if observers felt that group size and species could be determined from the transect line, as was frequently the case of nearby sightings of Dall's porpoise or large baleen whales. Approximately every third day of effort in 1996 was conducted in passing mode (during which the ship did not divert from the trackline except for sperm whales, short-finned pilot whales, and Baird's beaked whales), to investigate potential biases associated with the use of closing mode surveys. However, no consistent biases were found, and observers noted that group size estimation and species determination suffered in "passing mode" (Barlow 1997), so this experiment was not continued during the 2001 survey.

Analytical Methods

Group Size Calibration

Previous studies have shown that individual observers may tend to over- or under-estimate group sizes and that their estimates can be improved by calibration based on a subset of groups with known size (Gerrodette et al. 2002) or based on comparison to an unbiased observer (Barlow 1995; Barlow et al. 1998). Here I use the calibration factors developed by Gerrodette et al. (2002) to correct the observers who had been directly calibrated using aerial photographic estimates of group size on dolphin surveys in the eastern tropical Pacific. Because a helicopter could not be used on the west coast surveys (the weather is too rough and the water is too turbid), many observers on these surveys were not calibrated by this direct method. Therefore, I used an indirect calibration method (Barlow et al. 1998) to calibrate these observers relative to the previously calibrated observers. The indirect calibration coefficient, β_0, for a given observer was estimated by comparison to calibrated estimates of directly calibrated observers using log-transformed regression through the origin:

$$\ln N = \beta_0 \ln \overline{S}$$

where N = observer's "best"estimate of group size, and

$\overline{S}$ = mean of calibrated, bias-corrected estimates for all other calibrated observers.

Sightings were included in calculating indirect calibration coefficients if group size estimates were made by at least two other directly calibrated observers. I used a weighted mean of the calibrated group size estimates (weighted by the inverse of the mean squared estimation error) as the best estimate of overall group size in all the analyses presented here.

Preliminary Analyses

I used generalized additive models (GAMs) to investigate methods of pooling and stratification prior to line-transect modeling of effective strip width (Barlow et al. 2001). The natural logarithm of perpendicular sighting distance was modeled as a non-linear function of factors that are likely to affect it: *species*, *Beaufort* sea state, *group size*, *glare* on the trackline, presence of *rain/fog*, *ship* (*Jordan* vs. *McArthur*), *visibility* in nautical miles, geographic stratum (*GeoStrata*: CA vs OR/WA), and survey *year* (1991/93 vs. 1996 vs. 2001; which includes the effects of different observers and other un-modeled differences between surveys) (see Barlow et al. 2001 for more details on these factors). Factor names are identified with italics in this paper. Errors in the logarithm of perpendicular distance were assumed to be normally distributed using an identity link function. An offset (0.25 km for Dall's porpoise and 0.5 km for all other species) was added to perpendicular distance prior to analysis to normalize deviations from the mean and to avoid taking the logarithm of zero.

Group size entered the models as either a continuous variable (the natural log of the weighted mean of calibrated group size estimates) or as a categorical variable. Continuous variables (*Beaufort*, *group size*, *visibility*, and *time* of day) were allowed to vary as spline fits with the degrees of freedom selected to minimize AIC.

Models were built up in complexity starting with a null model (no covariate terms) using the forward and backward stepwise procedure "step.gam" as implemented in SPlus. The best-fit model was taken as the model with the lowest AIC value. The optimal model was considered to be the simplest model within 2 AIC units of the best-fit model (to correct for the tendency of AIC to select models with too much complexity). Alternative parameterizations were considered for the optimum model based on subjective evaluation of the coefficients from the best-fit model if those parameterizations resulted in a lower AIC value.

Line-transect Analyses

Cetacean abundance was estimated using line-transect methods (Buckland et al. 1993a). The study area was divided into two geographic strata: waters off California (south of 42°N; 817,500 km^2) and waters off Oregon and Washington (north of 42°N; 325,000 km^2) (Figure 1). For some species, sightings were stratified by group size to account for differences in visibility and to minimize size bias (Buckland et al. 1993a, p. 77). The density, $D_{a\,i\,j}$, for species j within geographic stratum a and group-size stratum i was estimated as

$$D_{aij} = \frac{n_{aij}\, S_{aij}\ \ f_{ik}(0)}{2\ L_a\ \ g_{ik}(0)} \qquad (1)$$

where

n = number of sightings,
S = weighted mean group size after calibration,
$f(0)$ = sighting probability density at zero perpendicular distance,
L = length of transect line completed,
$g(0)$ = probability of seeing a group directly on the trackline, and
k = species group to which species j belongs.

To allow use of prior estimates of g(0), I used the same group size strata that were used by Barlow (1995). Geographic strata for California and Oregon/Washington are also the same as used in previous papers. In estimating f(0), data from different surveys and geographic strata were pooled, and species were pooled into groups with similar sighting characteristics: small delphinids, Risso's dolphins, bottlenose dolphins and pilot whales, Dall's porpoise, small whales, medium whales, large whales, sperm whales and humpback whales (see results for justification). I estimated f(0) using options for a hazard-rate key function with hermite polynomial adjustments and a half-normal key function with cosine adjustments using the program DISTANCE[1]. AIC was used to select the best model. Within each species group, the truncation distances were selected to eliminate the most distant 15% of sightings before estimating f(0). Estimates of g(0) for these species and group size strata were taken from Barlow (1995) and Barlow (1999). Because g(0) increases dramatically with sea state for small whales and Dall's porpoise, estimates for those species were based on search effort conducted in Beaufort sea state 0 to 2 (Fig 1); abundances of other species were based on search effort in Beaufort 0 to 5 (Fig 1).

The total abundance for species j in area a, ($N_{a\,j}$), is estimated as the sum of the densities in all s group size strata times the size of the study area, A_a ,

$$N_{aj} = A_a \sum_{i=1}^{s} D_{aij}$$

The coefficients of variation (CV) for abundance were estimated as the square root of the sum of the squared CVs of f(0), g(0), and the encounter rate ($n \cdot S / L$). The CV of the encounter rate was estimated empirically by breaking the transects into 100 km segments and calculating the standard

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[1] Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., and Pollard, J.H. 2002. Distance 4.0. Release Beta 6. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

error among segments (Buckland et al. 1993a, p. 110). The CV of f(0) was estimated by the program DISTANCE using an information matrix approach. The CV of g(0) was estimated using an analytical formula for most species (Barlow 1995, Appendix) or from a simulation model based on search behavior and dive times for long-diving species (pygmy sperm whales, Baird's beaked whales, Cuvier's beaked whales, and mesoplodont beaked whales) (Barlow 1999).

Results

Search Effort

Survey effort in Beaufort sea states 0-5 covered the study areas uniformly in 1991/93, 1996, and 2001 (Fig. 1). Although not all the planned transects were covered (due to weather and mechanical breakdowns), the holes in the survey grid are relatively small, and all areas appear to be well covered. The density of survey effort in the California stratum was greatest for 1991/93 (16,437 km), less in 1996 (10,401 km), and least in 2001 (6,489 km). The density of coverage in the Oregon/Washington stratum was greater in 1996 (4,349 km) than in 2001 (3,133 km).

Survey effort in calm sea conditions (Beaufort 0-2) was not as uniformly distributed. Only in 1991/93 was geographic survey effort well distributed in both an a long-shore and an offshore direction in the California study area. In 1996, inshore waters were over-represented in calm conditions, and in 2001, extreme southern and northern areas were under-represented.

Group Size Calibration

Regression coefficients for the indirect method of group size calibration are presented in Table 3. Most of the coefficients are less than one, indicating that observers are more likely to underestimate group size.

Preliminary Analyses

The best generalized additive model varied among species groups in the number and type of predictor variables (Table 4). Generally, more complex models were accepted for species groups with larger samples sizes.

