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Abundance, food habits, and annual fish consumption of California sea lion (Zalophus californianus) and its impact on salmonid fisheries in Monterey Bay, California

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Abundance, Food Habits, and Annual Fish Consumption of California Sea Lion (*Zalophus californianus*) and Its Impact on Salmonid Fisheries in Monterey Bay, California

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Abstract

To assess competition between commercial fisheries and California sea lion (*Zalophus californianus*) in Monterey Bay, California I estimated sea lion seasonal abundance, seasonal food habits, annual fish consumption, and percentages of hooked fish taken by sea lions in commercial and recreational salmon fisheries during 1997 and 1998. Aerial and ground surveys indicated that peak numbers of sea lions occurred during their spring and fall migration. While salmon occurred in the sea lion diet year-round, sea lions primarily consumed schooling prey such as market squid (*Loligo opalescens*), Pacific sardine (*Sardinops sagax*), and northern anchovy (*Engraulis mordax*). Increased depredation of the salmon catch by sea lions in 1998 was most likely the result of the large 1997–1998 El Niño event. Hooked salmon from the fisheries were likely the majority of salmon in the sea lion diet. Assessing the impact of sea lions and other natural predators on prey populations is difficult, but necessary for effective fisheries management.

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Chapter 1

INTRODUCTION

Increases in many formerly depleted pinniped populations coupled with declining fish resources have intensified competition between humans and pinnipeds. Competition for marine resources can be categorized as ecological or operational (Harvey 1987, Mate and Harvey 1987, Olesiuk 1993). Ecological interactions include indirect interactions of pinnipeds and fisheries, such as competition for fishery resources. Fishery harvest levels may be reduced as a result of pinniped predation on commercially valuable species, and pinniped carrying capacities may be reduced by human exploitation of pinniped prey species. Operational interactions occur when pinnipeds and fisheries come into direct contact. For example, pinnipeds can be incidentally entangled and damage fishing gear and remove or damage fish caught in nets or on fishing lines. Ecological interactions are more difficult to assess requiring detailed information on pinniped populations, such as abundance, distribution, age-structure, feeding rates, and diet composition (Olesiuk 1993).

Understanding ecological interactions, such as trophic ecology of marine mammals, is necessary for effective management of fish populations and understanding interactions of fishing activities and marine mammal populations. Studying pinniped food habits provides information on seasonal prey utilization, feeding locations, and prey availability. Studies typically involve identification of fish sagittal otoliths and cephalopod beaks recovered from fecal samples (Cottrell *et al.* 1996).

When prey structures in addition to otoliths were identified, frequency and number of individual prey were at least two times greater for many prey taxa (Olesiuk 1993, Cottrell *et al.* 1996). Large fishes often are underestimated because they are less likely to be consumed whole, and their otoliths may not appear in fecal samples (Pitcher 1980). Fishes with small or less robust otoliths have lesser recovery rates due to the increased probability of complete digestion. The large body size and comparatively small otolith size of salmonids make their importance as prey difficult to describe using otoliths. Using other prey structures such as bones may help discern whether the increasing California sea lion population is consuming increasing quantities of salmon important to commercial and recreational fisheries in Monterey Bay, California.

The California sea lion population, occurring from offshore islands in Baja California, Mexico north to Vancouver Island, British Columbia, has increased annually by 5% along the West Coast since the passage of the Marine Mammal Protection Act in 1972 (Barlow *et al.* 1997). An estimated 161,066 to 181,355 California sea lions live in U.S. waters (NMFS 1997) and an additional 80,000 to 100,000 individuals in Baja California, Mexico (DeLong 1997). In contrast, serious declines in salmonid populations have occurred in recent years. Chinook salmon (*Oncorhynchus tshawytscha*) stocks in the Central Valley of California probably comprise 85%-95% of the chinook catches south of Pt. Arena and in Monterey Bay (PFMC 1999). Central Valley chinook originate in the Sacramento River, which has four distinct runs (portion of a salmon stock that returns to their native streams to spawn during a specific season): fall, late-fall, winter, and spring. Fall and late-fall runs are relatively healthy, but winter and spring runs are listed under the Endangered Species Act (ESA).

Because of public concern over declining salmonid populations and the contributing role of pinnipeds, Congress mandated, through 1994 amendments to the MMPA of 1972, a review of impacts of increasing pinniped populations on decreasing salmonid populations and impacts on West Coast ecosystems (NMFS 1997). Subsequently, the National Marine Fisheries Service (NMFS) drafted a report to Congress in March of 1997 outlining all available information on the subject and identified specific research needs. Research needs required to adequately manage salmonid stocks included conducting coast-wide surveys to determine seasonal distribution and abundance of California sea lions in areas where salmon are present, conducting pinniped food habit studies, and developing a working model of pinniped consumption estimates.

In this study, I identified major sea lion haul-out sites in central California, enumerated the seasonal abundance of sea lions, and characterized the age-structure of the population on a seasonal basis. I hypothesized that the greatest abundance of California sea lions in the Monterey Bay region would occur during the southern migration of sea lions in spring and the northern migration in late summer and autumn. I identified and determined the relative importance of prey species seasonally consumed by sea lions, and the role of salmonids in the sea lion diet. I hypothesized that sea lions would be opportunistic predators preying upon seasonally abundant schooling prey, such as Merluccidae, Engraulididae, Clupeidae, and cephalopods. Using sea lion population and diet data I constructed two contrasting models to estimate the annual consumption of salmonids and other prey by sea lions in the Monterey Bay area during 1997 and 1998.

METHODS

California Sea Lion Surveys

Counts of California sea lions on coastal haul-out sites were conducted from ground sites and during aerial photographic surveys year-round in the Monterey Bay region during 1997 and 1998 (Fig. 1). From June 1997 to October 1998 ground surveys of sea lions were conducted biweekly in conjunction with fecal collections at the Santa Cruz Municipal Wharf and the United States Coast Guard Jetty in Monterey. Binoculars and the naked eye were used to count adult male, sub-adult male, adult female, and juvenile animals. Because of the difficulty in distinguishing sub-adult males and adult females, they were pooled into one category for analysis. Trends in the proportion of different size classes of sea lions present along the central California coast were assessed using the monthly mean number of animals in each size class present at the two ground survey locations.

Flights were scheduled once a month during late morning or early afternoon low tides when peak number of sea lions were resting on haul-out sites (Nicholson 1986). From May 1997 to March 1998 a single engine, high-wing Cessna 172, was used while counting sea lions ashore traveling approximately 80 knots at an altitude of 600 m, and from April 1998 to September 1998 a single engine Lake flying at an altitude of 200m was used. Photographs were obtained out an open window in the Cessna 172 and through glass in the Lake using a hand-held Nikon 8008 35mm SLR camera equipped with a 75-300 mm telephoto lens while the plane circled over haul-out sites. Kodak Elite Ektachrome 400 ASA film was exposed at shutter speeds of 1/500 to 1/1000 seconds depending on weather conditions. A primary observer using 7X50 binoculars and the naked eye conducted visual counts after photographing haul-out sites, and a second observer recorded data.

Counts were obtained by projecting color slides on a large dry erase board and marking each pinniped with a pen and enumerating marks for each slide. Each haul-out site may have multiple slides with some overlap, in which case landmarks or distinguishable individuals were used to delineate the slide to avoid double counts. A single complete count from each photographic survey was conducted except for the 1997 surveys, which were counted twice. An additional count several days to months later of randomly selected slides for each survey was conducted to estimate the level of precision for total counts.

Seasonal mean counts of sea lions had a non-normal distribution and were heteroscedastic, therefore, data were transformed using $\sqrt{count+1}$ (Harvey 1987, Zar 1996) and compared using a Kruskal Wallis test. Seasons were defined as summer (May, June, July), autumn (August, September, October), winter (November, December, January), and spring (February, March, April; Yoklavich *et al.* 1991, Oxman 1995). These seasons were used because they approximate the atmospheric and oceanographic climatic seasonality in terms of rainfall, air and water temperatures, and salinity (Broenkow 1977, Yoklavich *et al.* 1991).

Food Habits

Information on prey composition and temporal changes in diet of California sea lions in Monterey Bay were obtained through examination and identification of prey hard parts found in fecal samples. Only fresh fecal samples were collected weekly at sites used exclusively by California sea lions. Sufficiency of numbers of samples for each season was evaluated by plotting cumulative numbers of prey taxa against randomly chosen fecal samples.

