Abstract—The abundance and distribution of California sea lions (*Zalophus californianus*) in central and northern California was studied to allow future evaluation of their impact on salmonids, the ecosystem, and fisheries. Abundance at-sea was estimated by using the strip transect method from a fixed-wing aircraft with a belly viewing port. Abundance on land was estimated from 126-mm-format aerial photographs of animals at haulouts between Point Conception and the California–Oregon border. The sum of these two estimates represented total abundance for central and northern California. Both types of survey were conducted in May–June 1998, September 1998, December 1998, and July 1999. A haulout survey was conducted in July 1998. The greatest number of sea lions occurred near Monterey Bay and San Francisco Bay for all surveys. Abundance was high in central and northern California in 1998 when warm water from the 1997–98 El Niño affected the region and was low in July 1999 when cold water La Niña conditions were prevalent. At-sea abundance estimates in central and northern California ranged from 12,232 to 40,161 animals, and haulout abundance was 13,559 to 36,576 animals. Total abundance of California sea lions in central and northern California was estimated as 64,916 in May–June 1998, 75,673 in September 1998, 56,775 in December 1998, and 25,791 in July 1999. The proportion of total abundance to animals hauled-out for the four complete surveys ranged from 1.77 to 2.13, and the mean of 1.89 was used to estimate a total abundance of 49,697 for July 1998. This multiplier may be applicable in the future to estimate total abundance of California sea lions off central and northern California if only the abundance of animals at haulout sites is known.

Abundance and distribution of California sea lions (*Zalophus californianus*) in central and northern California during 1998 and summer 1999

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The California sea lion (*Zalophus californianus*) is distributed from central Mexico to British Columbia, Canada. Four islands off southern California (Santa Barbara, San Clemente, San Nicolas, and San Miguel Islands) form the reproductive center for the U.S. population, although some pupping occurs at various other haulout sites in central California (Pierotti et al., 1977; Keith et al., 1984). The number of individuals off California varies throughout the year because sea lions from Mexico enter and leave California waters and individuals from California migrate southward into Mexico or northward as far as British Columbia, Canada (Bartholomew, 1967; Bigg, 1988; and Huber, 1991). In southern California, the abundance of California sea lions peaks during the summer breeding season (Bartholomew, 1967; Odell, 1975). In central and northern California, the number of sea lions typically increases in the autumn during the northward migration, declines in winter, increases in spring as sea lions move to rookeries in southern California and Mexico, and declines in summer (Orr and Poulter, 1965; Mate, 1975; Sullivan, 1980; and Griswold, 1985; Bonnell et al.[1]).

Since the mid-1970s, the California sea lion population in the United States has expanded at an average of 5.0% per year and was most recently estimated to be between 204,000 and 214,000 individuals in 1999 (Forney et al.[2]). This estimate is roughly 2.7 times greater than in 1981–83 (Bonnell et al.[1]). As the U.S. sea lion population has grown, concerns have arisen about potential impacts on commercially harvested fish stocks. California sea lions feed on a variety of fish and cephalopods, some of which are commercially important species, such as salmonids (*Oncorhynchus* spp.), Pacific sardines (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), Pacific whiting (*Merluccius productus*), rockfish (*Se-*

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[1] Bonnell, M. L., M. O. Pierson, and G. D. Farrens. 1983. Pinnipeds and sea otters of central and northern California, 1980–1983: status, abundance, and distribution. Center for Marine Studies, Univ. California, Santa Cruz. OCS Study MMS 84-0044, 220 p. Prepared for Pacific OCS Region, Minerals Management Service, U.S. Department of Interior, Camarillo, Calif. 93010, contract no. 14-12-0001-29090.

[2] Forney, K. A., J. Barlow, M. M. Muto, M. Lowry, J. Baker, G. Cameron, J. Mobley, C. Stinchcomb, and J. V. Carretta. 2000. U.S. Pacific marine mammal stock assessments: 2000. NOAA Tech. Memo.: NOAA-TM-NMFS-SWFSC-300, 276 p. National Marine Fisheries Service, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

bastes spp.), and market squid (*Loligo opalescens*) (Lowry et al., 1990, 1991; Lowry and Carretta, 1999; Weise, 2000). Effects on these resources have been estimated for Monterey Bay only, where during the 1997–98 El Niño sea lions consumed an estimated 269.1 to 804.7 metric tons (t) of salmon, 988.4 to 2206.8 t of sardine, and 533.4 to 1827.4 t of rockfishes annually (Weise, 2000). Recently, salmon in central and northern California have experienced population declines and some stocks have been listed as threatened or endangered under the U.S. Endangered Species Act. Although a variety of factors are responsible for the decline (e.g., logging, dams, agriculture, fishing), some salmonid populations are at such reduced levels that predation by sea lions may negatively affect their recovery (NMFS[3]). Sea lions also have been documented as interfering with recreational fisheries by consuming bait and chum and depredating hooked fish (Fluharty[4]).

Existing methods of population assessment have been based on pup counts obtained at California sea lion rookeries near the end of the breeding season and total population has been estimated by extrapolating data from a life history model (Barlow and Boveng, 1991; Boveng[5]; Barlow et al.[6, 7]; Forney et al.[2]). However, this approach cannot be used outside of the breeding season or in nonbreeding areas. Previous studies of California sea lion abundance and distribution in central and northern California during 1980–82 (Bonnell et al.[1])

and 1995–96 (Beeson and Hanan[8]) included only animals on land; animals at sea were either not considered or were included as a rough estimate. An assessment approach was, therefore, needed to provide quantitative estimates of California sea lion abundance in central and northern California that included both animals at sea and on land.

This study uses a combination of the strip-transect method (to estimate at-sea abundance) and aerial photographic counts (to estimate abundance of sea lions on land) in order to estimate the total abundance of California sea lions in central and northern California. Abundances were estimated separately for seven latitudinal zones within central and northern California. This study also describes distribution of sea lions by age and sex class in central and northern California, describes offshore distribution of sea lions, and introduces a new multiplier that can be used to estimate the total abundance of California sea lions at sea and on land, when only an estimate of the number of animals on land is available.

Methods

Survey dates and areas

Surveys were conducted during May–June, July, September, and December 1998, and July 1999. The May–June survey occurred when salmonid smolts were migrating out of rivers (NMFS[3]), the July survey when the United States stock of California sea lions was expected to be distributed mostly in California coastal waters, and the September and December surveys when adult salmon were migrating into rivers (NMFS[3]). The study area encompassed the waters and shoreline of central and northern California from Point Conception (34°26.8′N, 120°28.0′W) to the California–Oregon border (42°00.0′N, 124°12′W) within approximately sixty nautical miles of the coast (Fig. 1).