The most complex models were for delphinids, which had the largest sample size. *Species* was a significant factor and was added to the model after *GroupSize* and *Beaufort* sea state. Inspection of the coefficients for each species indicated that large delphinids (bottlenose dolphins, Risso's dolphins, and pilot whales) were seen at greater perpendicular distances than the other delphinids (after allowing for other factors that affect perpendicular sighting distance). I found that a new categorical variable (small delphinid or *Grampus* or *Tursiops/Globicephala*) could replace *species* as a factor and give a lower AIC value. *Ship* was a significant factor, and sightings were made at greater perpendicular distances from the *McArthur* than from the *Jordan*. *Time* of day was selected as being significant in the stepwise fit, but it's effect was small and was eliminated in the optimal model. For line-transect analyses of delphinids, the categories of small delphinid, *Grampus*, and *Tursiops/Globicephala* were analyzed separately, and sightings were stratified by group size, the variable that was added first in the stepwise fit.

For Dall's porpoise sightings in calm seas (Beaufort 0-2), geographic strata (*GeoStrata*), survey year (*SurveyYr*), and *visibility* were all significant factors in explaining variation in perpendicular sighting distance. None of these variables stood out as being more important than any of the others. For line-transect analyses of Dall's porpoises, all sightings were pooled to estimate f(0), and samples were limited to sea states of Beaufort 2 or better (as was done in previous analyses, Barlow 1995).

For small whales, *ship* was the only significant factor in the stepwise fitting, and, in this case, sightings were seen at greater distances from the *Jordan*. However, there were only 5 sightings of small whales from the *Jordan*, and the optimal model excludes this factor. For line-transect analyses of small whales, all sightings were pooled to estimate f(0) and samples were limited to sea states of Beaufort 2 or better.

For sightings of medium sized whales, *visibility*, *GeoStrata*, and *ship* were all significant factors in the stepwise fit. There were only six sightings in the OR/WA stratum and there were only six sightings of small whales made from the *Jordan*. *Ship* was dropped as a factor in the optimal model. Due to small sample size, all sightings of medium sized whales were pooled in the line-transect analyses.

For large whale sightings, *species*, *rain/fog*, and *ship* were added (in that order) by the step-wise fitting algorithm. Two species, sperm whales and humpback whales, stood as outliers, both being detected at greater perpendicular distances. When the factor *species* was replaced by a categorical factor (either sperm whale or humpback whale or other large whale), AIC was lowered and a better model was obtained. *Ship* and *rain /fog* remained as significant variables in the optimal model. In this case, sightings were made at greater perpendicular distances from the *McArthur*. Separate line-transect parameters were estimated for these three species group: sperm whales, humpback whales and other large whales (including blue whales, fin whales and killer whales).

Abundance Estimates

Estimated effective strip width (ESW) and truncation criteria for each of the species groups and group size strata are given in Table 5. As expected, for delphinids, ESW is greater for larger groups. Cetacean abundance estimates for each survey year and area (1991/93 CA, 1996 CA, 1996 OR/WA, 2001 CA, and 2001 OR/WA) are presented in Tables 6-10(respectively). Abundance estimates for all surveys are summarized in Table 11.

In estimating ESW for small delphinids, stratification by group size yielded better estimates (using either the hazard rate or half-normal key functions). Based on AIC, the best models were obtained using the hazard rate model with one hermite polynomial term for small groups (≤ 20 individuals), the hazard rate model for medium sized groups (>20, ≤ 100), and the half-normal model with one cosine term for large groups (>100). The correlation between estimated detection probability and group size was significant for small and medium groups, indicating some group size bias that was not accounted for by using this group size stratification. Overall, common dolphins were, by far, the most common cetacean. In the Oregon/Washington stratum, Pacific white-sided dolphins and northern right whale dolphins were the most common small delphinids, and the abundance of common dolphins appeared to vary greatly between years.

Stratification by group size also resulted in better estimates of ESW for large delphinids (*Grampus* and *Tursiops/Globicephala*). The best detection model used the half-normal function with one cosine term for smaller groups ($\leq$ 20) of Risso's dolphins and the half-normal function for all other categories. The most common large delphinids in the California stratum were bottlenose dolphins and Risso's dolphins. In the Oregon/Washington stratum, only Risso's dolphins were common. Pilot whales were seen only during the 1991/93 and 1996 surveys.

For Dall's porpoise, abundance estimates were based only on search effort in calm seas to ensure that animals were detected before they reacted to the vessel. Even under these good conditions, the effective strip width was only 820 m (Table 5). The hazard rate model gave the best fit to the sighting distribution for this species. Given the precision of the estimates, abundance appeared to be relatively constant among surveys in the California stratum but varied by almost an order of magnitude in the Oregon/Washington stratum (Table 1). The distribution of search effort in calm seas was not geographically uniform in 1996 or 2001, and this probably contributes to the among year variation seen in abundance estimates for Dall's porpoise.

The estimates of abundance for small whales were similarly based only on effort in calm seas. The half-normal key function with one cosine term gave the best fit for this species group. Beaked whales appeared more common in 1991/93 for both the common genera (7 sightings of *Mesoplodon* and 13 sightings of *Ziphius*). In 1996, there were only 3 sightings of *Mesoplodon* and two of *Ziphius*, and in 2001 *Mesoplodon* was not seen and there was only one sighting of *Ziphius*. Dwarf and pygmy sperm whales (*Kogia* spp.) were not seen in 2001. Minke whales were seen in each survey year and their abundance estimates did not appear to fluctuate as much as the other species in this group.

The medium sized whales were the species group with the smallest number of total sightings (23 within the truncation distance of 4.7 km). All sightings were pooled, and the best fit to their sighting distributions was obtained with a half-normal model. Bryde's and sei whales remained extremely rare in the study area throughout all survey years. The abundance of Baird's beaked whales, like that of smaller beaked whales, appeared to decline during the study period (Table 11).

The *a priori* category of large whales was split into three sub-categories for the purpose of estimating line-transect parameters. Of these groups, the effective strip width was least for blue, fin and killer whales, was intermediate for humpback whales, and was greatest for sperm whales. The best detection model was different for each group (Table 5). The estimated abundance of fin whales increased monotonically during the three survey periods, but the abundance of all other species showed patterns that included both ups and downs. Killer whale abundance in the Oregon/Washington stratum appeared comparable to or greater than that in the larger California stratum.

Discussion

Previous Abundance Estimates

Estimates presented here differ, typically by a small amount, from previous estimates from the 1991, 1993, and 1996 surveys (Barlow 1995; Barlow and Gerrodette 1996; Barlow 1997). The differences are primarily due to differences in the stratification and species groupings used for estimating ESW. The ability to pool samples from several surveys results in a larger sample size for estimating of ESW and allowed stratification by other factors (including more species groups). Both should result in more precise estimates of cetacean abundance. Also, the estimates of Barlow (1997) did not include group size calibration for individual observers, and therefore the present estimates for the 1996 survey should have corrected a small negative bias present in those earlier estimates. The estimates presented here are expected to be more precise and less biased than previous estimates. The greater precision is not necessarily reflected in lower CVs because CVs are often not estimated very accurately.

Delphinids

Delphinids off the U.S. west coast can be classified as either warm-temperate to tropical (short- and long-beaked common dolphins, striped dolphins, bottlenose dolphins, and short-finned pilot whales), cold-temperate (Pacific white-sided dolphins and northern right whale dolphins), or cosmopolitan (Risso's dolphin and killer whales). The abundance of two warm-water species (short-beaked common dolphins and striped dolphins) appeared lower in 1996 than in 1991/93 or 2001. Two other warm-water species exhibited the opposite pattern (long-beaked common dolphins and bottlenose dolphins), but in both of those cases, the high abundance estimate and high CV in 1996 was probably the result of the chance observation of a few very large groups. The cold-temperate species were more abundant in 1996. The cosmopolitan species did not vary much in abundance among years. The shifting patterns of warm and cold temperate species matches the seasonal changes in distributions seen for these species (Forney and Barlow 1998).