Fecal samples were collected using hand-trowels, spoons, and tweezers and placed in zip-lock storage bags. Bags were labeled with date, location, and number, and then frozen and stored for later analysis. Fecal samples were thawed by soaking them in soap and water until soft. Samples were mixed with water and were placed in an enclosed elutriator or passed through a series of nested sieves (2 mm, 1 mm, and 0.5 mm). Elutriators operate on the principle that soluble and flocculent components of feces can be separated from potentially identifiable undigested elements by differences in their densities (Bigg and Olesiuk 1990). The remaining solution from each sample was poured into a 0.5 mm mesh sieve and all prey hard parts were removed using forceps. Fish otoliths, skeletal bony material, eye lenses, and cephalopod hard parts were separated and placed in vials with 50% isopropyl alcohol. Fish otoliths and skeletal material were transferred into petri dishes, dried in a food dehydrator, and stored for later identification.

Prey species were determined by identifying prey hard parts recovered from fecal samples, such as fish otoliths, skeletal salmon bones, cartilaginous parts, eye lenses, teeth, and cephalopod beaks. Hard parts were identified and enumerated using illustrations and pictures (Morrow 1979, Clarke 1986, Cannon 1987, and Harvey *et al.* In press), a reference collection at Moss Landing Marine Laboratories (Harvey 1987), and standard protocols for identification of fish bones. Otoliths and cephalopod beaks were counted, and greatest number of right or left otoliths and upper or lower beaks determined a minimum number of individuals (MNI) of each prey species consumed by sea lions. Additionally, diagnostic salmon bones, cartilaginous parts, and teeth in each sample also were used to determine the MNI. Bone and tooth sizes were used to determine numbers of fish, so that if a fecal sample contained two different sized vertebrae, centrum, or teeth of a specific species, the MNI was recorded as two individuals.

Prey hard parts were measured to estimate standard length and weight of prey consumed by sea lions. Hand-held calipers were used to measure intact otoliths (nearest 0.1 mm) parallel to the sulcus from the anterior tip of the rostrum to the posterior edge, and for measuring teeth of hagfish and lamprey. Upper rostral lengths of squid beaks were measured to the nearest 0.1 mm using a computer image analysis system. Species-specific correction factors were applied to lengths of otoliths to compensate for degradation during digestion (Orr and Harvey unpubl. data). An average correction factor of 43% was applied to species not reported in the literature. Cephalopod beaks, and hagfish and lamprey teeth do not appreciably reduce in size during digestion, so no correction factor was required (Harvey 1989).

Standard length and mass of prey consumed by sea lions were estimated using species-specific linear regressions of otolith length (Harvey *et al.* In press), upper rostral beak length of squid (Wolff 1982), width at the base of bicuspid and tricuspid teeth for hagfish (Johnson 1994), and lower beak length for octopus (Oxman, unpublished data). Identifying species of rockfishes based on otoliths was difficult, so the length and weight regression equations for the most common rockfish in the sea lion diet was used (bocaccio; *Sebastes paucispinis*; Harvey *et al.* In press). When prey species regression relationships were not available, relationships for similar species were used.

Average weights reported in the literature were used for prey species identified from skeletal bones, cartilaginous parts, and species that did not have similar species with regression relationships. For samples with broken otoliths, a seasonal average mass was estimated for each species using the regression relationships from intact otoliths. For salmon identified from skeletal material, the average mass of gutted salmon was used in 1997 (5.0 kg) and 1998 (3.4 kg; PFMC 1999). Spiny dogfish shark (*Squalus acanthias*) teeth were the only identifiable elasmobranch hard part found in fecal samples, therefore, the minimum average mass of a spiny dogfish (3.1 kg) was used when elasmobranch hard parts occurred in samples (Castro 1983). Values from the literature also were used for Pacific mackerel (*Scomber japonicus*), lamprey (*Lamptera sp.*), and peamouth chub (*Mylocheilus caurinus*).

Percentage frequency of occurrence (%FO) and percentage number of prey (%N) were calculated for each fecal sample and averaged for a seasonal value. Mean percentage frequency of occurrence (%FO) data was arcsine transformed and then compared among seasons using an ANOVA. Mean percentage of diet composition (%N) was non-normally distributed, so comparisons among seasons were conducted using a Kruskal-Wallis test. Prey species composition and abundance were compared for each season using a percentage similarity index (PSI, Silver 1975):

$$PSI = \sum \text{ minimum } P1i\ P2i,$$

where P1*i* and P2*i* are relative abundance's of species *i* from seasons "1" and "2", respectively. Indices range from zero, no similarity, to 1.00, identical species composition. A significance level was arbitrarily set at 0.65 for percentage similarity index.

The following prey array indices were used to describe differences in seasonal prey items consumed by California sea lions.

Species richness (S) = Number of prey species

Shannon-Weaver diversity index: $H' = |(\sum p_i \ln p_i)|$

Prey Evenness: $J = H' / H'_{max}$, where $H'_{max} = \ln S$

Index of Specialization: $R = 1 - J$

Prey Dominance: $D = \sum p_i^2$

Prey array indices calculated for each fecal sample were non-normally distributed and heteroscedastic, so a Krusal-Wallis test was conducted to determine if there was any significant difference in mean prey array values among seasons.

Importance of individual prey species for each season was evaluated for each species using an index of relative importance (IRI), defined as:

IRI = (Mean %Number + Mean %Mass) * % Frequency Occurrence.

Percentage volume was originally used in IRI (Pinkas *et al.* 1971), however; percentage mass is an acceptable substitute (Hyslop 1980). Index of relative importance takes into account not only number and frequency occurrence of prey, but also size of prey. This is important for larger prey species, such as salmon, that may not occur in large numbers in sea lion diet but may represent a large portion of biomass consumed. Mean fish lengths of market squid and sardines were heteroscedastic and compared among seasons using a Kruskal-Wallis test.

Annual fish consumption by sea lions was compared with commercial fishery catches using the following prey consumption model:

$$B_{xa} = \sum_{s=1}^{4} (B_{xs} \sum_{t=1}^{3} (N_s * A_s * W_s * E_i * D_s) * P_{xs} / V_x)$$

Biomass (kg) of prey species x consumed by sea lions during year a is the sum of biomass of prey species x during seasons s one to four. The biomass of prey species x during season s is the sum of biomass consumed by sea lion stages t one to three (adult male, sub-adult male/female, and juvenile), which is a function of the numbers of sea lions present (N_s), stage structure of sea lion population for a season (A_s), proportion of sea lion population at sea during aerial surveys (W), stage-specific daily energetic requirements (kcal/day) of sea lions (E_i), number of days in season (D_s), proportion of species x in sea lion diet during season s based on mean percentage mass of prey species

x and based on reconstructed biomass (P_{xs}), and the energetic value (kcal/day) of species x (V_x). Number of sea lions present was the mean number of sea lions enumerated each season during aerial surveys corrected for the percentage of animals at sea during aerial surveys (18%; Bonnell and Ford 1987). Stage structure of population was the proportions of animals in each size class counted during ground surveys, which was assumed to be representative of the region. Daily energetic requirements of each size class from Perez et al. (1990; $E=372M^{0.73}$) were divided by two, with average sea lion masses (M) of 250 kg for adult males, 100 kg for sub-adult males/females, and 30 kg for juveniles. Proportion of species x in sea lion diet during season s (P_{xs}) was estimated in two contrasting ways, (1) mean percentage mass (MPM) per fecal sample and (2) proportion of the biomass reconstructed (BR). Both proportions were adjusted based on the energetic values of prey species, which were from Sidwell (1981) and Perez *et al.* (1990). Annual commercial fisheries catch data came from PFMC (1999), CalCOFI (1998 and 1999), and California Department of Fish and Game Monterey Bay commercial fisheries report. Estimates of annual sea lion consumption were compared with Central Valley salmon stock abundance estimates for central California (PFMC 1999).

Variances for consumption models were estimated using the following equations from Goodman (1960):

$$V(xy) = \bar{x}\,V(y) + V(x)\,\bar{y} - V(x)\,V(y) \qquad \text{(2 variables)}$$

$$V(xyz) = (\bar{x}\,\bar{y}\,\bar{z})^2\,[G(x) + G(y) + G(z) + G(x)G(y) + G(x)G(z) + G(y)G(z) + G(x)G(y)G(z)] \qquad \text{(3 or more variables).}$$

Where x, y, z were random variables with means of $\bar{x}$, $\bar{y}$, $\bar{z}$, variances of $V(x)$, $V(y)$, $V(z)$, and $G(x)$, $G(y)$, $G(z)$ are their respective squared coefficients of variation. Variances were expressed as coefficient of variation (CV).