Strip-transect surveys

A twin-engine, high-wing Partenavia PN68C- or PN68-observer model aircraft was flown at an airspeed of 185 km/h during strip-transect and coastal haulout surveys. Abundance of sea lions at sea was determined by using the strip-transect method because previous aerial surveys in central California indicated that densities of sea lions would be too great in some areas to obtain reliable measures of perpendicular distances for line-transect density estimation. Previous aerial surveys using line transect methods, conducted at 213 m altitude, indicated a relatively flat detection function for sea lions between

[3] NMFS (National Marine Fisheries Service). 1997. Investigation of scientific information on the impacts of California sea lions and Pacific harbor seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. NOAA Tech. Memo. NMFS-NWFSC-28, 172 p. Northwest Fisheries Science Center, 2527 Montlake Blvd. E., Seattle, WA 98112-2097 and National Marine Fisheries Service, Northwest Region, 7600 Sand Point Way N.E., Seattle, WA 98115-0070.

[4] Fluharty, M. J. 1999. California sea lion interactions with commercial passenger fishing vessel fisheries: a review of log book data from 1994, 1995, and 1996. California Department of Fish and Game Admin. report 99-2, 21 p. [Available from California Department of Fish and Game, Marine Region, San Diego Field Office, 4949 Viewridge Avenue, San Diego, CA 92123.]

[5] Boveng, P. 1988. Status of the California sea lion population on the U. S. west coast. National Oceanographic and Atmospheric Administration admin. report LJ-88-07, 26 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

[6] Barlow, J., R. L. Brownell Jr., D. P. DeMaster, K. A. Forney, M. S. Lowry, S. Osmek, T. J. Ragen, R. R. Reeves, and R. J. Small. 1995. U.S. Pacific marine mammal stock assessments. NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-219, 162 p. National Marine Fisheries Service, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

[7] Barlow, J., K. A. Forney, P. Scott Hill, R. L. Brownell Jr., J. V. Carretta, D. P. DeMaster, F. Julian, M. S. Lowry, T. Ragen, R. and R. Reeves. 1997. U.S. Pacific marine mammal stock assessments: 1996. NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-248, 223 p. National Marine Fisheries Service, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

[8] Beeson, M. J., and D. A. Hanan. 1996. An evaluation of pinniped-fishery interactions in California. Report to the Pacific States Marine Fisheries Commission, 47 p. [Available from Pacific States Marine Fisheries Commission, 205 SE Spokane St., Suite 100, Portland, OR, 97202-6413.]
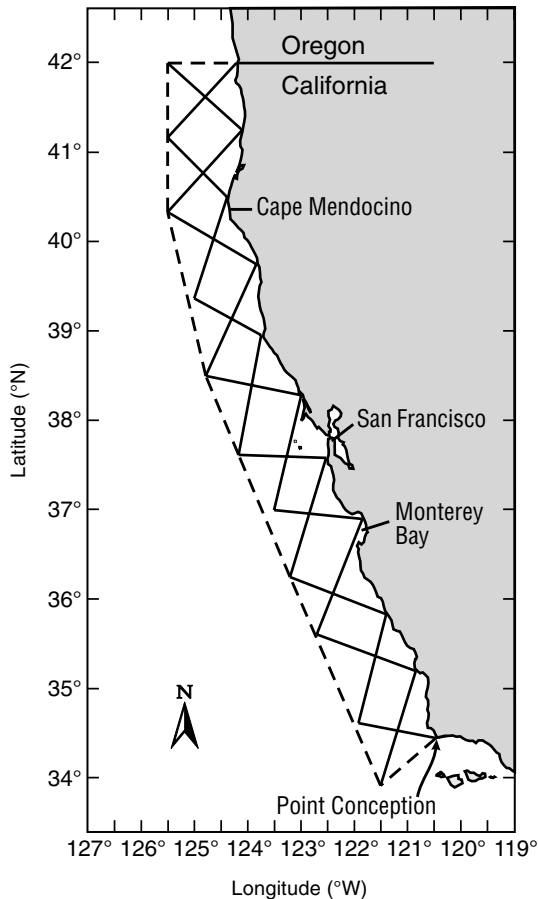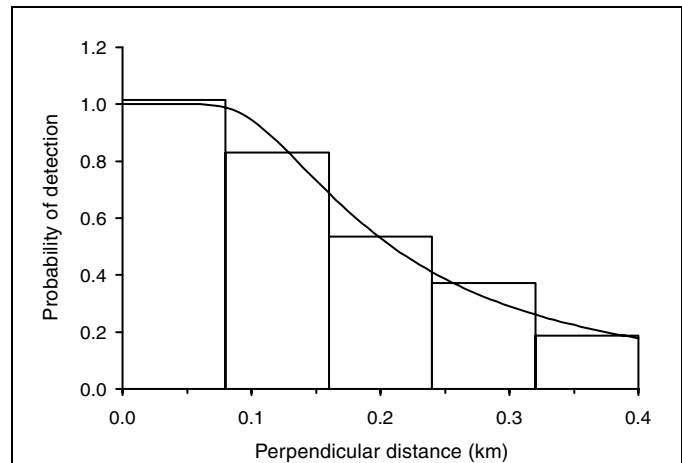
Figure 1

Strip-transect lines (solid lines) within the study area (dashed line) used for estimating at-sea abundance of California sea lions (*Zalophus californianus*) in central and northern California.
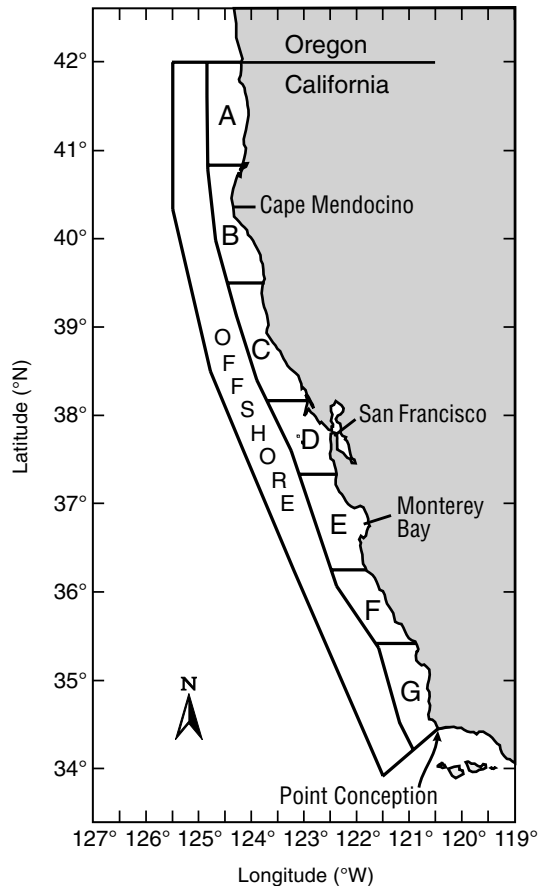