Dall's Porpoise

Abundance estimation for Dall's porpoise is difficult due to their attraction to vessels. To obtain unbiased estimates, these animals must be detected before they react to the survey vessel. Our data indicate that the behavior of the vast majority of Dall's porpoise seen at low sea states is "slow rolling". This contrasts with the "rooster-tailing" or fast swimming behavior seen by animals that are approaching the ship. However, limiting effort to calm conditions (Beaufort 2 and better) limits the number of sightings and, more importantly, limits effort to transect lines that are not geographically uniform (Fig. 1). As a result, the coefficients of variation for Dall's porpoise abundance are greater than would be expected for the relatively large number of sightings. The temporal pattern shows higher Dall's porpoise abundance in 1996, mirroring the higher abundance that year of other cold-temperate delphinids (see above); however, given the lack of precision and the lack of uniform geographic coverage, this pattern may be entirely coincidental.

Baleen Whales

The common baleen whales in California waters are blue, fin, and humpback whales. The abundance of these species is consistently high during this study period. More precise estimates of humpback whale abundance are available from mark-recapture studies (Calambokidis et al. 2002), and these data indicate an increase in abundance through most of the 1990s followed by a decrease. The same pattern is found in my abundance estimates, but with less precision and no statistically significant indication of a pattern. Estimates of blue whale abundance decreased markedly in 2001 compared to previous estimates. In the same year, Calambokidis et al. (2002) found that blue whales were very concentrated in California waters facilitating the collection of many identification photographs. This difference in perceived density of blue whales in 2001 may have been an artifact of their greater concentration; if whales were concentrated in one area, they could be easier to work for photo-identification, but such areas might be missed by chance on a random line-transect survey. Fin whales appear to be monotonically increasing in abundance during the three survey periods, and a more detailed study of trends in fin whale abundance would be warranted (possibly including an earlier 1979/80 survey as well).

After nearly a decade of survey effort, it is now clear that Bryde's and sei whales are not common off the U.S. west coast and that minke whale density is also low compared to other minke whale habitats. Bryde's whales are commonly viewed as tropical baleen whales, so their low abundance is expected. However, sei whales were previously harvested commercially in the region by coastal whaling stations, and their near absence is more of a mystery.

Sperm Whales

The abundance of sperm whales is more variable than that of the other large whales with similar population sizes. There may be several reasons for this. The most obvious is that sperm whales occur in larger groups and fewer groups are seen on each survey. High group size variation and low numbers of groups both contribute to higher CVs. Also, the sperm whale population is likely to extend outside the study area, at least during some times of year. Sperm whales that were marked off southern California in winter were later recovered by whalers north of the study area. It is likely that at least some fraction of the population is absent during part of the year, and that fraction may vary with oceanographic conditions. This differs from the situation with humpback and blue whales for which the majority of the population is believed to be feeding in U.S. west coast waters during the time of the surveys.

Beaked Whales

The apparent pattern of decreasing beaked whale abundance for all the common genera (*Mesoplodon*, *Ziphius*, and *Berardius*) is disconcerting, especially in light of recent discoveries about the susceptibility of this group to loud anthropogenic sounds (Anon. 2001, Simmonds and Lopez-Jurado 1991). However, sea states during the 1996 and 2001 surveys were rougher than in 1991/93 which could contribute to an apparent decline. Also, the geographic coverage in calm seas is not uniform, especially in later years. The distribution of all species extends outside the study area, and it is likely that some individuals move in and out of the study area based on habitat changes. An accurate analysis of trends in beaked whale abundance would have to include consideration of these effects. It is possible that sightings at higher sea states could also be used in an analysis of beaked whale trends if the relative sighting efficiencies in different conditions could be included as a covariate.

Future Research

The results presented here are preliminary and will be improved by future analyses. The GAMs analyses showed that many factors other than *species*, *Beaufort*, and *group size* can affect perpendicular sighting distance. For example, *ship* appeared several times as a significant factor, with sightings being made at greater average distance from the *McArthur* than from the *Jordan*. *GeoStrata* and *year* were also significant for some species groups. Line-transect abundance estimates can be improved by incorporating these factors as covariates when estimating ESW (Forcada 2002). The methods used in this paper are dependent on "pooling robustness", and pooled estimates should be unbiased, but estimates that are stratified by geographic region or year may be biased. Precision can likely be improved by using covariate models. Existing software for such analyses does not permit stratification by species and geographic area, so custom software will have to be written to facilitate such analyses.

The estimates of g(0) used here to account for perception bias for most species are based on independent observer data from 1991 only. Additional data have been collected in subsequent years and could be used to improve estimates of g(0) for many species. Also, acoustic data on the probability of detecting sperm whales have been collected on recent SWFSC surveys and could be used to improve estimates of g(0) for sperm whales to account for both perception and availability bias.

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Table 1. Survey dates, ships used, and areas surveyed.

Survey	Ship	Dates	Area
CAMMS-91	*McArthur*	28 Jul. - 05 Nov. 1991	California
PODS-93	*McArthur*	28 Jul. - 06 Nov. 1993	California
ORCAWALE-96	*McArthur* *Jordan*	17 Jul.- 14 Oct. 1996 04 Sep.-06 Nov. 1996	California/Oregon/ Washington
ORCAWALE-01	*McArthur* *Jordan*	30 Jul. - 08 Dec. 2001	California/Oregon/ Washington

Table 2. *A priori* species groups and number of sightings used in GAM analyses of factors affecting perpendicular sighting distance. GAM coefficients represent the component of perpendicular sighting distance attributable to the given species after accounting for other factors affecting perpendicular distance in the model. Overall GAM coefficients are based on the best-fit model including all species and within-group GAM coefficients are based on the best-fit model (plus *species*, if not in best-fit model) for a given species group (Table 4). Positive GAM coefficients indicate greater perpendicular distances.

Species Group **Common Name**	**Number Sightings**	**Overall GAM Coefficients**	**Within-Group GAM Coefficients**
Delphinids			
unidentified common dolphin	23	-0.18	0.06
striped dolphin	64	-0.28	-0.10
long-beaked common dolphin	15	0.02	0.11
short-beaked common dolphin	412	-0.35	-0.30
Pacific white-sided dolphin	70	-0.24	-0.13
northern right whale dolphin	67	-0.24	-0.15
bottlenose dolphin	39	0.02	0.17
Risso's dolphin	102	-0.12	0.06
short-finned pilot whale	5	0.03	0.29
Dall’s Porpoises			
Dall's porpoise	376	-0.31	N/A
Small Whales			
unidentified Mesoplodon	29	-0.01	0.50
Cuvier's beaked whale	46	-0.17	-0.11
dwarf or pygmy sperm whales	7	-0.25	-0.36
minke whale	19	-0.17	-0.31
Medium Whales			
Baird's beaked whale	15	-0.01	0.01
sei or Bryde's whales	12	0.41	-0.01
Large Whales			
killer whale	22	0.29	-0.01
fin whale	173	0.16	-0.11
blue whale	202	0.19	-0.19
humpback whale	113	0.36	0.07
sperm whale	62	0.40	0.25

Table 3. Regression coefficients, β_0 , estimated for the indirect calibration of group size based on a comparison of an individual observer's "best" estimates of group size with the mean calibrated group size estimated from two or more other "calibrated" observers for all years pooled. ASPE indicates the average squared prediction error using this regression coefficient. Calibration coefficients for directly calibrated observers are given by Gerrodette et al. 2002.

Observer Number	Sample Size	β_0	ASPE
077	58	0.984	.0849
088	61	0.822	.2945
104	125	0.887	.2281
138	27	0.903	.1550
143	41	0.943	.1764
145	45	0.898	.2377
148	23	1.005	.4293
154	23	0.947	.0902
201	85	0.886	.1970

Table 4. Factors included in generalized additive models that best estimate mean perpendicular distance for *a priori* species groups. Factors are listed in the order they were added to the model (most significant factors first). Best-fit models are the lowest-AIC models obtained using a stepwise fitting algorithm. Optimal models are the simplest models within 2 AIC units of the best-fit models. Alternative species groupings were adopted for optimal models if the best-fit models included species as a significant factor and if a lower AIC value could be obtained. Numbers in parentheses after continuous variables are the number of terms in spline-fit models.

