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Southern California Bight marine mammal density and abundance from aerial surveys, 2008-2013

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Abstract

We conducted 18 aerial surveys for marine mammals in the Southern California Bight in the vicinity of San Clemente Island from October 2008 to July 2013. Data were collected to obtain density and abundance estimates, as well as focal behavioral observations of marine mammals. The primary platform used was a *Partenavia* P68-C or P68-OBS (glass-nosed) high-wing, twin-engine airplane. A total of 76,989 km were flown with 2,510 marine mammal groups sighted. Nineteen marine mammal species were identified. Density and abundance estimates were made using line-transect methods and DISTANCE 6.0 software. Due to limited sample sizes for some species, sightings were pooled to provide 4 detection function estimates for baleen whales, large delphinids, small delphinids, and California sea lions. Estimates were limited to species observed at least 20 times during line-transect effort. For the May-October warm-water season, the estimated average numbers of individuals present (and coefficient of variation) were as follows: short-beaked common dolphins (8,520, CV=54%), long-beaked common dolphins (3,314, CV=54%), Risso's dolphins (1,450, CV=66%), California sea lions (818, CV=40%), bottlenose dolphins (496, CV=87%), fin whales (137, CV=49%), and gray whales (6, CV=13%). During the November-April cold-water season, estimates were: short-beaked common dolphins (15,955, CV=51%), long-beaked common dolphins (6,440, CV=51%), California sea lions (1,454, CV=53%), Risso's dolphins (993, CV=51%), bottlenose dolphins (290, CV=61%), gray whales (221, CV=53%), and fin whales (140, CV=33%). Several other species were observed for which sightings were too few to estimate numbers present and/or were seen only off effort: blue, Bryde's, minke, humpback, sperm, Cuvier's beaked, and killer whales; Pacific white-sided and northern right whale dolphins; Dall's porpoise; and northern elephant and harbor seals. [JMATE 2014;7(2):14-30]

Keywords: dolphin, whale, sea lion, line-transect analysis, population biology

Introduction

The Southern California Bight (SCB) is extensively used by humans for shipping, military activities, recreation, and fishing, among other uses. These waters are also heavily used by a wide diversity and relatively high numbers of marine mammal species for feeding, reproduction, migration, and other important life functions. Thus, the potential for spatio-temporal conflict not only exists, but is high. Ship-based marine mammal surveys of the entire United States (U.S.) West Coast Exclusive Economic Zone have been conducted by the National Marine Fisheries Service (NMFS) in the eastern North Pacific Ocean since the early 1980s (with more extensive and consistent coverage since the early 1990s). These surveys have provided estimates of marine mammal abundance and density, and in some cases trends, for U.S. waters of California, Oregon, and Washington (2, 4- 6, 8-10, 15, 23-25). Results represent large-scale data and associated densities over a wide geographic region, as determined by following widely-spaced survey lines. Effort has focused on the late summer to autumn period (July-November) with relatively little coverage in the cold-water season (November-April), when weather conditions are generally unfavorable for marine mammal survey work. Recent (2004-2013) vessel-based surveys published by Douglas *et al*. and Campbell *et al*. are an exception, with relatively even coverage across the year (14, 22).

Waters off San Diego (SD) County are heavily used by the U.S. Navy (USN) for various training operations from several coastal naval bases, in particular the San Clemente Island (SCI) region. Operations include exercises involving low- and mid-frequency active sonars and underwater detonations implicated as causing disturbance, and in some cases even injury and mortality, to some marine mammal species (20). To assess and mitigate impacts, smaller-scale density estimates than those discussed above, specific to ocean

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areas associated with USN at-sea training ranges are needed, but such information is limited. Carretta *et al.* conducted extensive year-round aerial surveys of waters near SCI in 1998 and 1999 (19). This information has been very useful for USN marine mammal resource management; however, the estimates are now over 15 years old and are thus out-of-date. Furthermore, there is compelling evidence that the distribution and density of some marine mammal species have changed in the area during this time period (41).

To provide relevant information, aerial surveys were conducted across the seasons to monitor behavior relative to USN activities, and to provide the most recent and comprehensive up-to-date information currently available on year-round marine mammal density and abundance in portions of the SCB used by the USN for training operations (total study area of 17,556 km^2).

Methods

Data Collection: Three types of aircraft were used. Most (79 or 88%) of the 90 survey days were conducted from a small high-wing, twin-engine *Partenavia* P68-C or P68-OBS (glass-nosed) airplane equipped with bubble observer windows on the left and right sides of the middle seats; the remaining 11 survey days (12%) occurred from an *Aero Commander* airplane (9 days) or a helicopter (2 days), both of which had flat observer windows (Table 1). Survey protocol was similar to previous aerial surveys conducted to monitor for marine mammals and sea turtles in the SOCAL Range Complex, and elsewhere, as described below (39, 40, 42, 43).

The 18 surveys were conducted at least once during 11 of the 12 calendar months: October and

Survey Year	Survey Dates	# Cold-Water Survey Days*	# Warm-Water Survey Days**	Aircraft	Observer Window	SOCAL Sub-area Surveyed
2008	17–21 October	0	5	P	B	SCI, SCatB, S SCI
2008	15–18 November	4	0	P	B	SNB, SCI, S SCI
2009	5–11 June	0	6	P	B	SCatB, SNB
2009	20–29 July	0	8	P	B	SCatB, SNB
2009	18–23 November	6	0	P	B	SCI, SCatB, SNB
2010	13–18 May	0	5	P	B	SCatB, SNB
2010	27 July–3 August	0	5	P	B	SCatB, SNB
			2	H	F	
2010	23–29 September	0	6	P	B	SCatB, SNB
2011	14–19 February	4	0	P	B	SCatB, SNB, Silver Strand
2011	29 March –3 April	3	0	P	B	SCatB, SNB
2011	12–20 April	9	0	AC	F	SCatB, SNB, Silver Strand
2011	9–14 May	0	6	P	B	SCatB, SNB, Silver Strand
2012	30 January–5 February	7	0	P	B	SCatB, SNB
2012	13-15 March	3	0	P	B	SCatB
2012	28 March–1 April	5	0	P	B	SCatB
2013	25-30 March	6	0	P	B	SCatB, SNB
2013	22-26 May	0	5	P	B	SCatB, SNB
2013	24-29 July	0	6	P	B	SCatB, SNB

*Table 1: List of Southern California Bight aerial surveys from 2008 to 2013. P = Partenavia; H = Helicopter; AC = Aero Commander; B = Bubble; F = Flat; SCI = San Clemente Island; S SCI= Ocean area south of San Clemente Island; SCatB (Santa Catalina Basin: representing the area between SCI and the California mainland); SNB (San Nicolas Basin: area west of SCI); *cold-water (November-April); ** warm-water (May-October).*

November 2008; June, July, and November 2009; May, July, and September 2010; February, March, April, and May 2011; January, February, March, and April 2012; and March, May, and July 2013 (Table 1).