Figure 2

Probability density function for California sea lion (*Zalophus californianus*) sightings from an aircraft flying at an altitude of 213 meters in Beaufort sea states 0–4. Figure was provided by J. Carretta, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA, 92037.

approximately 85 meters left and right of the transect line (Fig. 2; Carretta, personal commun.[9]). Therefore, strip transect assumptions, that all individuals within the observed strip are detected, were expected to be valid within 85 meters left and right of the transect line. In our study we lowered the altitude of the aircraft to 183 m to increase the detection probability for sea lions in the water, especially in Beaufort 3–4 sea states. At that altitude, the viewing area of a single observer viewing from the belly window extended from directly below (90°) to a declination angle of 65° on each side, resulting in a total strip width of 170 m, or 85 m on each side of the viewing window.

Transects followed predetermined lines that systematically zig-zagged the study area (Fig. 1). Surveys were conducted in Beaufort sea states of 0–4. The lines were flown from south to north to take advantage of

sun angle and to minimize sun glare, except on a few overcast days when southbound flights provided ample visibility. Geographical positions were recorded at one-minute intervals directly to a laptop computer by a serial cable connected to the aircraft's global positioning system (GPS). The following data were collected: number of California sea lions, GPS position, percentage of cloud cover over the survey area, name of the observer and data recorder, Beaufort sea state, transect number, and percentage of glare. Percentage of glare was defined as the proportion of the viewing area in which the observer could not see into the water because of surface reflection caused by sun or cloud glare. During the May–June survey we used a recorder, observer, and a resting person—the resting person rotating with the observer approximately every 30 minutes. During the July, September, and December surveys, the resting person was eliminated and the observer and recorder rotated at approximately 30-minute intervals.

Abundance at sea

We used the nonparametric Kruskal-Wallis test for two-way comparisons of the effects of glare and sea state on California sea lion sighting rates. For these tests, each transect segment with constant viewing conditions was randomly assigned to one of five substrata, which served as replicate samples for the tests. Viewing conditions with significantly lower sighting rates were excluded from the abundance analyses to reduce bias caused by missed animals.

Two *a posteriori* geographic strata were created, inshore (50,546 km² total surface area) and offshore

Figure 3

A posteriori stratification of study area into "offshore" stratum and into seven zones (**A** through **G**) within the "inshore" stratum for estimating abundance of California sea lions (*Zalophus californianus*) from strip-transect data and haulout count data.

(56,526 km² total surface area), using transect intersect points as the dividing line (Fig. 3). Differences between the definition of haulout sites for the surveys in this study and during previous surveys in 1980–82 and 1995 (Bonnell et al.[1], and Beeson and Hanan[8]) made it necessary to create additional zones within the inshore stratum to allow comparisons of the three data sets. The inshore stratum was thus divided into seven zones ("A" through "G"), separated at the following latitudes: 1) 35°25′N; 2) 36°15′N; 3) 37°20′N; 4) 38°10′N; 5) 39°30′N; and 6) 40°50′N (Fig. 3). The zones were separated where gaps occurred in the distribution of haulout areas along the coastline. Total area sizes for the seven zones were the following: A: 7647 km²; B: 7206 km²; C: 8025 km²; D: 6153 km²; E: 7790 km², F: 6030 km², and G: 7695 km². At-sea abundance was obtained separately for offshore and inshore strata, and for each zone within the inshore stratum, by using a modified strip-transect formula that included a correction, $g(0)$, for diving animals that were not available to be seen:

$$N_c = \frac{nA}{WLg(0)},\qquad(1)$$

where N_c = corrected total abundance (corrected for animals below the surface);
n = number of individuals sighted within the strip-transect;
A = total size of study area (in km²);
W = the strip width (in km);
L = distance surveyed (in km) calculated as the sum of the great circle distances between position fixes; and
$g(0)$ = probability that a sea lion will be visible at the surface within the strip viewed by the observer as the aircraft passes over the water.

Coefficients of variation (CV) and lognormal 95% confidence limits of these abundance estimates were calculated by using standard formulae (Buckland et al., 1993).

Probability of missing submerged sea lions

We estimated the probability of seeing sea lions at the surface, $g(0)$, from dive data in Feldkamp et al. (1989) derived from 14 foraging trips made by seven lactating adult female California sea lions during late breeding-season:

$$g(0) = \frac{t+s+r}{t+s+r+d},\qquad(2)$$

where t = average time (hours) spent at the surface between dives within diving bouts by an adult female sea lion;
s = average time (h) spent swimming near the surface between diving bouts by an adult female sea lion;
r = average time (h) spent resting at the surface between diving bouts by an adult female sea lion; and
d = average time (h) spent diving during diving bouts by an adult female sea lion.

From seven female sea lions, Feldkamp et al. (1989) calculated averages of 12.0 hours (no SD given) spent at the surface between dives within diving bouts (t), 21.9 hours (SD=9.5 hours) spent swimming near the surface between diving bouts (s), 1.6 hours (SD=1.6) spent resting at the surface between diving bouts (r), and 17.3 hours (SD=6.7) spent diving during diving bouts (d). We calculated the CV for $g(0)$ from the standard deviations of diving data. In using these data we assumed that between dives, sea lions swam near the surface and at a depth where they would be seen by an observer in the aircraft and that sea lions were not visible to an observer in the aircraft during dives. Dive data were not available for other age and sex classes; therefore,

it was assumed that the proportion of time spent at or near the surface was similar for adult females and other age and sex classes and did not vary significantly within region, season, and year.

Photographic surveys

The aircraft was flown from north to south directly over the coastline or slightly offshore at an altitude of 183 to 213 m (typically 213 m) to locate sea lions onshore. The low altitude ensured that California sea lions could be detected on rocky substrates, aided in identification of different pinniped species, and enabled accurate counts from aerial photographs. All hauled-out California sea lions onshore were photographed. At the Farallon Islands, the aircraft was flown at an altitude of 366 to 457 m (typically 396 m) to prevent disturbance of nesting seabirds. Multiple passes were made over large rocks or islands to ensure that the entire rock or island was photographed. Surveys were made without regard to tidal conditions at any time of day between approximately two hours after sunrise and two hours before sunset.