RESULTS

Pinniped Population Surveys

Although seasonal trends were observed in mean number of sea lions counted on haul-out sites during aerial surveys along the central California coast, there was no statistically significant difference among seasons or between years (Kruskal-Wallis, P=0.236; Fig. 2). Seasonal mean counts were highly variable with greater numbers of sea lions observed in summer 1998 and autumn 1998 than in summer 1997 and autumn 1997. No significant difference was detected between mean number of sea lions during replicate counts of aerial photographic surveys (Student's t-test, P=0.940). Differences between total numbers of sea lions counted in replicate counts was 3.8%, with an average CV=0.90 for the mean of replicate counts.

Most sea lions (mean=98.4%/month, SD=2.4%) were counted at eight sites along the central California coast (Table 1). Año Nuevo Island consistently had the greatest numbers of sea lions of any haul-out site and represented a majority of sea lions counted (mean=68.6%/month, SD=13.0%). The two greatest monthly counts of sea lions on any haul-out site were at Año Nuevo Island in June (5,963) and September 1998 (5,712).

Mean numbers of sea lions counted on Santa Cruz wharf and Monterey jetty from the ground were significantly different among seasons. In Santa Cruz, mean number of sea lions in summer 1997 (mean=5.0, SD=4.2) was significantly less than autumn 1997 (mean=104.8, SD=35.6), winter 1997-98 (mean=103.3, SD=61.9), spring 1998 (mean=62.3, SD=11.3), and autumn 1998 (mean=81.2, SD=28.7; Fig. 3). There was no statistically significant difference among summer 1997 and summer 1998 (mean=43.2, SD=23.6). Total numbers of sea lions along central California were greater in summer and autumn 1998, however, there were significantly fewer sea lions on the Monterey jetty in summer (mean=203.8, SD=84.7) and autumn 1998 (mean=203.7, SD=140.5) than in summer 1997 (mean=403.0, SD=159.8), fall 1997 (mean=425.0, SD=130.5), winter 1997-98 (mean=628.3, SD=238.5), and spring 1998 (mean=442.8, SD=108.0; Fig. 4).

A significantly greater proportion of sea lions observed on Santa Cruz Wharf were adult males (mean 83.1 %, SD=11.4 %; Kruskal-Wallis, $P<0.000$) than sub-adults/females (mean 12.4 %, SD=6.3 %) and juveniles (mean 4.4 %, SD=6.2 %). The greatest number of sea lions observed on the wharf was 186 animals in January 1998. On the Monterey jetty, a significantly greater proportion of sea lions counted were juveniles (mean 74.0 %, SD=18.1 %; Kruskal-Wallis, $P<0.000$) than sub-adult/females (mean 10.5 %, SD=6.7 %) or adults (mean 14.9 %, SD=15.3 %). The greatest number of sea lions counted on the Monterey jetty was 937 animals in February 1998.

Food Habits

Cumulative species curves indicated that approximately 48 fecal samples with identifiable hard parts were required to adequately assess prey consumed by California sea lions in most seasons, however, in spring 1998 approximately 62 samples were required (Fig. 5). Because 87 fecal samples with identifiable hard parts were collected in autumn 1997, 70 in winter 1997-98, 100 in spring 1998, 72 in summer 1998, and 68 in autumn 1998, I assumed an adequate number of samples were collected for comparing prey species number and composition among seasons.

Sixty-five days of collections from California sea lion haul-out sites yielded 503 fecal samples, of which 78.9% (397) contained identifiable prey hard parts. Twenty-six taxa were identified to species, an additional three to genus, one to family, one to order, and one to class. Of the 5,179 prey occurrences, 54.3% (2,813) were cephalopods and 45.7% (2,366) were fishes. Market squid (*L. opalescens*) was the predominant cephalopod prey species (53.5%), and octopus (*Octopus* sp.) was the other cephalopod species consumed (0.8%). Schooling fishes were the predominant prey fish species, such as Pacific sardine (*Sardinops sagax*; 19.3%), northern anchovy (*Engraulis mordax*; 7.9%), rockfish (*Sebastes* sp.; 6.6%), Pacific hake (*Merluccius productus*; 4.7%) and elasmobranch sp. (1.2%; Fig. 6). Most elasmobranch hard parts recovered from scat samples were accompanied by spiny dogfish teeth, leading to the assumption that most elasmobranchs consumed by sea lions were spiny dogfish (*Squalis acanthias*).

Fecal samples contained one to 13 prey taxa (mean=1.75, SE=0.06; Fig. 7), with the greatest number of species during spring 1998 and the least during autumn 1997 (Fig. 8). Significantly fewer prey species per fecal sample were found in autumn 1997 than spring and autumn 1998, and significantly fewer prey species were found in winter 1997-98 than spring 1998 (Kruskal-Wallis, P<0.000). The greatest diversity of prey taxa (H') consumed by sea lions was during spring 1998, therefore, spring had a low specialization index (R; mean=0.28, SE=0.15) and dominance index (D; mean=0.79, SE=0.15). Specialization index was significantly less in autumn 1997 than winter 1997-98, summer 1998, and autumn 1998 (Kruskal-Wallis, P<0.000). No significant differences in the dominance index were detected among seasons (Kruskal-Wallis, P=0.966). Niche breadth (B) was greatest in spring 1998, but there were no significant differences among seasons (Kruskal-Wallis, P=0.086). Prey evenness (J) was significantly greater in autumn 1997 than winter 1997-98, summer 1998, and autumn 1998, however, autumn 1997 was not significantly different than spring 1998 (Kruskal-Wallis, P<0.000).

Seasonal changes in diet composition were apparent when comparing percent similarity indices among seasons, with market squid, Pacific sardine, and northern anchovy being dominant prey species in autumn 1997, winter 1997-98, and spring 1998 (PSI > 70.0; Table 2). Prey composition changed significantly during summer and autumn 1998 (PSI < 43.0) because of increased importance of sardine in the diet and decreased importance of market squid. Frequency of occurrence of prey taxa among seasons was significantly different in autumn 1997 and spring 1998, resulting from increases in the occurrence of sardine, squid, elasmobranches, and rockfish in spring (%FO, ANOVA, P=0.040; Fig. 9). However, diet composition (%N) of prey taxa in sea lion diet was highly variable, so no significant differences were detected among seasons (%N, Kruskal-Wallis, P=0.358; Fig. 6).

Seasonal differences in prey composition also were apparent when comparing the mean index of relative importance (IRI) among seasons. Based on IRI, northern anchovy, Pacific hake, and market squid were the most important prey species in the sea lion diet in autumn 1997 (Table 3). In winter 1997-98, market squid dominated the sea lion diet followed by Pacific sardines, elasmobranchs, and northern anchovy (Table 4). California sea lions in spring 1998 had the greatest diversity of prey with sardine and market squid having the greatest mean IRI rankings (Table 5). Other important prey species were elasmobranchs, rockfishes, northern anchovy, and Pacific hake. In summer and autumn 1998, sardines dominated the diet in percentage number, frequency of occurrence, and mean IRI rankings (Table 6 and 7). Market squid had its lowest mean IRI ranking in the diet during summer 1998, increasing slightly in autumn 1998. The presence of salmonids in the diet varied by season composing the greatest proportion of the diet and the greatest IRI ranking in summer 1998, and relatively high mean IRI rankings in autumn of 1997 and 1998. Salmon was a relatively minor portion of the diet (i.e. low mean IRI rankings) in winter 1997-98 and spring 1998.

The mean length of fish consumed by sea lions in Monterey Bay in 1997 and 1998 was 17.7 cm (SD=13.40) with significant differences in fish length detected among seasons. Squid with significantly greater mean dorsal mantle length were consumed by sea lions in winter 1997-98, and the smallest squid were eaten in spring 1998 (Kruskal-Wallis, $P<0.000$; Fig. 10). Estimated mean dorsal length of market squid recovered from sea lion fecal samples was 10.6 cm (SD=1.08). Significant differences in mean standard length of Pacific sardines were detected among seasons, with smaller fish in virtually each successive season (Kruskal-Wallis, $P<0.000$; Fig. 10).