One pilot (2008-2010) or two pilots (2011-2013), three professionally trained marine mammal biologists (at least two with over 10 years of related experience) or two such biologists and a computer scientist were aboard the aircraft. Two biologists served as observers in the middle window seats of the aircraft; the third biologist (or computer scientist) was the data recorder in the front right co-pilot seat (2008-2010) or in the rear left bench seat (2011-2013). Surveys were flown at speeds of approximately 100 knots and altitudes of approximately 227-357 meters (m) (800-1000 feet [ft]). In practice, altitude at the time of sightings averaged 261 ± 49 m, based on readings from a WAAS-enabled GPS. When the plane departed the survey trackline, the pilot usually returned to the transect line within 2 km of the departure point. Occasionally, the return point was several km from the departure point.

Established line-transect survey protocol was used (12, 19, 39). Parallel transect lines were positioned primarily along a WNW to ESE orientation generally perpendicular to the bathymetric contours/coastline to avoid biasing of surveys by following depth contours (Figure 1). The study area within the SOCAL Range Complex overlapped transect lines of previous aerial surveys conducted 1-2 times per month over approximately 1.5 year in 1998-99 by the NMFS/ Southwest Fisheries Science Center (SWFSC) on behalf of the USN (19) (see Figure 1 for comparison of the Carretta *et al.* study area with ours) (19). However, transect lines were different from and spaced closer together than the 22 km spacing used by Carretta *et al*. (19). Given the current goal to intensively survey in a prescribed area, we followed transect lines spaced approximately 14 km apart between the coast and SCI (the Santa Catalina Basin sub-area; 8,473 km^2). Our transect lines were spaced 7 km apart to the west (the San Nicolas Basin sub-area; 4,180 km^2), 19 km south of SCI (South of SCI sub-area; 4,903 km^2) (Figure 1).

We used the following hardware and software for data collection, including basic sighting and environmental data (observation effort, visibility, glare,

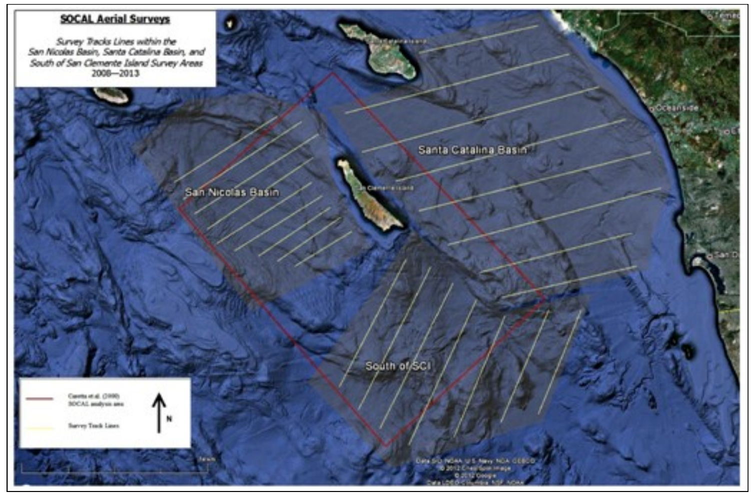

Figure 1: Systematic survey tracklines within the three survey sub-areas in the Southern California Bight, 2008–2013. Note that due to sample size considerations, estimates were only made for San Nicolas and Santa Catalina Basin areas.

etc.): (1) BioSpectator on a Palm Pilot TX (pull-down menus or screen keyboard) or an Apple iPhone or iTouch in 2008 and 2009; (2) a customized Excel spreadsheet on a Windows-based notebook computer (2010, 2011); or customized Mysticetus Observation Platform (Mysticetus™) software on a notebook computer (2011-2013). Each new entry was automatically assigned a time stamp, a sequential sighting number, and a GPS position. A Suunto handheld clinometer was used to measure declination angles to sightings when the sighting was perpendicular to the aircraft (2008-2010) and/or in 2011-2013 at the sighting location along with a horizontal bearing from the aircraft using Mysticetus. In 2008-2010, declinations were later converted to perpendicular sighting distance; in 2011-2013, declinations were instantly converted to perpendicular and radial sighting distances by Myticetus.

Photographs and video were taken through a small opening porthole on either the co-pilot seat window (2008-2010) or the rear left bench-seat window (2011-2013). One of four Canon EOS or Nikon digital cameras with Image Stabilized zoom lenses was used to document and verify species for each sighting, as feasible/needed. A Sony Handycam HDR-XR550 or a Sony Handycam HDR-XR520 video camera was used to document behaviors when off effort. Observers used Steiner 7 X 25 or Swarovski 10 X 32 binoculars as needed to identify species, group size, behaviors, etc.

Environmental data including Beaufort sea state (Bf), glare and visibility conditions, were collected at the beginning of each leg and whenever conditions changed. Aircraft GPS locations were automatically recorded at 2 to 10-second intervals on WAAS-enabled GPSs. In 2008-2010, sighting and effort data were merged with the GPS data using Excel after the survey, based on the time-stamp information, to obtain aircraft positions and altitudes at recorded event times and to calculate distances to sighted animals. In 2011-2013, Mysticetus merged these data automatically in the field.

Data analysis: We used standard line-transect methods (conventional distance sampling) to analyze the aerial survey data (12). Estimates of density and abundance (and their associated coefficient of variation) were calculated using the following formulae:

$$\hat{D} = \frac{n\ \hat{f}(0)\ \hat{E}(s)}{2\ L\ \hat{g}(0)}$$

$$\hat{N} = \frac{n\ \hat{f}(0)\ \hat{E}(s)\ A}{2\ L\ \hat{g}(0)}$$

$$C\hat{V} = \sqrt{\frac{\hat{\text{var}}\,(n)}{n^2} + \frac{\hat{\text{var}}\,[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{\text{var}}\,[\hat{E}(s)]}{[\hat{E}(s)]^2} + \frac{\hat{\text{var}}\,[\hat{g}(0)]}{[\hat{g}(0)]^2}}$$

Where: D = density (of individuals),
n = number of on-effort sightings,
f(0) = detection function evaluated at zero distance,
E(s) = expected average group size (using size-bias correction in DISTANCE),
L = length of transect lines surveyed on effort,
g(0) = trackline detection probability,
N = abundance,
A = size of the study area,
CV = coefficient of variation, and
var = variance.

Line-transect parameters were calculated using the software DISTANCE 6.0, Release 2 (44). Though previous estimates used both systematic and connector lines, those of Jefferson *et al.* and those herein did not (30-32). Due to concerns about possible bias, only survey lines flown during systematic (the main line-transect survey lines perpendicular to the coast) transects at a planned altitude of 213-305 m, with both observers on line-transect effort were used to estimate the detection function and other line-transect parameters (i.e. sighting rate, n/L, and group size). We used a strategy of selective pooling and stratification to minimize bias and maximize precision in making density and abundance estimates (12). Due to low sample sizes for most species, we pooled species with similar sighting characteristics to estimate the detection function. This was done to produce statistically robust values with sample sizes of at least 60-80 sightings for each of four groups: baleen whales, large delphinids, small delphinids, and California sea lions (see Table 2, Figure 2a-d).