Sea lions were photographed with a 126-mm-format KA-76 camera (Chicago Aerial Industries, Inc., Chicago, IL) equipped with image motion compensation (IMC) and operated at a cycle rate that achieved 67% overlap between adjacent frames. The geographical position of each photograph was recorded by linking the camera (mounted vertically inside the belly of the aircraft) to a computer and GPS unit. A 152-mm focal-length lens was used for low altitude photography (i.e., 183–213 m) and a 305-mm focal-length lens was used for higher altitude photography (i.e., 366–457 m). Kodak Aerochrome MS Film 2448, a very fine-grained, medium-speed, color transparency film, or Aerochrome HS Film SO-359, a very fine-grained, high-speed, color transparency film, was used. The camera was set at an aperture of f/5.6 and a shutter speed between 1/400 and 1/2000 second.

Photographic counts

Sea lions were counted from photographs illuminated with a light table by using a 7-30X zoom binocular microscope. Counts were obtained for five age and sex class categories: pups, juveniles, adult females or young males of similar size, subadult males, and adult males. Age and sex class distinctions were determined from size and other external characteristics (e.g., hair color on head, presence of sagittal crest, chest size, fore flipper width, snout shape, and body coloration). Animals of each age and sex class were marked on a clear acetate plastic overlay with different colored pens as each was counted. Marks on the acetate were then compared and verified with overlapping photographs. The acetate was placed on another photograph at the exact position of the coastline where the count ended previously and the count was continued on the uncounted portion. One count was made for each rock, island, or mainland haulout site.

All counts were conducted by the first author, who is an experienced counter with high intercount reliability (Lowry, 1999). Geographical positions (latitude and longitude) were assigned to each haulout site.

Analysis of haulout data

Counts of sea lions made in this study were compared to those obtained by earlier investigators in 1980–82 (Bonnell et al.[1]) and 1995–96 (Beeson and Hanan[8]) by using nested ANOVAs and paired *t*-tests. The null hypothesis of no difference in zonal counts was used to examine differences in counts by zone, season, year, and survey. The counts were 0.45 power transformed (with Systat 6.0 for Windows, SPSS Inc., Chicago, IL) because their distribution was skewed toward zero.

Results

Sighting rates and $g(0)$

No difference was found ($P>0.05$) for number of sightings, total animals seen, and mean group size during Beaufort sea state conditions 1 through 4. A sharp decline in sighting rates was observed when sightings were grouped into glare categories of 0–24% ($n=27.3$ sightings/1000 km), 25–49% ($n=17.5$ sightings/1000 km), 50–74% ($n=10.7$ sightings/1000 km), and 75–100% ($n=0$ sightings/1000 km). Sighting rates were significantly greater at 0–49% glare than at 50–100% glare ($P<0.001$ for all surveys combined); therefore, only data collected in 0–49% glare were used for at-sea abundance estimation. With only data collected in 0–49% glare, we used 48–76% of kilometers surveyed and 79–89% of sightings.

The probability of sighting a sea lion at the surface, $g(0)$, was estimated as 0.67 (with a CV of $g(0)=0.12$).

At-sea abundance

Strip-transect survey effort totaled 1272 km during 26–30 May 1998, 2856 km during 12–28 September 1998, 2993 km during 1–11 December 1998, and 1175 km during 13–21 July 1999 (Fig. 4). No transect survey was conducted in July 1998 because of persistent low clouds and high winds. Transect distances in 0–49% glare conditions are given in Table 1. Nearly all sightings were within the inshore stratum, and most were within 20 nautical miles from the mainland coast (Fig. 5). Corrected at-sea abundance estimates for sea lions in the study area (Table 1) were 28,340 (May 1998), 40,161 (September 1998), and 24,720 animals (December 1998). For July 1999, a corrected abundance estimate for the inshore stratum in July 1999 was 11,492 animals (Table 1). From the total abundance estimated in the three 1998 surveys, the average proportion represented by the offshore stratum was 0.073 (range: 0.000–0.204). From this proportion, we estimated that there were about 829 sea lions in the unsurveyed offshore stratum
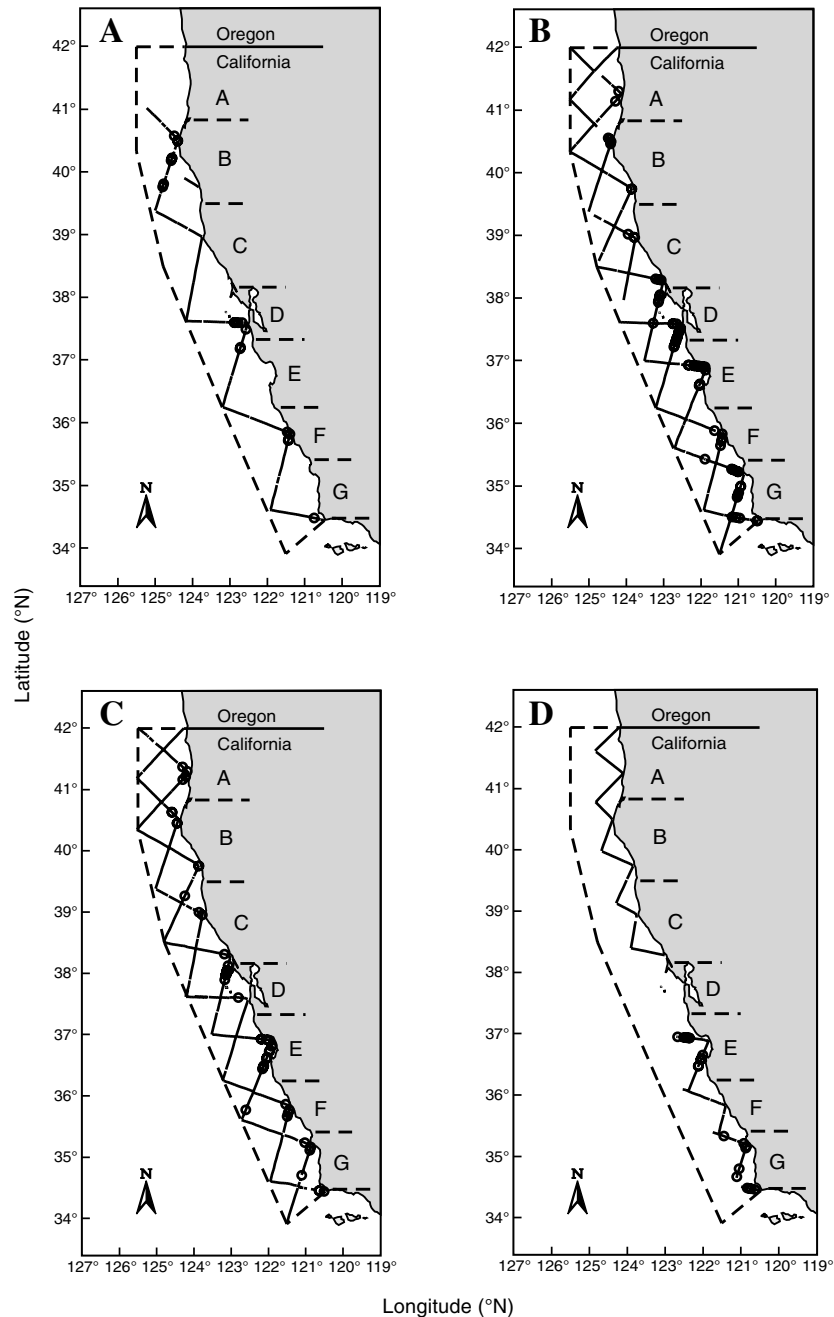
Figure 4