The difference between BR and MPM estimates of sea lion consumption was size specific, with the relative importance of larger, less numerous prey items increased in BR model and smaller more numerous prey items increased in the MPM model (Tables 8 and 9). In the BR model, large prey species such as salmon, elasmobranches, and rockfishes dominated the proportion of biomass consumed for most seasons, except in summer and autumn 1998 when the relative importance of sardines increased. Salmon ranked first, seventh, second, first, and third in biomass consumed during successive seasons beginning with autumn 1997. The MPM model was more varied with market squid, hake, anchovy, sardines ranking high in fall 1997, squid and sardine ranking high in winter 1997-98, and sardines ranking highest during the remainder of the study. The relative importance of salmon in the MPM model was less than in the BR model ranking sixth, twelvth, sixth, second, and forth in biomass consumed. Frequently occurring prey species with notable declines in proportions of biomass consumed throughout the study in both models were market squid, Pacific hake, octopus, and Pacific sanddab (*C. sordidus*).

Variances for consumption models were estimated using two to three variables out of six variables used to estimate consumption. Models included variability associated with the seasonal mean number of sea lions and daily energetic requirements of sea lions, and the MPM model included the variability in mean percentage mass of prey species. The greatest source of variability in consumption estimates was the variability associated with the seasonal mean number of sea lions.

Among the top nine commercially important fish species consumed by sea lions in 1998, Pacific sardines and rockfishes were consumed in largest quantities (Table 10). Estimated consumption of Pacific sardines by sea lions in 1998 represented the equivalent of 12.1% (BR) to 26.6% (MPM) of the commercial fishery landings for 1998.

Other commercially important species consumed by sea lions in 1998 were market squid, Pacific mackerel, rockfishes, and northern anchovies. Salmon ranked third (BR) and fifth (MPM) in biomass consumed by sea lions among commercially important prey species, but equivalent percentages of commercial catches consumed by sea lions were among the highest for salmon. Equivalent percentages of the total salmon catch, commercial and recreational catches combined, consumed by sea lions was 68.0 % (MPM) to 214 % (BR). This assumes that the average mass of commercially landed fish was equal to the mass of recreationally landed fish in 1998. Numbers of fish landed in the recreational fishery were available, but the mean mass was not estimated (PFMC 1999).

DISCUSSION

Pinniped Abundance

Seasonal trends in sea lion abundance were apparent in both aerial and ground surveys along the central California coast in 1997 and 1998. Observed trends were concurrent with the documented migratory pattern of sea lions, with animals moving south before the breeding season and north after the breeding season (Bartholomew 1967, Mate 1975, Beeson and Hanan 1996, NMFS 1997). Relatively low numbers of aerial surveys each season and the natural variability in number of sea lions on haul-outs contributed to high variability in counts seasonally. Greatest mean numbers of sea lions counted monthly during land-based surveys occurred in November and December of 1997, which coincided with greatest numbers of sea lions counted during aerial surveys during winter 1997-98.

More sea lions moved into the region in summer and autumn 1998, most likely because of poor foraging conditions in southern California resulting from the 1997-1998 El Niño Southern Oscillation (ENSO) event. During the 1983 and 1992 ENSO events, numbers of sea lions increased along the central California coast due to the enhancement of the normal northward migration resulting from poor food availability in the Southern California Bight (Sydeman and Allen 1997). During the northward migration in summer and autumn 1998, mean numbers of sea lions increased by approximately 2,000 animals from summer and autumn 1997. Numbers of adult male sea lions declined at the Santa Cruz wharf in summer of 1998 during the breeding season, however, the decline was less severe and shorter in duration than in June and July 1997. It is plausible that many adult male sea lions either did not make the southward migration and stayed in the Monterey Bay region, or migrated for a shorter than normal period of time. Sea lion pup mortality in the Channel Islands was extremely high in May and June 1998 (Lowry, pers. comm.), presumably because females increased their foraging time in response to less abundant schooling prey fish in the Southern California Bight resulting in reduced suckling time for pups. More female sea lions were counted on Año Nuevo Island in summer and fall 1998, presumably in response to poor foraging conditions in southern California (Morris pers. comm.). Drastic declines in squid abundance occurred in southern California waters during winter 1997-98 resulting from abnormally high water temperatures associated with ENSO conditions (CalCOFI 1998). During the 1983-84 ENSO, older juvenile sea lions migrated in greater than usual numbers from southern to central California (Trillmich *et al.* 1991). Although counts at inshore sites did not detect increases in numbers of juvenile sea lions, Año Nuevo Island, an outer coast haul-out, experienced the greatest increases in number of sea lions presumably in response to ENSO conditions, with the greatest counts in June and September 1998. Many of these additional animals were most likely juveniles and adult females that moved northward to avoid ENSO effects.

Alternative explanations for the influx of sea lions in summer and fall 1998 include range expansion of the California sea lion population and shifts in prey abundance and distributions resulting from overfishing. Bonnell *et al.* (1983) suggested that as a result of increases in the total sea lion population, juveniles were pushed to the limit of the range. Effects of population growth include breeding range expansion, California sea lions gave birth on Año Nuevo Island and the Farallon Islands from the early 1970s to present (Pierotti *et al.* 1977, Ainley *et al.* 1977, 1978, Huber *et al.* 1979, Keith *et al.* 1984, Morris pers. comm.). Numbers of female sea lions and pups born on Año Nuevo Island increased from 1997 to 1998, however, this increase was most likely in response to ENSO conditions (Morris pers. comm.). If range expansion resulting from an increasing population of sea lions existed, greater counts of sea lions over a long period of time would be more likely than an apparent one-time influx of large numbers of animals. Long term monitoring of abundance trends at central California sea lions haul-outs would be more conclusive.

Bailey and Ainley (1982) suggested that overfishing of Pacific hake, a major spring and summer prey of sea lions offshore, made offshore waters less attractive to pinnipeds during their northward migration forcing sea lions closer to the coast.

Decreases in fish populations offshore or in other coastal areas along the migration route of sea lions may cause sea lions to move into areas such as Monterey Bay. Sea lions are opportunistic predators feeding on a variety of prey species, therefore, it is unlikely that a decrease or shifting distribution of one prey species in response to overfishing would alter sea lion migration patterns. Large-scale oceanographic anomalies, such as ENSO events, however, may affect the abundance and distribution of many sea lion prey species causing shifts in sea lion migration patterns. Dramatic declines in the occurrence of market squid in the sea lion diet in 1998 and the concentrating effect on sardines along the central California coast during the 1997-98 ENSO event may have forced the distribution of the sea lion migration coastward explaining increased numbers of sea lions on haul-outs.

Aerial and ground surveys of sea lions on haul-outs have inherent problems in assessing pinniped abundance. Problems associated with aerial surveys include missing animals that are in the water, effects of the airplane on pinniped behavior, swell and weather restrictions, equipment or human error, and monetary costs (Harvey 1987, Westlake *et al.* 1997, and Lowry 1999). Ground counts of sea lions can be limited by partial visibility of the haul-out site, difficulty in counting large groups of animals, swell and weather conditions, and access to remote haul-out locations (Westlake *et al.* 1997, Lowry 1999). Aerial and ground surveys along the central California coast were conducted under relatively consistent environmental conditions and tidal levels, with the exception of surveys in spring 1998. Surveys in spring 1998 were conducted during late morning or early afternoon low tides, but consistent ENSO driven storms produced large swells and high winds with little to no opportunity for better conditions. Declines in the mean number of sea lions in spring 1998 were likely an artifact of sampling during conditions with large swells when greater numbers of animals were probably in the water. One of the criteria for selecting ground survey sites was the ability to survey entire haul-outs with no visible obstructions. Animals on the Monterey jetty may have been missed while hiding under large boulders, and animals on the Santa Cruz wharf may have vacated the wharf as a result of observer intrusion. The few animals possibly missed in both locations would not greatly affect counts or observed trends.

Precision of counts of sea lions from aerial photographs was relatively high. Variability resulting from these counts (± 3%) had little to no effect on monthly abundance estimates and seasonal trends. Although aerial photographic counts of sea lions are more precise than counts obtained from the ground (Lowry 1999), I also used ground counts because it was more economical and size classes of sea lions could be better distinguished during ground counts. Estimating precision of ground counts was not possible because disturbance to animals precluded multiple counts.

Food Habits

Pinniped food habit studies provide information on seasonal prey utilization, feeding locations, and prey availability. There is little doubt that pinnipeds are feeding on salmonids, and there is a growing concern about the declining stocks of salmonids. California sea lions are opportunistic predators, switching prey species depending on the availability of prey (Antonelis *et al.* 1984, Lowry *et al.* 1990). On San Miquel Island, sea lions preyed upon 15 species of fish and six species of cephalopod (Antonelis *et al.* 1984), on San Nicolas Island sea lions consumed 15 species of fish and seven species of cephalopods (Hawes 1983), and on San Clemente Island sea lions ate 44 species of fishes and five species of cephalopods (Lowry *et al.* 1990). In Monterey, Nicholson (1986) reported sea lions consumed only six species of fish and one species of cephalopod, but the number of scat samples analyzed was low. In this study the sea lion diet in Monterey Bay included 32 different prey taxa, dominated by Pacific sardines and market squid.