Species Group	Species Included	n	f(0)	% CV
Baleen whales	*Balaenoptera musculus, B. physalus, Balaenoptera.* sp., *Megaptera novaeangliae, Eschrichtius robustus,* unidentified baleen whale	158 (113)	0.0018 Uniform/ Cosine	13
Large delphinids	*Grampus griseus, Tursiops truncatus*	194 (144)	0.0023 Hazard Rate/ Cosine	20
Small delphinids	*Delphinus delphis, D. capensis, Delphinus* sp., *Lagenorhynchus obliquidens, Lissodelphis borealis*, unidentified small dolphin	369 (270)	0.0016 Hazard Rate/ Cosine	16
California sea lions	*Zalophus californianus,* unidentified pinniped	229 (132)	0.0048 Uniform/ Cosine	8

Table 2: Estimates of the detection function (f[0]) for the four analyzed species groups. In the sample size column (n), two numbers are given: total sample size and the sample size after truncation (in parentheses). CV = coefficient of variation.

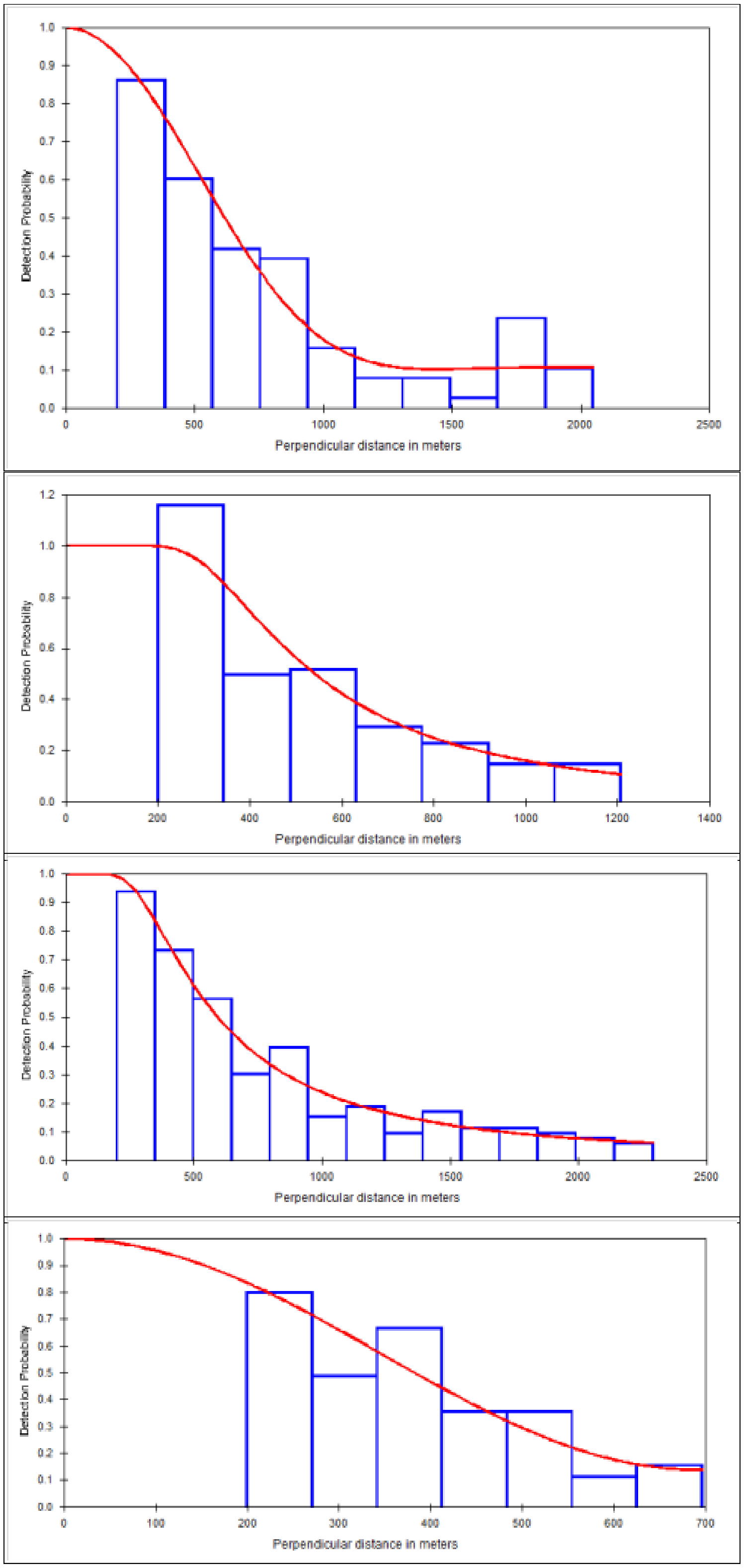

Figure 2: Perpendicular sighting distance plots and fitted detection functions for the four species groups: (a)baleen whales; (b)large delphinids; (c)small delphinids; (d) California sea lions.

We used all data collected in Bf conditions of 0-4 and did not stratify estimates by Bf or other environmental parameters. We produced stratified (in terms of sighting rate and group size) estimates of density and abundance for the two main survey sub-areas (Santa Catalina and San Nicholas Basins) and two seasons (warm and cold), using the pooled species-group f(0) values described above. We did not calculate density/abundance estimates for the South of SCI area, due to very small associated sample sizes. The seasons were defined as warm-water (May - October) and cold-water (November - April), after Carretta *et al.* (19).

Some sightings (19%) were unidentified as to species (although some of these were identified to a higher-level taxonomic grouping, e.g. unidentified baleen whale, unidentified small delphinid, unidentified pinniped, unidentified *Balaenoptera* sp., or unidentified *Delphinus* sp.). We thus pro-rated these sightings to species using the proportions of species in the identified sample, adjusted our sighting rates appropriately, and corrected the estimates with these factors. Because of the large proportion (81%) of sightings that were identified only to genus for *Delphinus*, we took a slightly different approach with this group. We calculated an overall estimate for *Delphinus* spp., then prorated the estimate to species (*D. delphis* and *D. capensis*), based on the proportion of each species represented in the known sample of sightings (0.72 for *D. delphis* and 0.28 for *D. capensis*).

To avoid potential overestimation of group size, we used the size-bias-adjusted estimate of average group size available in DISTANCE if it was less than the arithmetic mean group size. In most cases, group size for each estimate was calculated using a stratified approach (i.e. only groups from within a particular stratum were used to calculate average group size for that stratum).

Truncation involved the most-distant 5% of the sightings for each species group. We also used left truncation at 200 m, due to indications that poor visibility below the aircraft resulted in missed detections near the transect line (the 200 m cut-off was based on examination of the sightings by distance plots). This helped avoid potential underestimation of f(0) due to missed detection data immediately near the transect line.