Species Group	**Factors**	AIC
Delphinids		
Best-fit Model	*GroupSize*(4) + *Beauf*(2) + *Species* + *Ship* + *Time*	304.3
Optimal Model	*GroupSize*(4) + *RankBeauf* + (*Sm vs. Lg Delphinid*) + *Ship*	301.8
Dall's Porpoises (Beauf. <= 2)		
Best-fit Model	*GeoStrata* + *SurveyYr* + *Visibility*	174.9
Optimal Model	GeoStrata + SurveyYr + Visibility	174.9
Small Whales (Beauf. <= 2)		
Best-fit Model	*Ship*	44.6
Optimal Model	NULL	46.5
Medium Whales		
Best-fit Model	*Visibility* + *GeoStrata* + *Ship*	13.0
Optimal Model	*Visibility* + *GeoStrata*	14.0
Large Whales		
Best-fit Model	*Species* + *RainFog* + *Ship*	302.4
Optimal Model	(*Sperm whale vs. Humpback vs. Others*) + *RainFog* + *Ship*	301.3

Table 5. Estimates of effective strip width (ESW = 1/f(0)) and associated coefficients of variation (CV) used to estimate abundance in each species group. f(0) was estimated using the program DISTANCE (v. 4.x). The best model was chosen on the basis of AIC using either the hazard rate model modified as necessary with hermite polynomial terms or the half-normal model modified as necessary with cosine terms. Sample size (n) is the number of sightings within a truncation distance that was set to eliminate the most distant 15% of sightings.

Species Group	Beaufort Sea States Used	Group Size Strata	Best Key Function	Additional Terms	Sample Size n	Truncation Distance (km)	ESW (km)	CV ESW
Small delphinids	0-5	≤ 20	hazard	-	170	3.33	0.50	0.21
		>20, ≤ 100	hazard	-	184		1.24	0.18
		>100	half normal	1 cosine	136		1.84	0.12
Grampus	0-5	≤ 20	half normal	1 cosine	62	2.92	1.37	0.16
		>20	half normal	-	26		2.18	0.20
Tursiops/Globicephala	0-5	≤ 20	half normal	-	19	4.22	1.56	0.16
		>20	half normal	-	21		4.22	0.22
Dall's porpoise	0-2	All	hazard	-	196	2.22	0.82	0.14
Small whales	0-2	All	half normal	1 cosine	48	3.38	1.76	0.19
Medium whales	0-5	All	half normal	-	23	4.73	2.82	0.15
Blue/Fin/Killer whales	0-5	All	hazard	1 hermite	326	4.02	1.72	0.16
Humpback whales	0-5	All	half normal	1 hermite	95	4.74	2.89	0.15
Sperm whales	0-5	All	half normal	-	50	5.95	4.61	0.13

Table 6. Line-transect abundance estimates of cetaceans for the California stratum of the 1991/93 survey.

Cetacean Abudance Estimation	km surveyed	16,437		Area surveyed
1991-93 CAMMS/PODS Surv	Beauf 0-2	3,782	% Calm= 23.0	817,549 km^{-2}
CA Only	Beauf 3-5	12,654	% Rough= 77.0	

SPECIES GROUP Species Stratum	# sightings n	group size S	ESW (km) 1/f(0)	g(0)	transect length (km) L	density (km^{-2}) D	abundance N	CV N	CV n*S/L	CV f(0)	CV g(0)
SMALL DELPHINIDS											
short-beaked common dolphin											
Group size 1-20	46	11.4	0.502	0.77	16,437	0.0412		0.31	0.19	0.21	0.14
Group size 21-100	82	46.1	1.236	1.00	16,437	0.0929		0.23	0.15	0.18	0.00
Group size >100	76	335.2	1.880	1.00	16,437	0.4122		0.27	0.20	0.18	0.00
Total	204	146.0				0.5463	446,595	0.21			
long-beaked common dolphin											
Group size 1-20	1	13.4	0.502	0.77	16,437	0.0011		1.03	1.00	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	16,437	0.0000		N/A	N/A	0.18	0.00
Group size >100	3	250.5	1.880	1.00	16,437	0.0122		0.82	0.80	0.18	0.00
Total	4	191.2				0.0132	10,799	0.76			
unclassified common dolphin											
Group size 1-20	8	4.9	0.502	0.77	16,437	0.0031		0.48	0.41	0.21	0.14
Group size 21-100	2	37.1	1.236	1.00	16,437	0.0018		0.73	0.71	0.18	0.00
Group size >100	1	114.8	1.880	1.00	16,437	0.0019		1.02	1.00	0.18	0.00
Total	11	20.7				0.0067	5,513	0.41			
striped dolphin											
Group size 1-20	4	10.5	0.502	0.77	16,437	0.0033		0.67	0.62	0.21	0.14
Group size 21-100	6	20.6	1.236	1.00	16,437	0.0030		0.69	0.67	0.18	0.00
Group size >100	25	70.2	1.880	1.00	16,437	0.0284		0.36	0.31	0.18	0.00
Total	35	54.9				0.0347	28,396	0.31			
Pacific white-sided dolphin											
Group size 1-20	11	7.5	0.502	0.77	16,437	0.0065		0.46	0.39	0.21	0.14
Group size 21-100	7	32.6	1.236	1.00	16,437	0.0056		0.50	0.47	0.18	0.00
Group size >100	1	43.6	1.880	1.00	16,437	0.0007		1.02	1.00	0.18	0.00
Total	19	18.6				0.0128	10,500	0.33			
northern right whale dolphin											
Group size 1-20	11	8.8	0.502	0.77	16,437	0.0076		0.73	0.69	0.21	0.14
Group size 21-100	7	12.7	1.236	1.00	16,437	0.0022		0.56	0.53	0.18	0.00
Group size >100	2	71.3	1.880	1.00	16,437	0.0023		0.73	0.71	0.18	0.00
Total	20	16.4				0.0121	9,929	0.49			
GRAMPUS											
Risso's dolphin											
Group size 1-20	23	7.7	1.370	0.74	16,437	0.0053		0.50	0.26	0.16	0.39
Group size >20	18	30.7	2.180	1.00	16,437	0.0077		0.35	0.29	0.20	0.00
Total	41	17.8				0.0130	10,624	0.29			

Table 6. (Continued).