Changes in oceanographic conditions resulting from the 1997-98 ENSO were reflected by changes in diet of sea lions in Monterey Bay. From summer 1997 to spring 1998, the most numerous prey items in the sea lion diet were market squid, Pacific sardines, and northern anchovies, with significantly more Pacific sardines eaten in summer and fall 1998, and northern anchovies during ENSO conditions. The pelagic ecosystem was strongly influenced by ENSO conditions; macrozooplankton abundance during spring 1998 was the least recorded in the 50-year CALCOFI time series (Lynn *et al.* 1998). Large changes in the distribution and abundance of plankton and fish populations were observed (Lynn *et al.* 1998). Availability and abundance of sea lion prey species influences diet composition of sea lions (Baily and Ainley 1982, Antonelis *et al.* 1984). Shifts in distribution of pelagic schooling prey species in response to ENSO conditions and resulting changes in sea lion diet have been well documented (Lowry *et al.* 1990, Costa *et al.* 1991, Delong *et al.* 1991, Lowry *et al.* 1991).

It is assumed that prey identified from fecal samples represented all prey species consumed by sea lions, mainly because a variety of structures were used to identify prey.

In captive feeding studies, recovery rates of otoliths varied greatly among prey species and individual pinnipeds. Small fragile otoliths of some fish species had lower recovery rates because of the greater probability of complete digestion (Da Silva and Neilson 1985, Dellinger and Trillmich 1988, Harvey 1989). Otoliths of larger prey may be underestimated because pinnipeds sometimes discarded heads of larger prey before consumption (Pitcher 1980). Cartilaginous fishes may be underestimated in the diet if their statoconia are completely digested before excretion (Everitt and Gearin 1981). Frequency and number of individual prey have been underestimated by a factor of one-and-a-half to ten times if only otoliths were used to identify prey (Olesiuk 1993). Estimation of prey length and weight of prey species consumed by sea lions is difficult because of natural variability of otolith length to prey length relationships, and because the degree of erosion of an otolith during digestion is affected by meal size, activity level, size of prey, and physical structure of prey hard parts (Da Silva and Neilson 1985, Dellinger and Trillmich 1988, Harvey 1989, Cottrell *et al.* 1996, Marcus *et al.* 1998). Using all salmonid hard parts, and centra and teeth of cartilaginous fishes in fecal samples addresses potential biases that underestimate salmon and cartilaginous fishes in the diet. Use of non-specific correction factors compensates for otolith degradation during digestion. Conclusions regarding relative importance and proportions of prey species in sea lion diet, therefore, were probably valid.

Salmon occurred in the sea lion diet year-round, with the greatest frequency of occurrence in summer 1998. Hooked salmon from the fisheries were likely the majority of salmon in the diet of sea lions. Greatest frequency of occurrence and relative importance of salmon in the sea lion diet was in summer 1998, coinciding with salmon fisheries seasons and greatest rates of take by sea lions of hooked salmon (Chapter 2). Salmon was least important in the diet of sea lions in winter 1997-98, during which no ocean fishery was present and salmon were migrating upstream along the central California coast. Overall, frequency of occurrence of salmon was relatively low and total numbers of fish consumed were low, but the relative importance of salmon in the diet was consistently in the top 10 for all prey species in all seasons except winter. Assuming the entire fish was consumed by one sea lion, these high IRI values indicated that relatively infrequent prey were important prey of sea lions if the mass of prey consumed was large. An opportunistic predator would consume large prey less frequently due to the lower capture success and lower abundance of large prey, but when large prey are consumed a predator may be sustained for a relatively longer period of time (Laake *et al.* In press). Although large prey that are eaten infrequently may be more difficult to detect in food habit studies, these large prey species may represent the majority of the biomass consumed.

Market squid was one of the most important prey species for sea lions in central California before the onset of ENSO conditions. Market squid is normally abundant in Monterey Bay, occurring in approximately 90% of the commercial mid-water trawls from 1968 to 1976 (Cailliet *et al.* 1979), and representing the most valuable commercial fishery in 1997 (CalCOFI 1998). Squid was one of the most important prey species for sea lions in southern California from 1981 to 1995, however, declines in squid in the sea lion diet occurred during moderate and severe ENSO episodes (Lowry and Carretta

1999). Squid has been reported as a vital resource for marine birds and mammals in Monterey Bay (Morejohn *et al.* 1978). Prevalence of squid in the sea lion diet in Monterey Bay during autumn 1997 is not surprising because market squid dominated the commercial fishery landings in the Monterey Bay region at that time of year. Squid remained dominant in the sea lion diet through spring 1998, whereas commercial landing stopped abruptly at the end of September 1997 and no squid landings were reported in 1998 (CalCOFI 1998, 1999). The abrupt decline of commercial squid catches, smaller size of squid consumed by sea lions in Spring 1998, and low numbers of squid in the sea lion diet during 1998 were presumably a result of the 1997-98 ENSO event. The 1991-92 ENSO event also resulted in below average yields of commercially harvested market squid (CalCOFI 1992). Market squid occur offshore, but move inshore in large aggregations to spawn (Fields 1965). Spawning generally occurs in well-defined portions of Monterey Bay between April and July, with an additional peak between November and January (Fields 1965, Recksiek and Frey 1978), which corresponds to the high occurrence of squid in the sea lion diet during winter 1997-98 and spring 1998. ENSO conditions in late 1997 and 1998 may have resulted in a temporal shift in the spawning cycle of squid, and reduced growth rates of squid resulting from nutritional stress caused by declines in prey of market squid (Lowry and Carretta 1999). Significantly smaller squid in the sea lion diet in spring 1998 may have indicated nutritional stress in the squid population, which could explain the abrupt decline of the commercial harvest and absence of squid in the sea lion diet during the remainder of 1998.

Pacific sardines were found in the diet of sea lions during all seasons, and were increasingly important in the diet throughout the study period. Sardine populations have rebounded as has the sardine fishery, which in 1997 and 1998 reported some of the greatest landings since the reopening of the directed fishery in 1986 (CalCOFI 1998, 1999). Sardine schools occur up to 500 km offshore, moving inshore to spawn with peaks in late winter through early summer (Murphy 1960). In 1997, sardine eggs were distributed in a broad offshore band compared with 1998 when they were in a narrow, northward, near-shore pattern (Lynn *et al.* 1998). Increased dominance of sardines in the sea lion diet from 1997 to 1998 was concurrent with seasonal spawning movements of sardines, and more importantly, the apparent concentrating effect of oceanographic patterns on sardines along the central California coast region during the 1997-98 ENSO event.

Occurrence of northern anchovies in the diet of sea lions was relatively stable throughout the study period. The presence of market squid in autumn 1998 decreased as the relative importance of anchovies increased. Anchovies are an important commercial species in Monterey Bay, ranking third greatest in commercial landings in 1997, and fourth greatest in 1998 (CDF&G 1998, 1999). Most anchovies spawn year-round at night away from the coast, with peaks in southern California from December through May (Baxter 1966). Anchovy egg abundance in pelagic net tows is normally low in autumn along central California, but high rates of occurrence in autumn 1998 indicated that the anchovy population increased with the transition to cold-water La Niña conditions (Hayward *et al.* 1999). Increases in relative importance of anchovy in the sea lion diet in summer and fall 1998 were concurrent with inshore movements of anchovies and possibly with increasing egg abundance in response to cold water conditions.

Elasmobranchs (spiny dogfish) occurred in relatively low numbers in the diet of sea lions during all seasons, but their consistent occurrence and large size made them a relatively important prey species. Spiny dogfish is the most abundant and economically important shark off the North American coast (Castro 1983). Dogfish are long-lived schooling fish found from the intertidal zone down to water depths of 1000 m. Off California, dogfish move inshore during spring, remain near-shore through summer and autumn, and move offshore during winter (Love 1991). Greatest occurrence of dogfish in the diet of sea lions occurred in spring 1998, coinciding with these inshore movements. Because the size of spiny dogfish could not be estimated using centra or teeth recovered in scat samples, a minimum estimate of the size range of dogfish was used in estimating mass of fish consumed by sea lions. Sea lions may have preyed on spiny dogfish pups, in which case, estimates of fish mass would be erroneously high, inflating the IRI for dogfish and overestimating the number of dogfish consumed in the biomass reconstruction model. Sharks and spiny dogfish sharks have been found in the diet of sea lions in past studies (Lowry *et al.* 1990, 1991).