We modeled the data with half-normal (with hermite polynomial and cosine series expansions), hazard rate (with cosine adjustment), and uniform (with cosine and simple polynomial adjustments) models, selecting the model with the lowest value for Akaike's Information Criterion.

We did not have data available to empirically estimate trackline detection probability [g(0)] for this study. However, since our surveys were very similar to those of Carretta *et al.*, values for g(0) from their study were used to adjust for uncertain trackline detection (19). This results in an underestimate of the variance for the final estimates of density and abundance. However, estimates of density and abundance were produced only for those species with at least 20 useable, on-effort sightings in the line-transect database (an arbitrary cut-off, based on past experience).

Results

Of the total 76,989 km flown, 25% (19,521 km) were flown during on-effort periods for line transect in good sea conditions (Bf 4 or less) on systematic lines, and thus available to estimate density and abundance. Of the total 2,510 marine mammal groups sighted during all survey states (on-effort, off-effort), 39.7% (n = 997) were used to estimate density and abundance herein (Table 3). We sighted at least 19 species of marine mammals, although not all sightings were identified to species level (Table 4). The most commonly sighted marine mammals meeting analysis criteria (with the number of sightings shown parenthetically) in descending order were common dolphins ($n = 277$, including both species), California sea lions ($n = 212$), Risso's dolphins ($n = 158$), fin whales ($n = 69$), gray whales ($n = 47$), and bottlenose dolphins (n = 36). Abundance was thus estimated for these seven species. The locations of the sightings identified to species and used in estimating density and abundance are shown in Figures 3-5. Line-transect estimates of density and abundance (and their associated coefficients of variation) are shown in Table 4.

Identification of common dolphins to species level was often not possible during flights, especially when weather conditions were less than ideal. For this reason, extensive photos were taken of common dolphin schools for later detailed examination. We examined a sample of these photos to see if we could identify the species, and we could in many cases. Short-beaked common dolphins predominated in these sightings. Based on the photo samples from which we were able to determine species, 72% of common dolphin sightings were *D. delphis* and only 28% were *D. capensis*. Photographs of representative groups of the two species are provided in Figure 6, showing the diagnostic characteristics we used to identify them to species.

SPECIES	nT	nD
California sea lion, *Zalophus californianus*	553	212*
Common dolphin, *Delphinus* sp.	521	196*
Risso's dolphin, *Grampus griseus*	328	158*
Unidentified delphinid	305	73
Fin whale, *B. physalus*	136	69*
Bottlenose dolphin, *Tursiops truncatus*	123	36*
Gray whale, *Eschrichtius robustus*	104	47*
Short-beaked common dolphin, *Delphinus delphis*	84	58*
Blue whale, *Balaenoptera musculus*	66	11
Unidentified. baleen whale	49	23
Unidentified. pinniped	47	17
Long-beaked common dolphin, *D. capensis*	44	23*
Unidentified. marine mammal	43	23
Pacific white-sided dolphin, *Lagenorhynchus obliquidens*	21	11
Minke whale, *B. acutorostrata*	19	9
Humpback whale, *Megaptera novaeangliae*	18	8
Northern right whale dolphin, *Lissodelphis borealis*	16	8
Harbor seal, *Phoca vitulina*	15	1
Northern elephant seal, *Mirounga angustirostris*	6	5
Dall's porpoise, *Phocoenoides dalli*	5	3
Bryde's whale, *B. brydeii/edeni*	2	1
Cuvier's beaked whale, *Ziphius cavirostris*	2	2
Killer whale, *Orcinus orca*	2	2
Sperm whale, *Physeter macrocephalus*	1	1
TOTAL	**2,510**	**997**

Table 3: Marine mammal species observed during the surveys listed in taxonomic order, with total sightings (nT) and sightings available for line transect analysis (nD). Density and abundance estimates were limited to those species denoted by an asterisk, based on nD ≥ 20.

Discussion

Potential Biases of the Estimates: As is true of any

	WARM SEASON				COLD SEASON			
SPECIES	**Di**	**N**	**N'**	**%CV**	**Di**	**N**	**N'**	**%CV**
Fin whale	**0.909**	**115**	**137**	**-**	**0.933**	**118**	**140**	**-**
SCatB	0.342	29	35	60	0.740	64	76	32
SNB	2.047	86	102	37	1.270	54	64	34
Gray whale	**0.059**	**5**	**6**	**-**	**1.162**	**197**	**221**	**-**
SCatB	0.058	5	6	13	1.791	152	171	29
SNB	0.000	0	0	n/a	1.066	45	50	76
Risso's dolphin	**11.459**	**1,450**	**1,450**	**-**	**7.848**	**993**	**993**	**-**
SCatB	16.428	1,392	1,392	36	11.041	936	936	32
SNB	1.407	58	58	96	1.378	57	57	70
Bottlenose dolphin	**2.584**	**327**	**496**	**-**	**1.510**	**191**	**290**	**-**
SCatB	3.564	302	459	72	2.263	191	290	61
SNB	0.577	25	37	102	0.000	0	0	n/a
Short-beaked common dolphin	**67.336**	**8,520**	**8,520**	**-**	**126.097**	**15,955**	**15,955**	**-**
SCatB	96.471	8,174	8,174	32	150.54	12,755	12,755	32
SNB	8.278	346	346	75	76.555	3,200	3,200	69
Long-beaked common dolphin	**26.191**	**3,314**	**3,314**	**-**	**50.897**	**6,440**	**6,440**	**-**
SCatB	37.519	3,179	3,179	32	61.322	5,196	5,196	32
SNB	3.229	135	135	75	29.761	1,244	1,244	69
California sea lion	**5.825**	**737**	**818**	**-**	**10.345**	**1,309**	**1,454**	**-**
SCatB	3.305	280	311	28	4.567	387	430	39
SNB	10.933	457	507	51	22.057	922	1,024	67

Table 4: Estimates of individual density (Di, individuals/100 km^2), abundance (N), abundance incorporating proration of unidentified sightings (N'), and coefficient of variation (%CV) for marine mammals in the Southern California (SOCAL) Bight study area for the warm-water (May through October) and cold-water (November through April) seasons. The first line for each species is for the entire SOCAL Range Complex and the next two lines are stratified by the two survey sub-areas: Santa Catalina Basin (SCatB) and San Nicholas Basin (SNB). The species are listed in taxonomic order.

statistical technique, there are certain assumptions that must hold for line-transect estimates of density and abundance to be accurate. For instance, there are different ways to calculate correction factors for prorating unidentified sightings, and these differ in their statistical reliability. Therefore, we urge readers to view our prorated estimates with some caution, and we have presented the unprorated estimates alongside them for comparison. Below we go through the various assumptions of line transect and other issues that may cause bias in our estimates.