TURSIOPS/GLOBICEPHALA											
bottlenose dolphin											
Group size 1-20	**5**	**3.4**	**1.560**	**0.74**	**16,437**	**0.0004**		**0.75**	**0.62**	**0.16**	**0.39**
Group size >20	**12**	**13.0**	**4.220**	**1.00**	**16,437**	**0.0011**		**0.41**	**0.35**	**0.22**	**0.00**
Total	**17**	**10.2**				**0.0016**	**1,282**	**0.36**			
pilot whale											
Group size 1-20	**2**	**11.5**	**1.560**	**0.74**	**16,437**	**0.0006**		**0.83**	**0.71**	**0.16**	**0.39**
Group size >20	**2**	**18.5**	**4.220**	**1.00**	**16,437**	**0.0003**		**0.74**	**0.71**	**0.22**	**0.00**
Total	**4**	**15.0**				**0.0009**	**713**	**0.62**			
DALL'S PORPOISE											
Dall's porpoise											
Calm Seas	**58**	**3.2**	**0.819**	**0.79**	**3,782**	**0.0384**	**31,396**	**0.31**	**0.26**	**0.14**	**0.10**
SMALL WHALES											
ziphiid whale											
Calm Seas	**2**	**1.5**	**1.764**	**0.34**	**3,782**	**0.0006**	**530**	**0.79**	**0.71**	**0.19**	**0.29**
Mesoplodon spp.											
Calm Seas	**7**	**1.8**	**1.764**	**0.45**	**3,782**	**0.0020**	**1,668**	**0.48**	**0.38**	**0.19**	**0.23**
Cuvier's beaked whale											
Calm Seas	**13**	**2.4**	**1.764**	**0.23**	**3,782**	**0.0102**	**8,311**	**0.50**	**0.30**	**0.19**	**0.35**
***Kogia* spp.**											
Calm Seas	**4**	**1.0**	**1.764**	**0.35**	**3,782**	**0.0009**	**700**	**0.50**	**0.36**	**0.19**	**0.29**
minke whale											
Calm Seas	**3**	**1.0**	**1.764**	**0.84**	**3,782**	**0.0003**	**221**	**0.44**	**0.33**	**0.19**	**0.22**
MEDIUM WHALES											
Baird's beaked whale											
Total	**6**	**13.9**	**2.825**	**0.96**	**16,437**	**0.0009**	**765**	**0.61**	**0.55**	**0.15**	**0.23**
Bryde's whale											
Total	**1**	**2.0**	**2.825**	**0.90**	**16,437**	**0.0000**	**20**	**1.01**	**1.00**	**0.15**	**0.07**
sei whale											
Total	**3**	**1.4**	**2.825**	**0.90**	**16,437**	**0.0000**	**40**	**0.79**	**0.77**	**0.15**	**0.07**
sei/Bryde's whale											
Total	**5**	**1.0**	**2.825**	**0.90**	**16,437**	**0.0001**	**49**	**0.53**	**0.50**	**0.15**	**0.07**
LARGE WHALES											
killer whale											
Total	**5**	**5.6**	**1.715**	**0.90**	**16,437**	**0.0006**	**454**	**0.50**	**0.47**	**0.16**	**0.07**
fin whale											
Total	**51**	**2.0**	**1.715**	**0.90**	**16,437**	**0.0020**	**1,635**	**0.35**	**0.30**	**0.16**	**0.07**
blue whale											
Total	**92**	**1.8**	**1.715**	**0.90**	**16,437**	**0.0033**	**2,713**	**0.24**	**0.17**	**0.16**	**0.07**
HUMPBACK WHALE											
humpback whale											
Total	**26**	**2.2**	**2.894**	**0.90**	**16,437**	**0.0007**	**551**	**0.41**	**0.37**	**0.15**	**0.07**
SPERM WHALE											
sperm whale											
Total	**28**	**6.7**	**4.607**	**0.87**	**16,437**	**0.0014**	**1,168**	**0.40**	**0.37**	**0.13**	**0.08**

Table 7. Line-transect abundance estimates of cetaceans for the California stratum of the 1996 survey.

Cetacean Abudance Estimation	km surveyed	10,401		Area surveyed
1996 ORCAWALE Survey	Beauf 0-2	1,579	% Calm= 15.2	817,549 km^{-2}
CA Only	Beauf 3-5	8,821	% Rough= 84.8	

SPECIES GROUP Species Stratum	# sightings n	group size S	ESW (km) 1/f(0)	g(0)	transect length (km) L	density (km^{-2}) D	abundance N	CV N	CV n*S/L	CV f(0)	CV g(0)
SMALL DELPHINIDS											
short-beaked common dolphin											
Group size 1-20	21	11.9	0.502	0.77	10,401	0.0311		0.38	0.29	0.21	0.14
Group size 21-100	34	48.1	1.236	1.00	10,401	0.0636		0.35	0.30	0.18	0.00
Group size >100	41	348.4	1.880	1.00	10,401	0.3653		0.29	0.23	0.18	0.00
Total	96	168.4				0.4600	376,040	0.24			
long-beaked common dolphin											
Group size 1-20	1	15.2	0.502	0.77	10,401	0.0019		1.03	1.00	0.21	0.14
Group size 21-100	1	22.1	1.236	1.00	10,401	0.0009		1.02	1.00	0.18	0.00
Group size >100	4	1006.6	1.880	1.00	10,401	0.1030		0.74	0.72	0.18	0.00
Total	6	677.3				0.1057	86,414	0.72			
unclassified common dolphin											
Group size 1-20	6	8.8	0.502	0.77	10,401	0.0066		0.56	0.50	0.21	0.14
Group size 21-100	2	27.3	1.236	1.00	10,401	0.0021		0.73	0.71	0.18	0.00
Group size >100	2	18.9	1.880	1.00	10,401	0.0010		0.73	0.71	0.18	0.00
Total	10	14.5				0.0097	7,906	0.42			
striped dolphin											
Group size 1-20	1	2.0	0.502	0.77	10,401	0.0002		1.03	1.00	0.21	0.14
Group size 21-100	2	53.5	1.236	1.00	10,401	0.0042		0.73	0.71	0.18	0.00
Group size >100	8	11.3	1.880	1.00	10,401	0.0023		0.47	0.44	0.18	0.00
Total	11	18.1				0.0067	5,489	0.48			
Pacific white-sided dolphin											
Group size 1-20	5	8.9	0.502	0.77	10,401	0.0055		0.70	0.65	0.21	0.14
Group size 21-100	8	52.2	1.236	1.00	10,401	0.0162		0.46	0.43	0.18	0.00
Group size >100	6	520.1	1.880	1.00	10,401	0.0798		0.89	0.87	0.18	0.00
Total	19	188.6				0.1016	83,032	0.70			
northern right whale dolphin											
Group size 1-20	1	4.7	0.502	0.77	10,401	0.0006		1.03	1.00	0.21	0.14
Group size 21-100	3	24.0	1.236	1.00	10,401	0.0028		0.79	0.77	0.18	0.00
Group size >100	5	113.1	1.880	1.00	10,401	0.0145		0.66	0.64	0.18	0.00
Total	9	71.4				0.0178	14,593	0.55			
GRAMPUS											
Risso's dolphin											
Group size 1-20	10	7.7	1.370	0.74	10,401	0.0036		0.58	0.40	0.16	0.39
Group size >20	5	63.2	2.180	1.00	10,401	0.0070		0.70	0.67	0.20	0.00
Total	15	26.2				0.0106	8,672	0.50			

Table 7. (Continued).

TURSIOPS/GLOBICEPHALA											
bottlenose dolphin											
Group size 1-20	**4**	**2.7**	**1.560**	**0.74**	**10,401**	**0.0004**		**0.77**	**0.65**	**0.16**	**0.39**
Group size >20	**5**	**109.5**	**4.220**	**1.00**	**10,401**	**0.0062**		**1.12**	**1.10**	**0.22**	**0.00**
Total	**9**	**62.0**				**0.0067**	**5,464**	**1.05**			
pilot whale											
Group size 1-20	**0**	**0.0**	**1.560**	**0.74**	**10,401**	**0.0000**		**N/A**	**N/A**	**0.16**	**0.39**
Group size >20	**1**	**65.3**	**4.220**	**1.00**	**10,401**	**0.0007**		**1.02**	**1.00**	**0.22**	**0.00**
Total	**1**	**65.3**				**0.0007**	**608**	**1.02**			
DALL'S PORPOISE											
Dall's porpoise											
Calm Seas	**53**	**3.3**	**0.819**	**0.79**	**1,579**	**0.0859**	**70,207**	**0.56**	**0.53**	**0.14**	**0.10**
SMALL WHALES											
ziphiid whale											
Calm Seas	**2**	**1.0**	**1.764**	**0.34**	**1,579**	**0.0011**	**863**	**1.06**	**1.00**	**0.19**	**0.29**
Mesoplodon spp.											
Calm Seas	**1**	**1.0**	**1.764**	**0.45**	**1,579**	**0.0004**	**326**	**1.04**	**1.00**	**0.19**	**0.23**
Cuvier's beaked whale											
Calm Seas	**2**	**1.5**	**1.764**	**0.23**	**1,579**	**0.0023**	**1,876**	**0.81**	**0.71**	**0.19**	**0.35**
***Kogia* spp.**											
Calm Seas	**0**	**0.0**	**1.764**	**0.35**	**1,579**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.29**
minke whale											
Calm Seas	**4**	**1.1**	**1.764**	**0.84**	**1,579**	**0.0009**	**776**	**0.51**	**0.42**	**0.19**	**0.22**
MEDIUM WHALES											
Baird's beaked whale											
Total	**2**	**9.5**	**2.825**	**0.96**	**10,401**	**0.0003**	**275**	**0.76**	**0.71**	**0.15**	**0.23**
Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**10,401**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
sei whale											
Total	**2**	**2.8**	**2.825**	**0.90**	**10,401**	**0.0001**	**86**	**0.73**	**0.71**	**0.15**	**0.07**
sei/Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**10,401**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
LARGE WHALES											
killer whale											
Total	**4**	**6.0**	**1.715**	**0.90**	**10,401**	**0.0007**	**613**	**0.61**	**0.58**	**0.16**	**0.07**
fin whale											
Total	**56**	**1.9**	**1.715**	**0.90**	**10,401**	**0.0032**	**2,638**	**0.34**	**0.29**	**0.16**	**0.07**
blue whale											
Total	**73**	**1.4**	**1.715**	**0.90**	**10,401**	**0.0032**	**2,584**	**0.28**	**0.22**	**0.16**	**0.07**
HUMPBACK WHALE											
humpback whale											
Total	**53**	**1.9**	**2.894**	**0.90**	**10,401**	**0.0018**	**1,503**	**0.44**	**0.41**	**0.15**	**0.07**
SPERM WHALE											
sperm whale											
Total	**9**	**4.4**	**4.607**	**0.87**	**10,401**	**0.0005**	**391**	**0.56**	**0.54**	**0.13**	**0.08**