California sea lions (*Zalophus californianus*) sightings (o) during strip-transect surveys flown in Beaufort sea states 0–4 and 0–49% glare conditions (solid zig-zag line). (**A**) 26–30 May 1998, (**B**) 12–28 September 1998, (**C**) 1–11 December 1998, and (**D**) 13–21 July 1999.

in July 1999, and this number was used to extrapolate a total at-sea abundance estimate within the study area of 12,232 sea lions. CVs of corrected estimates were 0.32 (May 1998), 0.26 (September 1998), 0.50 (December 1998), and 0.43 (July 1999; Table 1).

During the May–June 1998 survey, sea lions were most abundant in the northern part of the study area

(Table 1). In September 1998, sea lions were most abundant in the central part of the study area (zones D and E). In December 1998 they were most abundant in the southern portion of the study area (zones E and F). During July 1999, sea lions were most abundant in the south-central portion of the study area (zone E).
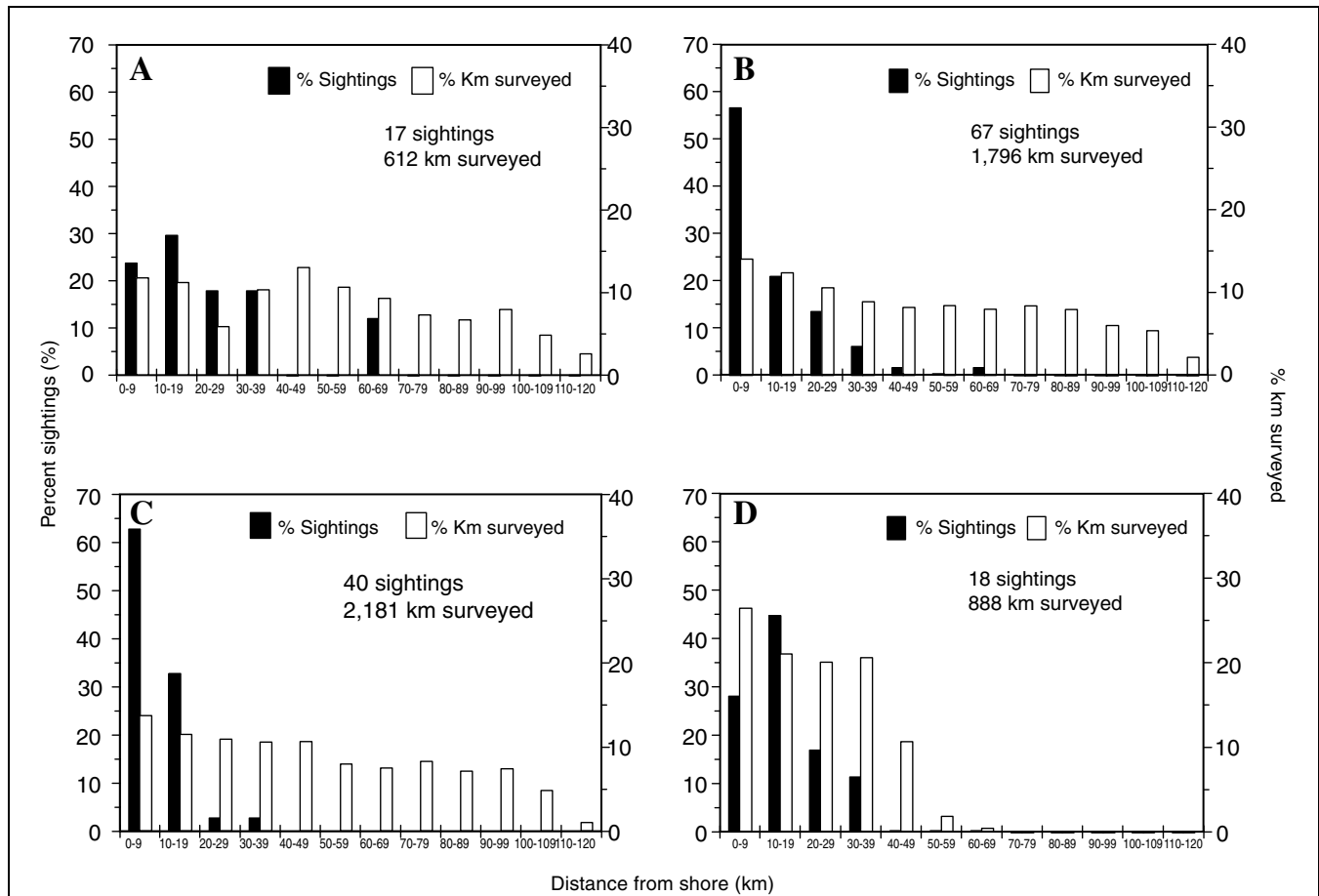
Figure 5

Distances from shore for California sea lions (*Zalophus californianus*) sighted and kilometers from shore for California sea lions that were surveyed during strip transect surveys in Beaufort sea state 0–4 and 0–49% glare conditions. (**A**) 26–30 May 1998, (**B**) 12–28 September 1998, (**C**) 1–11 December 1998, and (**D**) 13–21 July 1999.