<u>Assumption 1: Certain Trackline Detection:</u> Animals on and very near the trackline must be detected to avoid estimates that are biased low (13). This is a central assumption of basic line-transect theory. However, in reality, it is often violated, especially by diving animals like marine mammals. This can be addressed by incorporating a factor into the line-transect equation that accounts for the proportion of missed animals (trackline detection probability, g(0)).

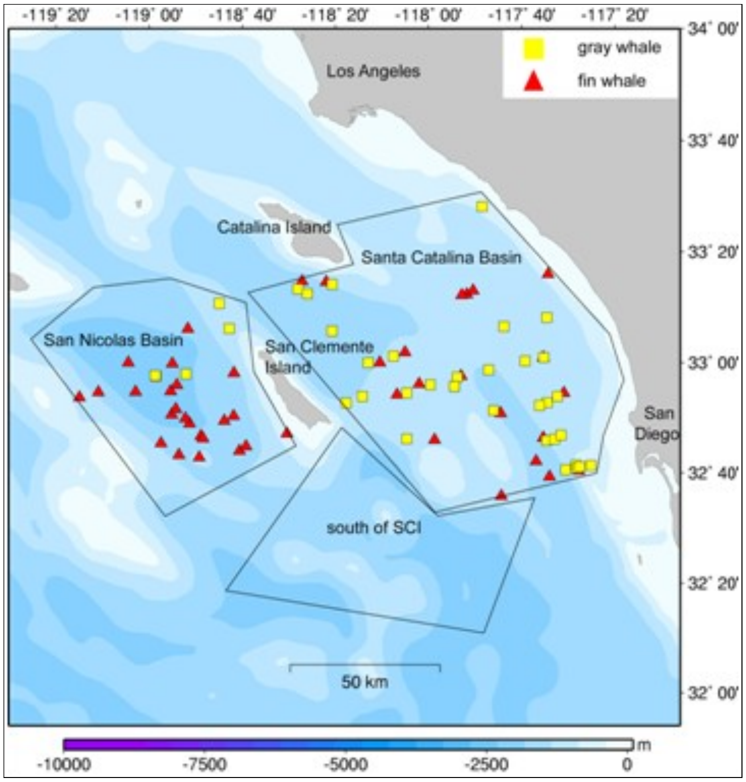

Figure 3: Sightings (identified to species) used for estimation of density and abundance of large whales in this study, 2008–2013.

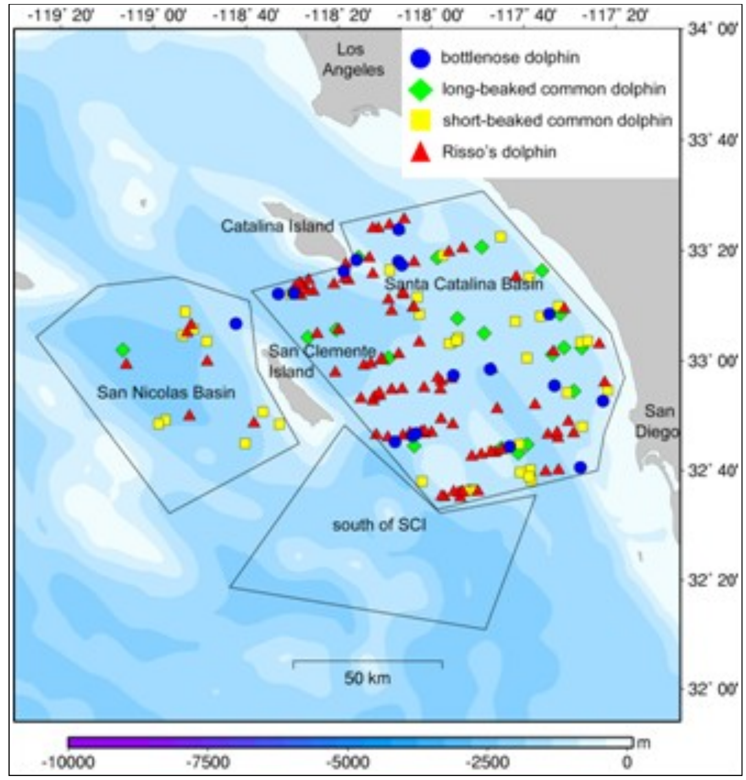

Figure 4: Sightings (identified to species) used for estimation of density and abundance of dolphins in this study, 2008–2013.

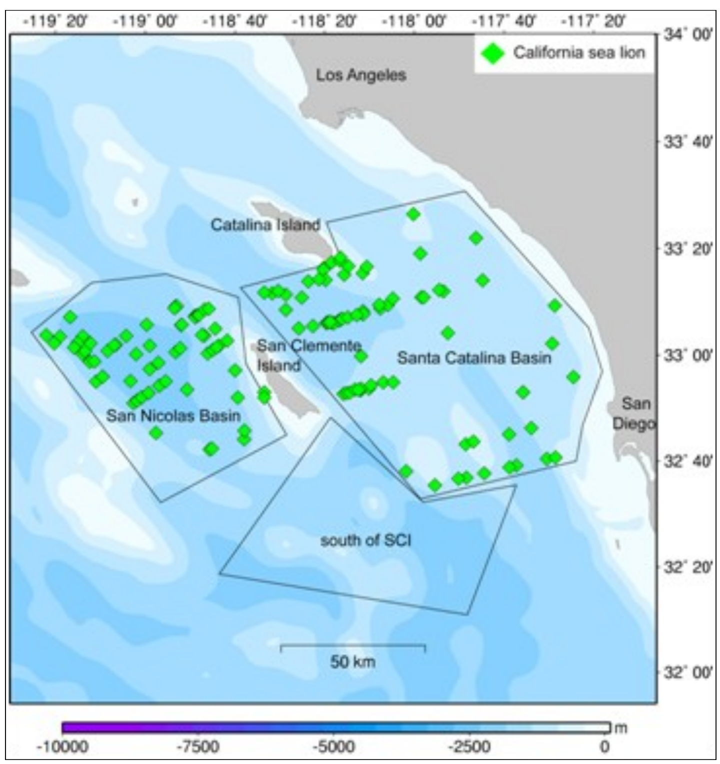

Figure 5: Sightings (identified to species) used for estimation of density and abundance of California sea lions in this study, 2008–2013.