Table 8. Line-transect abundance estimates of cetaceans for the Oregon/Washington stratum of the 1996 survey.

Cetacean Abudance Estimation	km surveyed	4,349		Area surveyed
1996 ORCAWALE Survey	Beauf 0-2	533	% Calm= 12.3	325,018 km^{-2}
OR+WA Only	Beauf 3-5	3,816	% Rough= 87.7	

SPECIES GROUP					transect	density					
Species	# sightings	group size	ESW (km)		length (km)	(km^{-2})	abundance	CV	CV	CV	CV
Stratum	n	S	1/f(0)	g(0)	L	D	N	N	n*S/L	f(0)	g(0)
SMALL DELPHINIDS											
short-beaked common dolphin											
Group size 1-20	0	0.0	0.502	0.77	4,349	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Group size >100	1	317.8	1.880	1.00	4,349	0.0194		1.02	1.00	0.18	0.00
Total	1	317.8				0.0194	6,316	1.02			
long-beaked common dolphin											
Group size 1-20	0	0.0	0.502	0.77	4,349	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Total	0	0.0				0.0000	0	N/A			
unclassified common dolphin											
Group size 1-20	0	0.0	0.502	0.77	4,349	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Total	0	0.0				0.0000	0	N/A			
striped dolphin											
Group size 1-20	0	0.0	0.502	0.77	4,349	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	4,349	0.0000		N/A	N/A	0.18	0.00
Group size >100	1	3.2	1.880	1.00	4,349	0.0002		1.02	1.00	0.18	0.00
Total	1	3.2				0.0002	64	1.02			
Pacific white-sided dolphin											
Group size 1-20	1	11.0	0.502	0.77	4,349	0.0033		1.03	1.00	0.21	0.14
Group size 21-100	2	16.3	1.236	1.00	4,349	0.0030		0.73	0.71	0.18	0.00
Group size >100	1	333.9	1.880	1.00	4,349	0.0204		1.02	1.00	0.18	0.00
Total	4	94.4				0.0267	8,683	0.79			
northern right whale dolphin											
Group size 1-20	2	7.4	0.502	0.77	4,349	0.0044		0.75	0.71	0.21	0.14
Group size 21-100	1	20.3	1.236	1.00	4,349	0.0019		1.02	1.00	0.18	0.00
Group size >100	2	74.9	1.880	1.00	4,349	0.0092		0.73	0.71	0.18	0.00
Total	5	37.0				0.0155	5,026	0.50			
GRAMPUS											
Risso's dolphin											
Group size 1-20	4	4.2	1.370	0.74	4,349	0.0019		0.70	0.56	0.16	0.39
Group size >20	5	88.4	2.180	1.00	4,349	0.0233		0.73	0.70	0.20	0.00
Total	9	50.9				0.0252	8,187	0.68			

Table 8. (Continued).

TURSIOPS/GLOBICEPHALA											
bottlenose dolphin											
Group size 1-20	**0**	**0.0**	**1.560**	**0.74**	**4,349**	**0.0000**		**N/A**	**N/A**	**0.16**	**0.39**
Group size >20	**0**	**0.0**	**4.220**	**1.00**	**4,349**	**0.0000**		**N/A**	**N/A**	**0.22**	**0.00**
Total	**0**	**0.0**				**0.0000**	**0**	**N/A**			
pilot whale											
Group size 1-20	**0**	**0.0**	**1.560**	**0.74**	**4,349**	**0.0000**		**N/A**	**N/A**	**0.16**	**0.39**
Group size >20	**0**	**0.0**	**4.220**	**1.00**	**4,349**	**0.0000**		**N/A**	**N/A**	**0.22**	**0.00**
Total	**0**	**0.0**				**0.0000**	**0**	**N/A**			
DALL'S PORPOISE											
Dall's porpoise											
Calm Seas	**48**	**3.4**	**0.819**	**0.79**	**533**	**0.2365**	**76,874**	**0.59**	**0.57**	**0.14**	**0.10**
SMALL WHALES											
ziphiid whale											
Calm Seas	**0**	**0.0**	**1.764**	**0.34**	**533**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.29**
Mesoplodon spp.											
Calm Seas	**2**	**2.8**	**1.764**	**0.45**	**533**	**0.0067**	**2,169**	**1.04**	**1.00**	**0.19**	**0.23**
Cuvier's beaked whale											
Calm Seas	**0**	**0.0**	**1.764**	**0.23**	**533**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.35**
***Kogia* spp.**											
Calm Seas	**1**	**1.0**	**1.764**	**0.35**	**533**	**0.0015**	**494**	**1.06**	**1.00**	**0.19**	**0.29**
minke whale											
Calm Seas	**2**	**1.0**	**1.764**	**0.84**	**533**	**0.0013**	**411**	**0.77**	**0.71**	**0.19**	**0.22**
MEDIUM WHALES											
Baird's beaked whale											
Total	**3**	**1.6**	**2.825**	**0.96**	**4,349**	**0.0002**	**64**	**0.68**	**0.62**	**0.15**	**0.23**
Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**4,349**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
sei whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**4,349**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
sei/Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**4,349**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
LARGE WHALES											
killer whale											
Total	**3**	**5.8**	**1.715**	**0.90**	**4,349**	**0.0013**	**420**	**0.68**	**0.66**	**0.16**	**0.07**
fin whale											
Total	**9**	**1.3**	**1.715**	**0.90**	**4,349**	**0.0009**	**283**	**0.56**	**0.53**	**0.16**	**0.07**
blue whale											
Total	**0**	**0.0**	**1.715**	**0.90**	**4,349**	**0.0000**	**0**	**N/A**	**N/A**	**0.16**	**0.07**
HUMPBACK WHALE											
humpback whale											
Total	**1**	**1.1**	**2.894**	**0.90**	**4,349**	**0.0000**	**15**	**1.01**	**1.00**	**0.15**	**0.07**
SPERM WHALE											
sperm whale											
Total	**4**	**11.8**	**4.607**	**0.87**	**4,349**	**0.0014**	**440**	**0.71**	**0.69**	**0.13**	**0.08**

Table 9. Line-transect abundance estimates of cetaceans for the California stratum of the 2001 survey.