Sea lion foraging behavior has been described as a plastic specialist rather than a generalist or opportunistic predator because the diet of sea lions is temporally dynamic with animals feeding on seasonally abundant schooling or aggregating prey, exploiting several species at a time (Lowry *et al.* 1991, Orr 1998). Significant changes in diet were detected among seasons, but the number of relatively important prey species being exploited each season depended on how I defined the sea lion diet. In terms of numbers of prey consumed per season, a few prey species dominated the sea lion diet each season supporting the theory of a plastic specialist. In contrast, when considering the biomass of prey species consumed, numbers of relatively important prey species in the sea lion diet each season increased because of the increased importance of large species that occurred in low numbers and less frequently. Further information is needed on identifying hard parts of infrequently occurring prey in sea lions scats and relationships between hard parts and fish size to better describe the diet and foraging behavior of sea lions.

The validity of a biomass consumption model depends on information and assumptions regarding population size and age-structure, proportion of the sea lion population at sea, diet composition and proportions of prey species in the diet, daily energetic requirements of sea lions, and energetic value of prey. Information used in the biomass consumption model was variable, and required numerous assumptions, some of which cannot be tested to estimate the magnitude of their impacts.

California sea lion population size in Monterey Bay varied seasonally during the annual sea lion migration potentially introducing error in consumption models estimates. Timing of northward and southward movements of sea lions would influence seasonal mean number of sea lions based on aerial surveys. For instance, if large movements of animals into the Monterey Bay occurred toward the end of a season after the last monthly aerial survey, this increase would not be reflected in the seasonal mean count, and consumption estimates would be erroneously low. In the reverse scenario if large numbers of animals vacated the region, consumption estimates would be high. Without replicate monthly aerial surveys there is no measure of variability in the number of animals.

Stage-structure of the sea lion population in Monterey Bay used for consumption model estimates was based on the assumption that the mean stage-structure of ground survey locations was representative of sea lion population structure along the central California coast. Greatest numbers of sea lions were counted on Año Nuevo Island and other offshore rocks that could not be surveyed from land. It is possible that the stage-structure of sea lions at locations surveyed from land were different than Año Nuevo Island and other offshore rocks. Juvenile sea lions may have sought shelter from storm activity at more protected haul-outs in Monterey Bay. This hypothesis was supported by the observation of proportionally greater numbers of juvenile animals on the Monterey jetty than the more exposed Santa Cruz wharf. Stage structure of animals on Año Nuevo Island and other offshore rocks could not be assessed accurately from aerial photographs; however, based on visual counts of animals during aerial surveys most animals appeared to be adult males. If the number of adult sea lions were underrepresented in counts, consumption estimates would be low because of the greater daily energetic requirements of adult male sea lions. The magnitude of this bias is difficult to evaluate without information on the stage-structure of sea lions on Año Nuevo Island and other offshore rocks.

Aerial surveys used in consumption models underestimated the sea lion population because a proportion of the population was in the water during surveys. A conservative estimate of 18% was used to represent the portion of the population at sea, however, Bonnell and Ford (1987) estimated as much as 54% of the population was at sea in late July and early September 1975 to 1978. Number of animals at sea may be greater during years of limited food availability, such as El Niño events, because of the increased time required for successful foraging (Bonnell and Ford 1987). Using 18% may have underestimated the proportion of the sea lion population at sea by up to 30%, which would result in erroneously low consumption estimates.

Estimates of sea lion diet could be affected by not identifying all prey species potentially introducing bias into consumption estimates. Relative proportions of prey were probably valid, but species-specific biomass estimates may be inflated because of the complete digestion of smaller size classes of prey. Identification of skeletal remains (i.e. salmon and elasmobranch) may have artificially inflated their respective proportions of the mean percentage mass and reconstructed biomass. Possibly omitting some species and size classes of prey, and only identifying skeletal remains of salmon and elasmobranchs has the potential to bias consumption estimates, however, these errors are just as likely to cancel as they are to compound one another.

Information on feeding rates or daily energetic requirements of free-ranging sea lions was not available for consumption models. Klieber (1961) found a relationship between body mass and basal metabolism for terrestrial mammals, and Lavigne *et al.* (1986) suggested a similar relationship existed for marine mammals. Rates of energy expenditure of free-ranging sea lions varies depending on basal metabolism, age, activity levels, reproductive state, season, and environmental conditions (Perez *et al.* 1990). For example, juvenile marine mammals consume food at a greater rate per body mass than do adults (Perez *et al.* 1990). Rates of food consumption of captive pinnipeds were used to simulate a feeding rate relationship for free-ranging animals. The equation used in this study provided an estimate of energy use of active individuals compared with basal metabolism (Perez *et al.* 1990). Based on this equation feeding rates of active otariids were 5.3 times the basal metabolic level, however, to be conservative I used an estimate of 2.65 times the basal metabolic level. Although there are a few direct measurements of metabolic rates for marine mammals, free-ranging pinnipeds may have metabolic rates three times greater than resting metabolic rates (Costa *et al.* 1985). Feldkamp (1985) reported the energy required for extended swimming by California sea lions was 2.5 times the resting metabolic rate. Walrus were reported to have metabolic rates 5.4 times greater than resting metabolic rates (Fay 1982), and sea otter metabolic rates were 8.0 times greater than resting metabolic rates (Costa 1982).

Energy values of some prey species vary significantly between spawning in summer and foraging in winter (Bigg *et al.* 1978, Sidwell 1981, Krzynowek and Murphy 1987) potentially introducing bias into consumption models. Fat content varies by age, body mass, and stage of migration of the fish (e.g., salmon; Krzynowek and Murphy 1987). For example, gravid adult salmon returning to spawn have a greater energetic content than non-reproductive individuals of the same species and weight (Thompson *et al.* 1998). Seasonal and age-specific energetic values of prey species based on calorimetry studies are necessary because they provide the most accurate estimates of energetic value of prey and sea lion consumption estimates. Energetic values of prey species used in the consumption model were annual averages, presumably taking into account the seasonal variation in the energetic value of prey. Without seasonal and age-specific energetic values for prey it is difficult to evaluate the magnitude of bias of using annual averages for prey energetic values.

Despite inherent biases and necessary assumptions in biomass consumption models, some of which are not testable or easily testable, the models provided some insight into the foraging patterns of California sea lions in Monterey Bay. Pacific sardine and market squid, two of the most abundant fish representing as much as 57.6% (MPM) of the biomass consumed by sea lions in 1998, are two of the most important schooling prey species. Salmon and elasmobranchs, presumably spiny dogfish sharks, are the two most important large, less frequently occurring, prey species. Combined, salmon and dogfish may account for up to 45.1% (BR) of the total biomass consumed by sea lions in Monterey Bay.

It is possible that squid, sardine, salmon, and dogfish stocks may play an important role in regulating the sea lion population, assuming carrying capacity is food-limited. Assuming the study region is approximately 9% of California's coast, sardines are equally distributed along the coast, and the most recent stock assessment of sardines along California's coast is 1.07 million metric tons (t; CDF&G 1999), then the sardine stock in Monterey Bay is approximately 96,300 t. Annual consumption of sardines by sea lions in 1998 represents approximately 1.3% to 2.8% of the total sardine biomass in Monterey Bay or the equivalent of up to 26.6% of the commercial catch. A stock assessment was not available for market squid and no commercial landing were reported in 1998; however, sea lion consumption of squid in 1998 was the equivalent of up to

11.0% of the commercial landings in 1997. The best estimate of numbers of chinook salmon passing through the Monterey Bay is the California central valley Index (CVI), which is a combination of ocean and inland harvest plus escapement estimates for all races of central valley chinook. Assuming the average mass of salmon landed in the commercial fishery in 1998 (4.2 kg, adding 20% to compensate for gutted mass) represents the average CVI chinook and the average mass of fish consumed by sea lions, sea lions consumed approximately 11.9% to 37.3% of the total biomass of chinook salmon available in Monterey Bay in 1998. A stock assessment was not available for spiny dogfish sharks and no commercial landings were reported in Monterey Bay during 1998. Other estimates of California sea lion consumption along the U.S. West Coast are limited and questionable. Estimates of sea lion consumption coast wide are complicated because different age-classes of sea lions are present along different areas of the coast for varying amounts of time during the year (NMFS 1997). Estimates of sea lion consumption are available for Puget Sound, WA, the lower Columbia River, Oregon Coast, and the southern California Bight. In Puget Sound from 1986 to 1994, a monthly average of 24 to 444 sea lions consumed 830 t of biomass. In 1995, an increased number of sea lions consumed 2,064 t of prey (NMML 1996). For the Oregon coast, an average of 52 to 3,695 sea lions per month ate 5,287 t of biomass annually from 1985 to 1994 (NMFS 1997). In the Southern California Bight, an estimated 90,135 sea lions consumed 140,684 t of prey in 1994 (NMFS 1997). Although numbers of sea lions have increased since 1994, sea lion consumption in Monterey Bay in 1998 was approximately 4.2% to 4.6% of the minimum coast wide estimate of sea lion consumption in 1994.