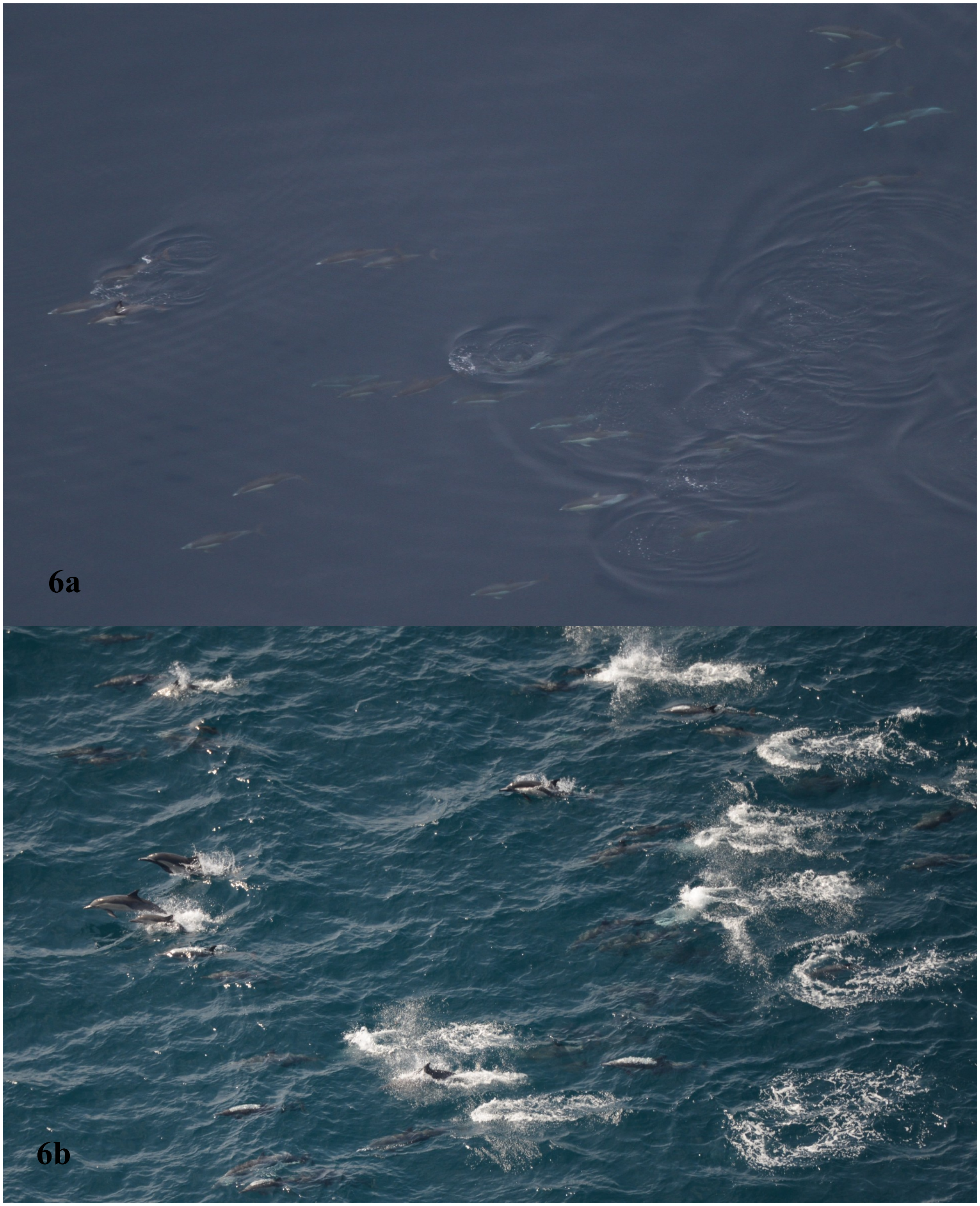

Figure 6: Photographs of the aerial views showing the features used for species identification. (a) Delphinus delphis - *For* D. delphis*, the short beaks, robust bodies, white beak blazes, and frequent white patches on the dorsal fins and flippers can be seen. (b)* D. capensis - *For* D. capensis*, the long beaks, more-slender bodies, shallow foreheads, wide gape-to-flipper stripes, and infrequent light patches on fins can be seen. Used with permission.*

We did this in the present study, by using g(0) factors from studies by other researchers of the target species. However, these often only account for part of the potential bias.

Visibility bias in marine mammal surveys is generally divided into two categories. Availability bias is the proportion of animals on the trackline missed due to being on a dive and thus unavailable to be seen by the observers. It is usually modeled from information on dive times (3, 7, 19). Perception bias, on the other hand, is the proportion of animals on the trackline that was available to be seen, but was not detected by the observers due to operational factors (such as adverse conditions or observer fatigue). It is well known that certain species (e.g. blue whales and Risso's dolphins) are more easily seen, due to their large size, "showy" behavior, or highly visible coloration. Perception bias is usually modeled based on detection data collected from multiple-platform or independent/conditionally independent observer studies (17, 25, 26). Ideally, both should be accounted for in marine mammal surveys, but in practice suitable data are usually not available to correct for both types of bias. Since our estimates for some species do not account for both of these types of bias, this results in some residual underestimation.

The inability to see all animals directly under the aircraft also clearly affects the trackline detection. Due to aircraft and personnel limitations, we did not have the ability to use a belly observer. We have strived to minimize the potential effects of this limitation on the resulting density and abundance estimates by using a 200-m left-truncation approach. It is uncertain how much remaining bias from this factor may affect our estimates.

<u>Assumption 2: No Responsive Movement :</u> Although it is often stated that there must be no responsive movement to the survey platform, this is not strictly true. However, any responsive movement must occur after detection by the observers, and such movement must be slow relative to the speed of the survey platform (13). In our case, the use of a fast-moving aircraft as the survey platform minimizes the chances of this being a significant issue. There is much more concern with vessel surveys, and this is generally not considered to be a problem for aerial surveys.

<u>Assumption 3: No Distance Errors:</u> Distances must obviously be measured accurately to avoid inaccuracies in the resulting estimates (13). However, in practice, distances are difficult to measure at sea, and it is likely that every marine mammal line-transect survey has suffered from some inaccuracy in distance measurement. However, small and random errors generally do not cause significant problems. It is large and/or directional errors that that cause large biases and are thus of more serious concern. We have strived to measure angles and distances as accurately as possible during this study. At this point, we have no indications that large or directional errors in distance measurement were an issue in this study, and we are conducting studies to further examine this potential bias.

<u>Placing the Estimates into Context</u>: Historically, patterns of cetacean relative abundance and presence in SOCAL waters are, in many cases, very different from what are currently observed (41). This is likely related to previous exploitation and depletion of these species, long-term changes in oceanographic conditions, and/or concomitant changes in prey distributions and densities. Peterson *et al.* summarized the anomalous conditions (including several El Niño and La Niña events) that have characterized the California Current System in the last several years (37). Henderson *et al.* have examined how these factors may affect small cetacean distribution and abundance in the SOCAL area (28). Below, we place the information obtained during the current study into the context of our historical knowledge.

Recent ship-based surveys of the SOCAL area using data collected from CalCOFI cruises have provided abundance estimates for cetaceans in an area overlapping ours. However, as these surveys used very different methods and did not produce estimates for the same strata and seasonal partitions as ours, the results are not directly comparable (14, 22). Carretta *et al.* conducted extensive year-round aerial surveys of an overlapping (although not completely so) area in 1998/1999, totaling 7,732 km of systematic line-transect effort (19). We flew 18,831 km of systematic line-transect effort. We followed very similar methods and used similar equipment to the surveys of Carretta *et al.*, including even using some of the same aircraft and pilots (19). Although, we cannot compare abundance estimates directly, since our study area boundaries differ somewhat (Figure 1), estimates of density from our study area can be reasonably compared with those of Carretta *et al.* (19). Comparisons to those estimates, in particular, can provide some useful information on potential changes in distribution and abundance of marine mammal species over the last 15 years. These data are discussed by species below.