Cetacean Abudance Estimation	**km surveyed**	**6,489**		**Area surveyed**
2001 ORCAWALE Survey	**Beauf 0-2**	**863**	**% Calm= 13.3**	**817,549 km^{2}**
CA Only	**Beauf 3-5**	**5,626**	**% Rough= 86.7**	

SPECIES GROUP Species Stratum	# sightings n	group size S	ESW (km) 1/f(0)	g(0)	transect length (km) L	density (km^{-2}) D	abundance N	CV N	CV n*S/L	CV f(0)	CV g(0)
SMALL DELPHINIDS											
short-beaked common dolphin											
Group size 1-20	17	9.7	0.502	0.77	6,489	0.0328		0.36	0.26	0.21	0.14
Group size 21-100	19	50.4	1.236	1.00	6,489	0.0597		0.35	0.30	0.18	0.00
Group size >100	26	506.5	1.880	1.00	6,489	0.5397		0.47	0.44	0.18	0.00
Total	62	230.5				0.6323	516,938	0.41			
long-beaked common dolphin											
Group size 1-20	0	0.0	0.502	0.77	6,489	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	1	6.0	1.236	1.00	6,489	0.0004		1.02	1.00	0.18	0.00
Group size >100	0	0.0	1.880	1.00	6,489	0.0000		N/A	N/A	0.18	0.00
Total	1	6.0				0.0004	306	1.02			
unclassified common dolphin											
Group size 1-20	1	11.5	0.502	0.77	6,489	0.0023		1.03	1.00	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	6,489	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	6,489	0.0000		N/A	N/A	0.18	0.00
Total	1	11.5				0.0023	1,872	1.03			
striped dolphin											
Group size 1-20	0	0.0	0.502	0.77	6,489	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	1	25.2	1.236	1.00	6,489	0.0016		1.02	1.00	0.18	0.00
Group size >100	5	125.5	1.880	1.00	6,489	0.0257		0.68	0.66	0.18	0.00
Total	6	108.8				0.0273	22,316	0.65			
Pacific white-sided dolphin											
Group size 1-20	5	7.1	0.502	0.77	6,489	0.0070		0.93	0.90	0.21	0.14
Group size 21-100	2	37.8	1.236	1.00	6,489	0.0047		0.73	0.71	0.18	0.00
Group size >100	2	93.9	1.880	1.00	6,489	0.0077		0.73	0.71	0.18	0.00
Total	9	33.2				0.0194	15,899	0.48			
northern right whale dolphin											
Group size 1-20	6	5.6	0.502	0.77	6,489	0.0067		0.52	0.46	0.21	0.14
Group size 21-100	3	35.3	1.236	1.00	6,489	0.0066		0.63	0.60	0.18	0.00
Group size >100	1	1.9	1.880	1.00	6,489	0.0001		1.02	1.00	0.18	0.00
Total	10	14.1				0.0134	10,915	0.41			
GRAMPUS											
Risso's dolphin											
Group size 1-20	12	7.7	1.370	0.74	6,489	0.0070		0.74	0.61	0.16	0.39
Group size >20	4	31.4	2.180	1.00	6,489	0.0044		0.62	0.59	0.20	0.00
Total	16	13.6				0.0114	9,357	0.51			

Table 9. (Continued).

TURSIOPS/GLOBICEPHALA											
bottlenose dolphin											
Group size 1-20	**5**	**10.8**	**1.560**	**0.74**	**6,489**	**0.0036**		**1.05**	**0.96**	**0.16**	**0.39**
Group size >20	**4**	**28.8**	**4.220**	**1.00**	**6,489**	**0.0021**		**0.83**	**0.80**	**0.22**	**0.00**
Total	**9**	**18.8**				**0.0057**	**4,666**	**0.73**			
pilot whale											
Group size 1-20	**0**	**0.0**	**1.560**	**0.74**	**6,489**	**0.0000**		**N/A**	**N/A**	**0.16**	**0.39**
Group size >20	**0**	**0.0**	**4.220**	**1.00**	**6,489**	**0.0000**		**N/A**	**N/A**	**0.22**	**0.00**
Total	**0**	**0.0**				**0.0000**	**0**	**N/A**			
DALL'S PORPOISE											
Dall's porpoise											
Calm Seas	**25**	**2.3**	**0.819**	**0.79**	**863**	**0.0513**	**41,940**	**0.63**	**0.61**	**0.14**	**0.10**
SMALL WHALES											
ziphiid whale											
Calm Seas	**0**	**0.0**	**1.764**	**0.34**	**863**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.29**
Mesoplodon spp.											
Calm Seas	**0**	**0.0**	**1.764**	**0.45**	**863**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.23**
Cuvier's beaked whale											
Calm Seas	**1**	**1.6**	**1.764**	**0.23**	**863**	**0.0023**	**1,892**	**1.08**	**1.00**	**0.19**	**0.35**
***Kogia* spp.**											
Calm Seas	**0**	**0.0**	**1.764**	**0.35**	**863**	**0.0000**	**0**	**N/A**	**N/A**	**0.19**	**0.29**
minke whale											
Calm Seas	**2**	**1.1**	**1.764**	**0.84**	**863**	**0.0009**	**716**	**0.77**	**0.71**	**0.19**	**0.22**
MEDIUM WHALES											
Baird's beaked whale											
Total	**0**	**0.0**	**2.825**	**0.96**	**6,489**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.23**
Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**6,489**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
sei whale											
Total	**1**	**1.0**	**2.825**	**0.90**	**6,489**	**0.0000**	**25**	**1.01**	**1.00**	**0.15**	**0.07**
sei/Bryde's whale											
Total	**0**	**0.0**	**2.825**	**0.90**	**6,489**	**0.0000**	**0**	**N/A**	**N/A**	**0.15**	**0.07**
LARGE WHALES											
killer whale											
Total	**2**	**5.9**	**1.715**	**0.90**	**6,489**	**0.0006**	**480**	**0.73**	**0.71**	**0.16**	**0.07**
fin whale											
Total	**20**	**4.0**	**1.715**	**0.90**	**6,489**	**0.0040**	**3,257**	**0.56**	**0.53**	**0.16**	**0.07**
blue whale											
Total	**10**	**1.9**	**1.715**	**0.90**	**6,489**	**0.0010**	**788**	**0.44**	**0.40**	**0.16**	**0.07**
HUMPBACK WHALE											
humpback whale											
Total	**16**	**1.9**	**2.894**	**0.90**	**6,489**	**0.0009**	**743**	**0.49**	**0.46**	**0.15**	**0.07**
SPERM WHALE											
sperm whale											
Total	**9**	**11.2**	**4.607**	**0.87**	**6,489**	**0.0019**	**1,581**	**0.59**	**0.57**	**0.13**	**0.08**

Table 10 Line-transect abundance estimates of cetaceans for the Oregon/Washington stratum of the 2001 survey.

Cetacean Abudance Estimation	km surveyed	3,133		Area surveyed
2001 ORCAWALE Survey	Beauf 0-2	863	% Calm= 27.5	325,018 km^{-2}
OR+WA Only	Beauf 3-5	2,270	% Rough= 72.5	

SPECIES GROUP Species Stratum	# sightings n	group size S	ESW (km) 1/f(0)	g(0)	transect length (km) L	density (km^{-2}) D	abundance N	CV N	CV n*S/L	CV f(0)	CV g(0)
SMALL DELPHINIDS											
short-beaked common dolphin											
Group size 1-20	1	3.0	0.502	0.77	3,133	0.0012		1.03	1.00	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Total	1	3.0				0.0012	398	1.03			
long-beaked common dolphin											
Group size 1-20	0	0.0	0.502	0.77	3,133	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Total	0	0.0				0.0000	0	N/A			
unclassified common dolphin								N/A	N/A		
Group size 1-20	0	0.0	0.502	0.77	3,133	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Total	0	0.0				0.0000	0	N/A			
striped dolphin											
Group size 1-20	0	0.0	0.502	0.77	3,133	0.0000		N/A	N/A	0.21	0.14
Group size 21-100	0	0.0	1.236	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Group size >100	0	0.0	1.880	1.00	3,133	0.0000		N/A	N/A	0.18	0.00
Total	0	0.0				0.0000	0	N/A			
Pacific white-sided dolphin											
Group size 1-20	4	10.0	0.502	0.77	3,133	0.0164		0.62	0.57	0.21	0.14
Group size 21-100	2	13.9	1.236	1.00	3,133	0.0036		0.73	0.71	0.18	0.00
Group size >100	1	160.4	1.880	1.00	3,133	0.0136		1.02	1.00	0.18	0.00
Total	7	32.6				0.0336	10,934	0.52			
northern right whale dolphin											
Group size 1-20	6	8.7	0.502	0.77	3,133	0.0215		0.57	0.51	0.21	0.14
Group size 21-100	3	20.8	1.236	1.00	3,133	0.0080		0.75	0.73	0.18	0.00
Group size >100	1	20.9	1.880	1.00	3,133	0.0018		1.02	1.00	0.18	0.00
Total	10	13.5				0.0314	10,190	0.44			
GRAMPUS											
Risso's dolphin											
Group size 1-20	6	13.2	1.370	0.74	3,133	0.0125		0.70	0.56	0.16	0.39
Group size >20	2	39.1	2.180	1.00	3,133	0.0057		0.74	0.71	0.20	0.00
Total	8	19.7				0.0182	5,917	0.53			

Table 10. (Continued).