Consumption by California sea lions is most likely impacting west coast ecosystems and directly competing with commercial and recreational fisheries in Monterey Bay. Levels of indirect interaction with fisheries were difficult to assess, with the number of assumptions and biases in biomass reconstruction models probably affecting results, either increasing or decreasing estimates. Several of these assumptions can and should be addressed in future studies, including determining energetic requirements of different size classes of sea lions, estimating the proportion of animals at sea during aerial surveys, and estimating seasonal energetic values of prey species. Different consumption models, such as the split frequency of occurrence model (Oliesiuk 1993), should be used to compare estimates and develop a range of possible estimates. Any conclusions derived from these consumption models should be limited and precursory in nature.

At minimum, it is reasonable to conclude that sea lions consumed commercially important fish species. While competition most likely exists between sea lions and commercial fisheries, dynamics of how and if this competition may regulate predator and prey populations and affect fisheries remain unknown. An evaluation of this competition is essential for fisheries managers to more accurately estimate levels of natural predation. Further, this competition is not static but changes through time, as indicated by this study, with changes in sea lion diet. Changes in oceanographic conditions, such as those caused by ENSO events, and changes in sea lions diet greatly impacted some prey species, which when coupled with fisheries harvests could have a devastating impact on prey populations. Sea lions are only one of many natural predators of commercially important fish species. Identifying other natural predators and assessing their impact on prey populations is difficult, but necessary for effective fisheries management.

Impacts of California Sea Lion (*Zalophus californianus*) on Salmon Fisheries in Monterey Bay, California

Chapter 2

INTRODUCTION

Competition between pinnipeds and humans for fisheries resources has existed as long as fisheries itself. Historically, competition between pinnipeds and humans was of limited importance because many fishermen harvested both fish and pinnipeds. In recent years, however, declining fish resources coupled with the recovery of many formerly depleted pinniped populations have intensified this competition (Harwood and Croxall 1988). Competition for marine resources can be categorized as operational or ecological interactions (Harvey 1987, Mate and Harvey 1987, Olesiuk 1993). Operational interactions occur when pinnipeds and fishery operations come into direct contact. For example, pinnipeds can be incidentally entangled and damage fishing gear, and remove or damage fish from nets or fishing lines. Ecological interactions encompass indirect interactions of pinnipeds and fisheries, such as, competition for commercially important fishery resources.

Operational interactions occur with pinnipeds and almost all commercial and recreational fisheries along the California coast causing entanglement and damage to fishing gear and loss of catch, as well as, incidental mortality to pinnipeds (Miller *et al.* 1983, Beeson and Hanan 1996, NMFS 1997). Between 1986 and 1998, 7.5% of the pinnipeds admitted to a rehabilitation center on the central California coast had human related injuries, including gunshots, and lesions from net and marine debris entanglement

(Goldstein *et al.* 1999). In recent years, increasing numbers of California sea lions has resulted in increasing reports of pinnipeds interacting with fishing boats and taking hooked fish in salmonid fisheries along the West Coast (Beeson and Hanan 1996, NMFS 1997). In 1995, Monterey Bay and San Francisco dominated commercial and recreational ocean salmon landings off California, and Monterey Bay had the greatest degree of sea lion depredation on hooked salmon along the California coast (Beeson and Hanan 1996).

The California sea lion population, occurring from offshore islands in Mexico north to Vancouver Island, British Columbia, has increased steadily throughout the latter part of the twentieth century (NMFS 1997). In the early 1900's, the over-riding management philosophy was to limit the California sea lion population because of damage to commercial catches and competition for salmonid fishery resources (Everitt and Beach 1982). Sea lions increased in number in the 1940's with curtailment of commercial harvests, but bounties were paid for seals and sea lions in Oregon and Washington until the early 1970's. Following passage of the Marine Mammal Protection Act in 1972 (MMPA), the California sea lion population increased at an annual average greater than 5% along the West Coast (NMFS 1997). There are an estimated 161,066 to 181,355 sea lions in U.S. waters (Barlow *et al.* 1997), and possibly an additional 80,000 to 100,000 animals along Baja, Mexico (DeLong 1997).

In contrast to increases in numbers of sea lions, serious declines in salmonid populations have occurred in recent years as a result of changes and degradation of riverine habitat, declines in water quality, overharvest, changes in oceanic condition, and development of hydroelectric power systems obstructing major riverine migration routes.

Chinook salmon (*Oncorhynchus tshawytscha*) stocks in the central valley of California probably comprise 85%-95% of the chinook catches south of Pt. Arena and in Monterey Bay (PFMC 1999). Central valley chinook stocks are fish that originate in the Sacramento River, which has four distinct runs (portion of a salmon stock that returns to their native stream to spawn) of chinook salmon: fall, late-fall, winter, and spring runs. Fall and late-fall runs are relatively healthy, but winter and spring runs required federal protection under the Endangered Species Act (ESA). Sea lions can affect salmon stocks by taking hooked fish in salmonid fisheries. Commercial fishers and recreational anglers continue fishing to replace fish taken by sea lions resulting in greater numbers of fish removed from the population. Consumption of hooked salmon by sea lions may not only impact salmonid stocks, but the economic viability of fisheries.

Recreational and commercial salmon fishing is an important social and economic asset in California representing $28,856,000 in revenues in 1995 (PFMC 1995). Concern over declining salmonid stocks has resulted in adjustments of fishing regulations including allocation between ocean and inland user groups, harvest quotas, and time and area closures (Beeson and Hanan 1996). Increasing losses of fish to California sea lions may produce further restrictions for the recreational and commercial salmon fisheries.

In this study, I estimated the percentage of salmon taken by California sea lions in commercial and recreational salmon fisheries in Monterey Bay during 1997 and 1998. I hypothesized that the percentage of fish taken by California sea lions in salmon fisheries would be greater than found in previous studies (Briggs and Davis 1972, Miller *et al.* 1983, Hanan *et al.* 1989, Beeson and Hanan 1996). Based on percentages of fish taken by sea lions in fisheries, I estimated the total number of fish removed from the California central valley chinook stock. Based on numbers of fish lost and the type and amount of gear lost or damaged as a result of pinniped interactions, I also estimated the monetary losses associated with pinnipeds interacting with commercial and recreational salmon fisheries in Monterey Bay during 1997 and 1998.

METHODS

Fishery Interactions

Field observations of interactions between pinnipeds and salmon fisheries were conducted during 1997 and 1998 onboard boats and dockside at the three major ports in the Monterey Bay region: Santa Cruz, Moss Landing, and Monterey (Fig. 1). Salmon fishing operations included the commercial troll fishery and recreational fisheries consisting of Commercial Passenger Fishing Vessels (CPFV) and private skiffs. The commercial salmon season in 1997 was 1 – 31 May, 23 June to 18 July, 1-30 September, and in 1998 the season was 1-31 May and 16 June to 30 September. In 1997, the recreational fishing season was 15 March through 19 October, and in 1998 the season was 14 March to 7 September. The commercial troll fishery included day boats and multiple-day boats. Fishing areas included in this study were from Pt. Sur north to Año Nuevo Island. Data regarding fisheries interactions collected at the three different ports were pooled because fisherman from all three ports would fish as a group wherever the fish were being caught.

Dockside surveys were conducted to achieve a greater sampling effort than with only onboard observations. Onboard surveys were conducted to test reliability of dockside surveys, and to ensure that investigators fully understood the nature of the interaction. Small biases have occurred when combining onboard and dockside surveys, but were attributed to onboard sampling in areas where interaction was more prevalent (Miller *et al.* 1983). Captains were requested during onboard surveys to conduct normal fishing operations and not intentionally seek out areas with higher or lower interaction rates.