Haulout abundance

In 1998 and 1999, aerial photographic surveys of sea lion haulouts in central and northern California were conducted during 31 May–8 June 1998, 7–18 July 1998, 11–20 September 1998, 14–16 December 1998, and 6–11 July 1999. For the July 1998 survey, low clouds prevented aerial surveys of the coastline from Point Sal (34°54.1′N, 120°40.0′W) to Point Conception (counts from 1999 were used for these areas) and from the Klamath River (41°32.5′N, 124°04.7′W) to Humboldt Bay (40°45.4′N, 124°14.4′W). To estimate abundance in the latter missed area, we obtained ground counts from the mainland at all haulouts except Turtle Rocks (41°08.0′N, 124°10.9′W) and Redding Rock (41°20.6′N, 124°10.5′W). In July 1999 a low cloud layer prevented surveys of the coastline between Golden Gate Bridge (37°51.1′N, 122°34.0′W) and just north of Año Nuevo Island (37°06′N, 122°20′W). This gap should have had virtually no effect on the total counts, however, because there is only one minor haulout in this region.

The number of sea lions hauled-out in the study area (Table 2) were 36,576 (May 1998), 26,260 (includes estimate, July 1998), 35,512 (September 1998), 32,055 (December 1998), and 13,559 (July 1999). There was no significant difference in total number of sea lions between the seven zones (P=0.229) and between seasons (P=0.179; Table 3). More sea lions were counted in 1998–99 than during previous surveys in 1980–82 and 1995–96 (P<0.003 for both tests), but no difference in counts was found between 1980–82 and 1995–96 surveys (P=0.232; Table 3).

In 1998, the greatest numbers of sea lions were found in zone D and E (Table 2), corresponding to the San Francisco and Monterey Bay regions; most animals hauled out at Año Nuevo Island and South Farallon Islands. Juveniles and adult-females or young-males were the most prevalent age and sex classes found in the study area in 1998 (Table 2). More adult males were counted during the May–June 1998 survey than during other surveys. In 1998 the number of pups in the study area ranged from 22 (December 1998) to 149 (May–June 1998).

Table 1

Abundance estimates for California sea lions (*Zalophus californianus*) at sea from sightings during strip-transect surveys in the central and northern California study area during three surveys in 1998 and one survey in 1999, under 0–49% glare and Beaufort 0–4 sea state conditions. No survey was conducted within the offshore stratum in July 1999. Insufficient kilometers were surveyed for estimating at-sea abundance, CV(N_c), and 95% confidence limits for strata noted with a dash (—). Corrected estimates are based on $g(0)$ calculated from dive studies on lactating adult females during late breeding-season (Feldkamp et al., 1989).

Stratum	No. of sightings	No. of animals	Kilometers surveyed (km)	Corrected			
				CV (N_c)	Abundance (N_c)	Lower 95% CL	Upper 95% CL
26–30 May 1998							
Inshore: zone A	—	—	0	—	—	—	—
Inshore: zone B	5	6	96	—	3977	—	—
Inshore: zone C	—	—	19	—	—	—	—
Inshore: zone D	6	6	63	—	5156	—	—
Inshore: zone E	—	—	0	—	—	—	—
Inshore: zone F	4	4	118	—	1793	—	—
Inshore: zone G	—	—	6	—	—	—	—
Inshore: total	15	16	302	0.29	23,541	11,224	49,376
Offshore	2	3	310	1.01	4799	561	41,040
Inshore + offshore	17	19	612	0.32	28,340	15,237	52,713
12–28 September 1998							
Inshore: zone A	1	1	121	—	556	—	—
Inshore: zone B	5	5	140	—	2256	—	—
Inshore: zone C	6	7	117	—	4235	—	—
Inshore: zone D	18	23	108	—	11,552	—	—
Inshore: zone E	16	25	146	—	11,752	—	—
Inshore: zone F	5	5	69	—	3852	—	—
Inshore: zone G	15	16	220	—	4919	—	—
Inshore: total	66	82	919	0.27	39,595	24,210	64,757
Offshore	1	1	877	1.1	566	82	3923
Inshore + offshore	67	83	1796	0.26	40,161	24,205	66,635
1–11 December 1998							
Inshore: zone A	4	4	213	—	1262	—	—
Inshore: zone B	6	7	219	—	2026	—	—
Inshore: zone C	4	4	238	—	1185	—	—
Inshore: zone D	2	3	124	—	1303	—	—
Inshore: zone E	15	25	175	—	9773	—	—
Inshore: zone F	3	18	59	—	16,129	—	—
Inshore: zone G	6	6	175	—	2316	—	—
Inshore: total	40	67	1203	0.5	24,720	9333	65,479
Offshore	0	0	977	0	0	0	0
Inshore + offshore	40	67	2181	0.5	24,720	9726	62,831
13–21 July 1999							
Inshore: zone A	0	0	124	—	0	—	—
Inshore: zone B	0	0	174	—	0	—	—
Inshore: zone C	0	0	185	—	0	—	—
Inshore: zone D	—	—	0	—	—	—	—
Inshore: zone E	11	14	146	—	6573	—	—
Inshore: zone F	0	0	135	—	0	—	—
Inshore: zone G	7	9	128	—	4762	—	—
Inshore: total	18	23	888	0.5	11,492	4,358	30,304
Offshore (estimated)	0	0	23	0.9	829	183	3752
Inshore + offshore	18	23	911	0.43	12,232	5427	27,572

Table 2

Counts of California sea lions (*Zalophus californianus*) made from 126-mm-format aerial color photographs for five age- and sex-class categories found in seven zones along the central and northern California coast during four surveys in 1998 and one survey in 1999.

Zone	Pups	Juveniles	Adult females or young males	Subadult males	Adult males	Total
31 May–8 June 1998						
A	0	299	1948	1554	528	4329
B	0	3195	1534	2371	911	8011
C	0	698	751	513	530	2492
D	11	3639	5821	1636	555	11,662
E	99	3481	2993	678	464	7715
F	5	186	380	93	52	716
G	34	684	886	32	15	1651
All	149	12,182	14,313	6877	3055	36,576
7–18 July 1998						
A	0	358	206	148	22	734
B	0	2382	116	162	62	2722
C	0	320	287	190	101	898
D	55	1918	7318	1283	290	10,864
E	54	2920	3226	564	178	6942
F	12	63	510	125	50	760
G	0	779	1362	92	30	3340[1]
All	121	8740	13,025	2564	733	26,260[1]
11–20 September 1998						
A	0	73	1325	1548	559	4165
B	0	1136	351	938	173	2598
C	0	524	594	584	56	2028
D	18	1506	8453	1136	100	11,213
E	22	2122	8056	671	188	11,059
F	6	470	1440	78	24	2018
G	0	1224	1175	29	3	2431
All	46	7985	21,394	4984	1103	35,512
14–16 December 1998						
A	0	27	105	162	123	663
B	0	193	1790	2950	429	5362
C	0	54	201	995	516	1766
D	1	765	10,310	632	97	11,805
E	12	1566	8035	311	103	10,027
F	9	307	903	84	15	1318
G	0	201	831	63	19	1114
All	22	3359	22,175	5197	1302	32,055
6–11 July 1999						
A	0	111	167	5	4	287
B	0	6	6	1	1	14
C	0	0	0	1	0	1
D	3	193	970	109	91	1366
E	4	1226	5652	398	65	7345
F	0	270	578	90	14	952
G	0	919	2426	186	63	3594
All	7	2725	9799	790	238	13,559

[1] Includes 1077 unknown age- and sex-class sea lions that were estimated to have been missed in zone G.