TURSIOPS/GLOBICEPHALA											
bottlenose dolphin											
Group size 1-20	0	0.0	1.560	0.74	3,133	0.0000		N/A	N/A	0.16	0.39
Group size >20	0	0.0	4.220	1.00	3,133	0.0000		N/A	N/A	0.22	0.00
Total	0	0.0				0.0000	0	N/A			
pilot whale											
Group size 1-20	0	0.0	1.560	0.74	3,133	0.0000		N/A	N/A	0.16	0.39
Group size >20	0	0.0	4.220	1.00	3,133	0.0000		N/A	N/A	0.22	0.00
Total	0	0.0				0.0000	0	N/A			
DALL'S PORPOISE											
Dall's porpoise											
Calm Seas	12	2.4	0.819	0.79	863	0.0253	8,213	0.51	0.48	0.14	0.10
SMALL WHALES											
ziphiid whale											
Calm Seas	0	0.0	1.764	0.34	863	0.0000	0	N/A	N/A	0.19	0.29
Mesoplodon spp.											
Calm Seas	0	0.0	1.764	0.45	863	0.0000	0	N/A	N/A	0.19	0.23
Cuvier's beaked whale											
Calm Seas	0	0.0	1.764	0.23	863	0.0000	0	N/A	N/A	0.19	0.35
***Kogia* spp.**											
Calm Seas	0	0.0	1.764	0.35	863	0.0000	0	N/A	N/A	0.19	0.29
minke whale											
Calm Seas	1	1.0	1.764	0.84	863	0.0004	127	1.04	1.00	0.19	0.22
MEDIUM WHALES											
Baird's beaked whale											
Total	2	3.1	2.825	0.96	3,133	0.0004	117	0.76	0.71	0.15	0.23
Bryde's whale											
Total	0	0.0	2.825	0.90	3,133	0.0000	0	N/A	N/A	0.15	0.07
sei whale											
Total	0	0.0	2.825	0.90	3,133	0.0000	0	N/A	N/A	0.15	0.07
sei/Bryde's whale											
Total	0	0.0	2.825	0.90	3,133	0.0000	0	N/A	N/A	0.15	0.07
LARGE WHALES											
killer whale											
Total	4	8.7	1.715	0.90	3,133	0.0036	1,167	0.51	0.48	0.16	0.07
fin whale											
Total	10	1.1	1.715	0.90	3,133	0.0012	380	0.51	0.48	0.16	0.07
blue whale											
Total	3	1.0	1.715	0.90	3,133	0.0003	101	0.71	0.69	0.16	0.07
HUMPBACK WHALE											
humpback whale											
Total	8	2.3	2.894	0.90	3,133	0.0011	366	0.45	0.42	0.15	0.07
SPERM WHALE											
sperm whale											
Total	2	2.0	4.607	0.87	3,133	0.0002	52	0.73	0.71	0.13	0.08

Table 11. Summary of line-transect estimates of cetacean abundance and associated CVs stratified by year and geographic region.

Cetacean Abudance Estimation	California			Oregon+Washington		CA+OR+WA		CA+OR+WA
SPECIES GROUP Species	1991-93 Abundance	1996 Abundance	2001 Abundance	1996 Abundance	2001 Abundance	1996 Abundance	2001 Abundance	1996+2001 Abundance
SMALL DELPHINIDS								
short-beaked common dolphin	446,595 0.21	376,040 0.24	516,938 0.41	6,316 1.02	398 1.03	382,356 0.23	517,335 0.41	449,846 0.25
long-beaked common dolphin	10,799 0.76	86,414 0.72	306 1.02	0 N/A	0 N/A	86,414 0.72	306 1.02	43,360 0.72
unclassified common dolphin	5,513 0.41	7,906 0.42	1,872 1.03	0 N/A	0 N/A	7,906 0.42	1,872 1.03	4,889 0.39
striped dolphin	28,396 0.31	5,489 0.48	22,316 0.65	64 1.02	0 N/A	5,553 0.48	22,316 0.65	13,934 0.53
Pacific white-sided dolphin	10,500 0.33	83,032 0.70	15,899 0.48	8,683 0.79	10,934 0.52	91,715 0.64	26,833 0.35	59,274 0.50
northern right whale dolphin	9,929 0.49	14,593 0.55	10,915 0.41	5,026 0.50	10,190 0.44	19,619 0.43	21,104 0.30	20,362 0.26
GRAMPUS								
Risso's dolphin	10,624 0.29	8,672 0.50	9,357 0.51	8,187 0.68	5,917 0.53	16,858 0.42	15,274 0.38	16,066 0.28
TURSIOPS / GLOBICEPHALA								
bottlenose dolphin	1,282 0.36	5,464 1.05	4,666 0.73	0 N/A	0 N/A	5,464 1.05	4,666 0.73	5,065 0.66
pilot whale	713 0.62	608 1.02	0 N/A	0 N/A	0 N/A	608 1.02	0 N/A	304 1.02
DALL'S PORPOISE								
Dall's porpoise	31,396 0.31	70,207 0.56	41,940 0.63	76,874 0.59	8,213 0.51	147,081 0.41	50,153 0.54	98,617 0.33
SMALL WHALES								
ziphiid whale	530 0.79	863 1.06	0 N/A	0 N/A	0 N/A	863 1.06	0 N/A	432 1.06
Mesoplodon spp.	1,668 0.48	326 1.04	0 N/A	2,169 1.04	0 N/A	2,495 0.92	0 N/A	1,247 0.92
Cuvier's beaked whale	8,311 0.50	1,876 0.81	1,892 1.08	0 N/A	0 N/A	1,876 0.81	1,892 1.08	1,884 0.68
Kogia spp.	700 0.50	0 N/A	0 N/A	494 1.06	0 N/A	494 1.06	0 N/A	247 1.06
minke whale	221 0.44	776 0.51	716 0.77	411 0.77	127 1.04	1,187 0.43	843 0.67	1,015 0.37
MEDIUM WHALES								
Baird's beaked whale	765 0.61	275 0.76	0 N/A	64 0.68	117 0.76	339 0.63	117 0.76	228 0.51
Bryde's whale	20 1.01	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
sei whale	40 0.79	86 0.73	25 1.01	0 N/A	0 N/A	86 0.73	25 1.01	56 0.61
sei/Bryde's whale	49 0.53	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
LARGE WHALES								
killer whale	454 0.50	613 0.61	480 0.73	420 0.68	1,167 0.51	1,033 0.45	1,647 0.42	1,340 0.31
fin whale	1,635 0.35	2,638 0.34	3,257 0.56	283 0.56	380 0.51	2,921 0.31	3,636 0.50	3,279 0.31
blue whale	2,713 0.24	2,584 0.28	788 0.44	0 N/A	101 0.71	2,584 0.28	888 0.40	1,736 0.23
HUMPBACK WHALE								
humpback whale	551 0.41	1,503 0.44	743 0.49	15 1.01	366 0.45	1,518 0.44	1,109 0.36	1,314 0.30
SPERM WHALE								
sperm whale	1,168 0.40	391 0.56	1,581 0.59	440 0.71	52 0.73	831 0.46	1,634 0.57	1,233 0.41

Figure 1. Distribution of search effort within defined geographic strata (CA and OR/WA) during 1991/93, 1996, and 2001 surveys in Beaufort sea states 0-2 (left) and 0-5 (right).