Fin whale: The fin whale is one of the most common large whales off SOCAL and is seen in all seasons (16, 22, 25, 27). Fin whales were heavily hunted in the 20th century, but have been protected by the International Whaling Commission (IWC) since 1976. The species is listed as Endangered under the U.S. Endangered Species Act (ESA). Thus, the population would be predicted to have recovered somewhat since then (41). The fin whale was not mentioned in reports of cetacean surveys conducted in SOCAL waters in the 1950s (11, 36). Although there was no evidence of a population increase in the California/Oregon/Washington stock from traditional analysis of SWFSC line-transect surveys, a Bayesian analysis of the same dataset showed a significant increase in this species from 1991 to 2008 (18, 35). The past effects of illegal whaling, as well as ship strikes and gillnet entanglement, may have slowed recovery of the species. However, the current best estimate of stock size is 3,044 whales (CV = 0.18) (18). Carretta *et al.* sighted fin whales 21 times (6 in the cold- and 15 in the warm-water season), which for large whales was second only to the gray whale (sighted only in the cold-water season) (19). Densities of 0.27 animals/100 km^2 (CV = 0.34, cold) and 0.89 (CV = 0.33, warm) were calculated from the Carretta *et al.* surveys (19). Overall, our estimates (0.91 animals/100 km^2, warm; 0.93 animals/100 km^2, cold) are well above theirs, based on our 61 sightings. This is consistent with the documented increase in fin whale abundance along the U.S. west coast (35).

Gray whale: Gray whales migrate along the coast of California twice per year: once during their fall southward migration and again during their spring northward migration. They are commonly seen off the SOCAL coast during these times. The species was heavily exploited in the 19th and early 20th centuries and was subsequently protected from commercial whaling by the IWC in the mid-20th century. The ensuing recovery of the eastern North Pacific stock has been so successful that it has since been removed from the U.S. Endangered Species List. The current best estimate of the eastern North Pacific stock size is 19,126 (CV = 0.07), up from a low estimate of just a few thousand individuals (18, 38). Despite this overall increase, there have been several population 'dips' in recent years, thought to be mostly related to harsh environmental conditions on the northern feeding grounds and resulting detrimental effects on calf survival (1). Gray whales were observed 31 times by Carretta *et al.* all during the cold-water season (19). They calculated an overall density estimate of 5.1 animals/100 km^2 (CV = 0.29) for this species. We observed gray whales 39 times during the cold-water season, with a corresponding density of 1.16 animals/100 km^2 which is quite a bit lower than that of Carretta *et al.* (19).

Risso's dolphin: Risso's dolphins are currently one of the most common species of delphinids off the California coast, apparently due to significant changes in numbers and/or distribution over the last several decades (27, 41). Older reports from the mid-20th century did not identify these animals as common in SOCAL. In fact, they were not even mentioned by Brown and Norris or Norris and Prescott, who conducted extensive cruises in the SCB in the 1950s (11). Similarly, Risso's were not discussed by Walker, who conducted many searches in the SCB in 1966-1972 to live-capture small cetaceans (36, 45). Leatherwood *et al.* stated that Risso's were most abundant in SOCAL during periods of protracted warm water, and were considered to be primarily a tropical species (34). However, our current understanding of this species does not support this view. In contrast, greatest abundance generally appears to occur in areas with colder waters, such as central California (33). The California/Oregon/Washington stock of Risso's dolphin is currently estimated at 6,272 individuals (CV = 0.30), which appears to be an underestimate (18). There is no empirical evidence of an overall trend in abundance from recent line-transect surveys conducted off the

U.S. west coast (18). However, we believe that this species has increased off SOCAL in recent years. In general, we found much greater densities in our study than were found by Douglas *et al.* for 2004-2008, though their study covered a much larger area (22).

Risso's dolphins were common in the late 1990s when the Carretta *et al.* surveys were conducted, and those authors observed 23 groups (16 of them during the cold-water season) (19). They calculated densities of 6.1 (CV = 56, warm) and 18.0 individuals/100 km^2 (CV = 40%, cold). Based on a total of 142 sightings, our calculated warm-water density (11.46 animals/100 km^2) is much higher; however, our cold-water density (7.85 animals/100 km^2) is quite a bit lower than that of Carretta *et al.* (19). These densities indicate that a substantial number of Risso's dolphins used the area during our study period (up to about 1,500 individuals). They were thus the third-most abundant dolphin species we saw, after the two common dolphin species. This may be generally indicative of increased use of the SCI area during the warmer season and decreased use during the colder season, although this remains to be determined.

<u>Bottlenose dolphin:</u> In the 1950s, bottlenose dolphins were considered uncommon north of Orange County, although they were often still seen inside SD Bay at that time (36). The NMFS currently recognizes two stocks of bottlenose dolphins in SOCAL. The coastal stock remains within 1 km from the mainland shore. Thus, animals observed in the present study around SCI would presumably belong mostly to the California/Oregon/Washington stock. So-called offshore bottlenose dolphins in California may actually comprise more than one stock, and there is some evidence of separate island-associated populations; however, this remains unconfirmed. Nevertheless, the currently recognized offshore (California/Oregon/Washington) stock is estimated to number 1,006 individuals (CV = 0.48), and there is no information on trends for this stock (18).

Older records of bottlenose dolphins in more offshore waters of SOCAL usually stated that they were almost always in the company of short-finned pilot whales (36, 45). Pilot whales were previously considered to be "quite common" in SOCAL waters

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(11). This association was not seen in the present study, as pilot whales were never observed. Bottlenose dolphins were seen by Carretta *et al*. in both warm- and cold-water seasons (19). They estimated densities of 1.5 (CV = 0.67, warm) and 3.4 animals/100 km^2 (CV = 0.66, cold) from their late 1990s surveys. Their estimates were based on a total of 14 sightings, while we included 34 for this species. Our warm-water estimate of 2.58 animals/100 km^2 is higher. Our cold-water estimate of 1.51 animals/100 km^2 is lower than that of Carretta *et al.*, which may be expected as our surveys did not cover coastal waters extensively (19).

<u>Short-beaked common dolphin:</u> Until 1994, only a single species of common dolphin was considered to occur off the California coast, *D. delphis* (29). We now know that there are actually two species, *D. delphis* and *D. capensis*. Before 1994, the two species were erroneously lumped as *D. delphis*. Work conducted before the mid-1990s generally did not distinguish the two species. However, conclusions from these studies are probably mainly attributable to the more abundant short-beaked species. This species has long been known as one of the most abundant and widespread in the SCB (2, 11, 21, 22, 27, 36, 45). Although older records are sometimes contradictory, extensive aerial surveys for common dolphins in the 1980s showed them to be much more widespread and have much higher densities (0.8-2.4 individuals/km^2) in summer/autumn than during winter/spring (0.2-1.2 individuals/km^2) (11, 21, 36). The latter authors identified an influx of animals from the south into the SCB during the warm-water season.