Table 3

Results of four nested ANOVAs on haulout counts of California sea lions (*Zalophus californianus*) found in 7 zones within central and northern California (refer to text and Fig. 3 for zone descriptions). The tests of ANOVA revealed differences between zones, season, years, and surveys. 1980–82 surveys were conducted by Bureau of Land Management (Bonnell et al.[1]) and 1995–96 surveys were conducted by the California Department of Fish and Game (Beeson and Hanan[8]). Year was nested within survey, season was nested within year, and zone was nested within season.

Source	Sum-of-squares	df	Mean-square	F-ratio	P
1998–99 surveys					
Season	1427.2	3	475.7	2.177	0.179
Zone (season)	9157.0	24	381.5	1.746	0.229
1998–99 surveys *vs.* summer and autumn 1995 and winter 1996 surveys					
Survey	1610.7	1	1610.7	11.449	0.003
Season (survey)	2019.4	5	403.9	2.871	0.037
Zone (season)	11,008.8	24	458.7	3.260	0.003
1998–99 surveys *vs.* 1980–82 surveys					
Survey	1731.6	1	1731.6	21.224	<0.001
Year (survey)	2235.9	3	745.3	9.135	<0.001
Season (year)	3576.5	12	298.0	3.653	<0.001
Zone (season)	14,761.2	24	615.0	7.538	<0.001
1980–82 surveys *vs.* summer and autumn 1995 and winter 1996 surveys					
Survey	81.9	1	81.9	1.457	0.232
Year (survey)	649.0	3	216.3	3.849	0.013
Season (year)	3491.5	10	349.1	6.211	<0.001
Zone (season)	11,027.6	24	459.5	8.174	<0.001

In 1999, the majority of sea lions were found between the San Francisco Bay area and Point Conception (zones D through G). Zone E had the greatest number of sea lions (Table 2); the majority of these animals hauled out at Año Nuevo Island. As in 1998, juveniles and adult-females or young-males were the most prevalent age and sex classes (Table 2). Only seven pups were counted in the study area during July 1999. The number of sea lions counted in 1999 was 52% of that counted in July 1998.

Total abundance

There was a significant correlation (r=0.468, P=0.024) between at-sea abundance and haulout abundance within zones. Total abundance of California sea lions in central and northern California during 1998 was estimated to be 64,916 in May–June, 75,673 in September, and 56,775 in December. Total abundance in July 1999 was estimated at 25,791 individuals. The proportion of total abundance to animals hauled-out was 1.77, 2.13, 1.77, and 1.90, respectively, with a mean of 1.89 and a CV for small samples (Sokal and Rohlf, 1995) of 0.09. Using the mean multiplier of 1.89 on haulout counts obtained in July 1998 (Table 2), when at-sea abundance could not be estimated, we estimated total abundance as 49,697 (CV=0.09) animals for that period.

Discussion

This abundance study of California sea lions in central and northern California successfully integrated two methods: 1) strip transect surveys to estimate abundance at sea; and 2) aerial photographic surveys to estimate haulout abundance. The $g(0)$ detection probability derived from previously published dive data allowed estimation of total abundance, including animals expected to be underwater during at-sea strip transect surveys. Previous surveys where transect methods similar to ours were used in the Southern California Bight in 1975–78 and in central and northern California in 1980–83 (Bonnell and Ford, 1987; Bonnell et al.[1, 10]) did not have information for deriving $g(0)$, and, therefore, densities of sea lions at sea were underestimated in these studies.

California sea lions were abundant in central and northern California during May through September

[10] Bonnell, M. L., B. J. Le Boeuf, M. O. Pierson, D. H. Dettman, G. D. Farrens, C. B. Heath, R. F. Gantt, and D. J. Larsen. 1980. Summary of marine mammal and seabird surveys of the Southern California Bight area 1975–1978. Vol. 3: Investigators reports, part 1—pinnipeds of the Southern California Bight, 535 p. Univ. Calif., Santa Cruz, Calif. 95064. Final Report to the Bureau of Land Management, under Contract AA550-CT7-367. [NTIS PB81-248-71.]

1998 when waters were warm because of the strong 1997–98 El Niño. Increased abundance of juveniles and adult females were observed in this region during previous El Niños (Huber, 1991; Sydeman and Allen, 1999) and during our May–June, July, and September 1998 surveys. The increase in adult females in central California in 1998 resulted in an increase in the number of pups counted at Año Nuevo and South Farallon Islands (106 pups in 1998 *vs.* 23 in 1997), and below normal births at rookeries in southern California (Lowry, unpubl. data, Forney et al.[2]). In contrast to 1998, during the summer of 1999 fewer sea lions were found in central and northern California, especially north of San Francisco (zones A, B, and C), and greater numbers were found at rookeries in southern California (M. Lowry, unpubl. data) when waters were cold as a result of the La Niña oceanographic condition that began in October 1998 (Hayward et al., 1999).

The abundance and distribution of California sea lions were distinctly different between El Niño and La Niña periods. During El Niño, sea lions were very abundant in central and northern California, and were distributed throughout the region. In contrast, during summer 1999 (our only survey that year [La Niña]), sea lions were less abundant than during summer 1998, and they were distributed only south of the San Francisco Bay area. The abundance and distribution pattern of summer 1999 is similar to the observed abundance and distribution pattern described by earlier studies (Chambers, 1979; Griswold, 1985; Weise, 2000; Bonnell et al.[1]). During periods of elevated sea lion abundance in central and northern California, such as those observed during the 1998 El Niño, we would expect 1) increased consumption of prey species because of more sea lions feeding in the area, 2) increased pressure on coastal fisheries resources because sea lions feed on commercially valuable species (see Lowry et al., 1990, 1991; Lowry and Carretta, 1999; Weise, 2000), and 3) increased interactions with commercial and sport fisheries. The opposite would occur during periods of low sea lion abundance during non-El Niño years. Greater abundance of California sea lions in central and northern California during the 1997–98 El Niño event, therefore, would be expected to have a greater effect on salmonids and other sea lion prey species, and on fisheries than would occur during non-El Niño years.