Short-beaked common dolphins are extremely common and abundant in SOCAL waters. The current population estimate is 411,211 individuals (CV = 0.21), making it the most abundant cetacean in the SCB (18). There is some evidence of an increasing trend in SOCAL waters. This may be correlated with a decline in numbers of 'northern common dolphins' (which includes both species) in Mexican waters and the eastern tropical Pacific (18). Overall, the species' abundance off California is highly variable (2, 21, 25).

The short-beaked common dolphin was the

most frequently observed cetacean species during the Carretta *et al.* study (61 sightings) (19). They observed them in both seasons, with estimated densities of 465.0 (CV = 0.39, warm) and 178.0 animals/100 km^2 (CV = 0.37, cold). We observed both common dolphin species in our surveys (total 191 useable sightings). However, *D. delphis* was much more common: 17% of all common dolphin sightings were *D. delphis* vs. 6% *D. capensis*. The remaining 77% could not be reliably identified to species and were classified as *Delphinus* sp.

Warm-water densities of short-beaked common dolphins in our study (67.34 animals/100 km^2) were much lower than for Carretta *et al.*'s warm-water season (465 animals/100 km^2) (19). This may be at least partly related to colder water temperatures in recent years (for instance 2010 was a La Niña year, with unseasonably cold water temperatures). Our cold water estimate (126.10 animals/100 km^2) is more similar to that of Carretta *et al.* (178 animals/100 km^2) (19). Clearly, short-beaked common dolphins were very abundant in our study area (the most abundant species, by far) with an estimate of about 16,000 individuals present at the peak.

<u>Long-beaked common dolphin:</u> The long-beaked species of common dolphin is frequently observed in nearshore waters of SOCAL within 90 km of the mainland coastline (18, 27). Highest densities are found near the mainland coast and Channel Islands (22). There is little information on the historical status of the species, as it was not recognized as a separate species until 1994 (29). The California long-beaked common dolphin stock is currently estimated at 107,016 individuals (CV = 0.42) (18). This is much higher than the previous estimate of 27,046 (15). While no formal population trends analysis has been done for this species, their numbers do appear to be increasing off SOCAL (15). Oceanographic conditions (especially warming of local waters during El Niño conditions) cause density fluctuations among these dolphins in the SCB (15, 18, 29). Our abundance estimates suggest a ratio of about 2.5:1 (*delphis:capensis*), which includes a much higher proportion of *D. capensis* than reported by Douglas *et al.* (22). This is expected, as their study area was more offshore and extended further north, where *D. capensis* density is lower (29).

During the late 1990s, Carretta *et al*. did not report any sightings of this species, and all their identified common dolphins were considered to be *D. delphis* (19). We did identify 37 groups of long-beaked common dolphins to species (16 of which were were "useable" for density estimates). However, they were less frequent and in smaller groups than short-beaked common dolphins. We estimated densities of 26.19 animals/100 km^2 (warm), and 50.90 animals/100 km^2 (cold) for this species. This is consistent with the idea that long-beaked common dolphins are becoming much more abundant in SOCAL, as recently suggested by Carretta *et al*. (15). It should be noted that we observed a much higher proportion of *D. delphis* in our study (2.5:1) than Carretta *et al*. who encountered the two *Delphinus* species in nearly equal proportions during 2009 ship surveys conducted throughout the reported range for *D. capensis* (15). It is likely that if our study effort had focused more in coastal waters, we would have obtained a higher ratio of *D. capensis,* as this species' highest reported densities occur within several kilometers of the coast. Many of the local *D. capensis* schools in the San Diego area appear to be inshore of the eastern boundaries of our study area.

<u>California sea lion:</u> California sea lions are very common in SOCAL waters and are the most abundant pinniped species along the California coast. The current best estimate of this single U.S. recognized stock is 296,750 individuals (18). The population has generally been increasing for many decades, although there have been several recently reported dips in abundance (18). The stock is considered to have reached carrying capacity, though this is currently unconfirmed (18).

Density in the water has not traditionally been estimated for pinnipeds in SOCAL. However, Carretta *et al.* provided the first such estimates based on several hundred sightings (19). Their California sea lion estimates ranged from 19.4 to 119.0 animals/100 km^2 during the cold-water season, and from 5.6 to 75.0 animals/100 km^2 during the warm-water season based on 371 total sightings. Our warm-water estimate of 5.83 individuals/100 km^2 and our cold-water estimate of 10.35 individuals/100 km^2

(based on 132 sightings) are generally much lower than those of Carretta *et al*. (19). The lower densities recorded in our study, vs. Carretta *et al.,* may be expected, as our surveys did not have extensive coverage in the nearshore shallow waters where California sea lions are most frequently observed (19). Carretta *et al.* focused their coverage in these waters specifically for pinniped surveys (19). California sea lion density at sea tends to be lower during summer months, when much of the population is ashore for the breeding season.

Conclusion

This report provides the most current (2008-2013), fine-scale estimates of density and abundance within portions of the offshore marine waters in SOCAL used by the USN. In particular, densities derived for the cold-water season represent information that has been largely absent from the region over the last 15 years. Abundance of marine mammals is known to fluctuate from year to year based on changing and dynamic oceanographic conditions in SOCAL (El Niño Southern Oscillation events, prey availability/distribution, etc.) (28). For instance, the NMFS in their spatial habitat models and density estimates generally prefers to pool multi-year survey data to reduce effects of inter-annual variation. Based on comparisons to historical data, such as Carretta *et al.*, we believe that our estimates reported herein are generally reflective of marine mammal numbers within the USN's SOCAL Range Complex during the 2008-2013 survey period (19). Although our study spans a nearly 6-year period, we did not attempt to evaluate trends in abundance, largely due to sample size limitations. We plan to further investigate this dataset through density modeling.

Overall, our results indicate that the study area continues to be used by a substantial number of marine mammal species during both the warm and cold water seasons. Although direct comparisons are problematic due to methodological, geographical, and temporal differences in the studies, the sometimes dramatic differences in the general patterns of seasonal density for some species suggest strong variability in occurrence and density patterns. These are most likely related to prey species shifts mediated by oceanographic events, and also anthropogenic impacts and recovery from such impacts (28, 38).

Our survey results, when compared to past studies, indicate that the relative density of some species has changed in the SCB since the 1950s and 1960s (41). Both increases and decreases have been indicated, depending on species (41). We hope that further survey work will facilitate continued estimation of abundance for all species occurring in the study area, allowing longitudinal refinement and updating of these estimates in the future. There are ongoing plans to synthesize data from this project with other data in an environmental modeling study to ultimately provide more accurate, fine-scale information and predictive capabilities for USN monitoring and assessment efforts relative to SOCAL marine mammals.

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