Abundance of sea lions in central and northern California during 1998 was greater in May–June (spring) and September (fall) and less in July (summer) and December (winter). This bimodal phenomenon, also observed in the past (Sullivan, 1980; Bonnell et al.[1]), is due to migrating subadult and adult male sea lions on their way to (in fall) and from (in spring) Oregon (Mate, 1975), Washington, and British Columbia (Bigg, 1988). However, these seasonal differences were not significantly different, likely because of low power (only one year of data), or because the animals behaved differently from other years. In fact, fewer subadult and adult males were present at southern California rookeries during the 1998 July census (near the end of breeding

season) than were present during 1997 and 1999 (M. Lowry, unpubl. data). The large number of sea lions in central and northern California during 1998 was the result of a more numerous population (U.S. population estimated at 204,000 to 214,000 in 1999) than existed when previous surveys were conducted in 1980–82 and 1995–96 (U.S. population estimated at 76,000 in 1982 and at 167,000 to 188,000 in 1995) (Barlow et al.[7]; Forney[2]; Bonnell et al.[1], and Beeson and Hanan[8]).

In central and northern California, California sea lions have been sighted during aerial surveys (Carretta and Forney[11]; present study) and tracked with satellite tags (Melin and DeLong, 2000; Melin, 2002) up to 100 nautical miles from shore. However, our surveys indicated that they forage predominantly within 20 nautical miles from shore.

The strip transect method assumes that all animals within a strip are sighted by the observer. Although we found no difference in sighting rate between Beaufort sea state scales 0–1, 2, 3, and 4, Carretta et al.[12] found during their 1998–99 line transect survey in waters off San Clemente Island, California, that the effective strip width of pinniped sightings at 213 m altitude was slightly less in Beaufort sea states 3–4 (184 m on each side) than in Beaufort sea states 0–2 (256 m on each side). Their results suggest that if our analysis suffered from reduced detection probability at high sea states, then we may have underestimated at-sea abundance of sea lions or increased the variance of at-sea sea lion abundance. This potential negative effect was minimized in our surveys by surveying at a lower altitude (183 m) than the 213 m altitude surveyed by Carretta et al.[12]

The $g(0)$ correction derived from dive and foraging studies of lactating adult-female California sea lions during late breeding season (July–August) may be an additional source of error in our at-sea abundance estimates. It may not be representative of nonlactating adult females and other age- and sex-class sea lions, and it may not be representative for all seasons or different oceanographic cycles (e.g., El Niño and non-El Niño). Dive data from various ages and sexes are needed to test these assumptions, but existing dive data from a single age+sex group provided a rough correction to account for animals underwater during at-sea

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[11] Carretta, J. V. and K. A. Forney. 1993. Report of two aerial surveys for marine mammals in California coastal waters utilizing a NOAA DeHavilland twin otter aircraft March 9–April 7, 1991 and February 8–April 6, 1992. NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-185, 77 p. National Marine Fisheries Service, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

[12] Carretta, J. V., M. S. Lowry, C. E. Stinchcomb, M. S. Lynn, and R. E. Cosgrove. 2000. Distribution and abundance of marine mammals at San Clemente Island and surrounding offshore waters: results from aerial and ground surveys in 1998 and 1999. National Oceanographic and Atmospheric Administration admin. report LJ-00-02, 51 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

surveys. Seasonal differences may exist, but data in Feldkamp et al., (1989, 1991) and Melin (2002) indicate that these differences are negligible. Feldkamp et al. (1991) showed differences in diving behavior during El Niño and non-El Niño, but Melin (2002) did not find as much difference in diving behavior during El Niño and non-El Niño (with the exception of longer transit time to foraging grounds during El Niño).

Error in age- and sex-class abundance estimates at haulouts is also affected by subjectivity and inter-observer differences in age and sex classification of sea lions. Therefore, age- and sex-class counts provided in these surveys, although conducted by a single experienced observer (M. Lowry), serve as approximate indices of sea lion age- and sex-class distributions in central and northern California. These indices will be useful for future attempts to estimate consumption of prey by sea lions along central and northern California, given that nutritional requirements differ among age and sex classes.

By estimating abundance of sea lions on land as well as at-sea, we were able to derive a multiplier for estimating total abundance from counts of animals hauled out on land. This multiplier can be applied to future land counts of California sea lions in central and northern California to estimate total abundance, as has been done for harbor seals in California, Oregon, and Washington (Huber et al., 2001; Barlow et al.[6]; Forney et al.[2]). It may also be useful for estimating total abundance from counts of sea lions hauled out in Oregon, Washington, and British Columbia because the age- and sex-class structure of sea lions is similar to that found in central and northern California. However, the multiplier should not be used for smaller areas (such as the zones in the inshore stratum) or for other species, because regional and interspecies differences may exist. In particular, it would not be appropriate for regions where sea lions reproduce, such as in the Southern California Bight (SCB) and in Mexico, because adult females that are rearing pups may spend a different proportion of their time at sea. For that reason, it would be judicious to conduct concurrent offshore and haulout surveys in the SCB and Mexico to derive a correction factor for each geographical region of the sea lion's range. Multipliers could also be derived for smaller areas (such as our zones) by conducting suitably designed smaller-scale at-sea surveys in conjunction with counts of animals hauled out, or by using satellite or radio telemetry tags to directly measure the relative times at sea and on land.

The multiplier for deriving total abundance from haulout counts provides researchers and resource managers with an alternative method for estimating total population abundance or abundance of a stock. Abundance estimates derived with this new approach can be compared to abundance estimates obtained with more conventional methods (such as the life history model), and may provide a means for estimating total abundance when life history data are unavailable.

The approach used in the present study may be particularly useful for estimating abundance at times and places unrelated to breeding activities, or for periods when breeding is disrupted, as with El Niño conditions. Abundance estimates and distributional data provided by these methods can be used to determine where and when the greatest effects on salmon and other prey species may occur. Diet studies at major hauling areas in conjunction with abundance surveys to derive consumption estimates are required to determine the effect of California sea lions on salmon and other sea lion prey species of the region.

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