Sampling of commercial and recreational salmon fisheries was stratified by month with approximately equal numbers of onboard and dockside surveys conducted monthly. Sampling days and ports were selected randomly for onboard and dockside surveys of commercial fishing operations, but onboard surveys were limited by crew cooperation and space availability. Onboard surveys in the commercial fishery consisted of a full fishing day onboard one boat, and dockside samples were four-hour periods in the middle to late afternoon during the peak time that vessels return to port. For CPFVs, which operate virtually every day but have a greater number of boats and passengers on weekends, two-thirds of onboard and dockside sampling dates were selected randomly from possible weekend dates and one-third from all possible weekdays. Onboard surveys of CPFV were a full fishing day aboard one vessel, and dockside surveys were two to three hour periods in early afternoon during peak return times for CPFVs at a randomly selected port. The goal of CPFV dockside surveys was to sample all CPFVs fishing salmon in a port for the sample day. In the skiff fishery, greater numbers of fishing trips occurred on weekends, so approximately three-quarters of sampling days were on weekends, and one-quarter were weekdays. Onboard surveys in 1997 were a full fishing day aboard one skiff, and dockside surveys in 1997 and 1998 were two hours in late morning and early afternoon during the peak return time for private skiffs.

Information collected dockside included port of call, number of fish landed, number of fish taken by pinnipeds at the surface or below, species and number of marine mammal involved in surface take, number of fish released, number of released fish taken by marine mammals, and type and amount of gear loss resulting from pinniped interactions. Onboard surveys included the same information collected dockside, and standard length of all fish landed.

Surface takes (or definite takes) were defined as a pinniped taking a hooked salmon when the species and number of marine mammals involved could be determined. Surface takes also were recorded when fish were hooked and the action of the line indicated that a fish was no longer hooked, and a pinniped surfaced immediately with a fish in its mouth. Takes below the surface (or probable takes) were defined as fish removed from the hook when the species and number of marine mammals were not observed directly. Evidence required to record the occurrence of below surface takes included bent hooks, lost gear, or a sea lion surfacing within several minutes with a salmon provided no other fishing boats were in close proximity. Two types of takes were designated because takes below surface were not witnessed, and other predators including sharks take fish from lines, or fish may have escaped. Total catch was defined as numbers of fish hooked, including all legal size fish, fish taken by pinnipeds, and undersize fish. Legal catch only included fish of legal size landed by anglers.

Mean percentages of fish taken by sea lions relative to total catch (hereafter referred to as mean percentage of fish taken by sea lions) for the commercial, CPFV, and skiff fisheries for onboard and dockside surveys in 1997 and 1998 were non-normal in distribution and were transformed using the arcsine transformation for parametric statistical comparisons (Zar 1996). Mean percentages of fish taken by sea lions in the three fisheries (commercial, CPFV, and skiff) were compared between onboard and dockside surveys, between years (1997 and 1998), between seasons (sea lion breeding and non-breeding), and between takes (surface and below surface) using a Students t-test for normal homoscedastic data or a Mann-Whitney test for non-normal heteroscedastic data. Sea lion breeding and non-breeding seasons in 1997 and 1998 were estimated using both aerial and ground counts from Chapter 1. Mean catch per unit effort, or the numbers of fish hooked per day, in commercial, CPFV, and skiff fisheries data were non-normal and heteroscedastic, therefore, were transformed using $\sqrt{count+1}$ (Harvey 1987, Zar 1996). Mean catch per unit effort for the three fisheries was compared between years (1997 and 1998) using Student's t-test (if normal homoscedastic data) and Mann Whitney U-test (if non-normal heteroscedastic data). A comparison of numbers of hooked salmon taken by sea lions and Central California Valley Index (CVI) for chinook salmon abundance was used to estimate impacts of sea lions on salmon populations in Monterey Bay. The CVI is the number of ocean and inland harvested chinook salmon and the sum of all runs of chinook on the Sacramento river (PFMC 1999).

Monetary Impacts

Monetary losses resulting from sea lion interactions with salmon fisheries were estimated by evaluating numbers of fish taken by sea lions and types and quantities of fishing gear damaged or lost during these interactions. Information for the analysis of monetary losses was collected dockside and during onboard observations for commercial and recreational salmon fisheries in Monterey Bay during 1997 and 1998.

Annual monetary losses resulting from fish taken by sea lions were estimated using total numbers of estimated takes by sea lions, average dressed mass (mass of gutted and cleaned fish) of salmon landed in Monterey in 1997 and 1998, and average ex-vessel price (price per pound of fish paid to fishers) for chinook salmon in California during the 1997 and 1998 salmon fishing seasons. Estimated takes by sea lions in Monterey Bay in 1997 and 1998 were a function of numbers of observed takes (based on dockside samples) and proportions of the total catch sampled. Estimates of commercial and recreational salmon catches, average gutted masses, and ex-vessel prices for salmon came from PFMC (1999).

Estimates of lost and damaged gear were calculated using average costs for each type of gear used in commercial and recreational salmon fishing operations. A survey of seven local retail fishing tackle stores in Santa Cruz, Moss Landing, and Monterey was used to estimate mean value of each type of fishing gear used in the recreational (CPFV and skiff combined) salmon fishery. All charter fishing companies in the three ports in Monterey Bay were surveyed to estimate mean cost of a 'setup' sold by charter boat companies to customers. A 'setup' was defined as a hook and leader, or a hook, leader, and a 4 oz. or 8 oz. lead sinker. Costs of commercial fishing gear were estimated by surveying 19 local fishers from the three ports in Monterey Bay. To reduce costs commercial fishers buy the majority of their gear in bulk, and often by mail order.

RESULTS

Fishery Interactions

From 20 April through 30 September 1997, 337 hours of onboard and dockside surveys were conducted, 144 hours in the commercial fishery, 103 hours in the CPFV fishery, and 90 hours in the skiff fishery. From 15 March through 30 September 1998, 704 hours of onboard and dockside surveys were conducted, 370 hours in the commercial fishery, 270 hours in the CPFV fishery, and 64 hours in the skiff fishery.

California sea lions were almost exclusively responsible for the depredation of hooked salmon in the commercial and recreational fisheries in Monterey Bay. Of the estimated 2,420 takes in 1997, 647 of which were directly observed surface takes, sea lions were identified in 98.6% of the takes. In 1998, approximately 501 of 5,542 takes were at the surface, and sea lions were identified in 98.4% of those takes. Sea lions were assumed to represent similar percentages of takes that occurred below the surface. During many takes below the surface, sea lions would come to the surface within minutes with a fish, providing evidence supporting this assumption. Pacific harbor seal (*Phoca vitulina richardsi*) was responsible for other observed takes, 1.4% in 1997 and 1.6% in 1998.

In 1997, four onboard commercial surveys, four onboard CPFV surveys, and five onboard private skiff surveys were conducted, whereas in 1998, 22 surveys were conducted in both the commercial and CPFV fishery. There were no significant differences in mean percentages of fish taken by sea lions between onboard and dockside surveys in 1997 for commercial (Mann-Whitney, P=0.329), CPFV (Mann-Whitney, P=0.276), or skiff fisheries (Mann-Whitney, P=0.052; Fig. 11). Differences in percentages of fish taken between onboard and dockside surveys for all three fisheries in 1997 were marginal, so in 1998 onboard sampling efforts were increased and concentrated in commercial and CPFV fisheries. In 1998, no significant differences in mean percentages of fish taken by sea lions were found between onboard and dockside surveys in the commercial (Student's t-test, P=0.623) and CPFV fisheries (Mann-Whitney, P=0.660). I assumed, therefore, that dockside surveys provided a realistic measure of pinniped takes.

In the commercial fishery, 297 boats were surveyed dockside accounting for 17,943 hooked salmon or 5.9% of the fish landed in Monterey Bay during 1997, and 293 boats were surveyed dockside accounting for 15,446 hooked salmon or 10.8% of the salmon landed in 1998 (Table 11). Mean percentages of takes by sea lions based on dockside surveys in the commercial fishery were significantly greater in 1998 than in 1997 (Mann-Whitney, P<0.000; Fig. 12). A significantly greater mean percentage of takes by sea lions occurred during the sea lion non-breeding season than the breeding season in 1997 (Mann-Whitney, P<0.000) and 1998 (Student's t-test, P= 0.001; Fig. 13). Percentages of takes by sea lions were high early in the season in both May 1997 (21.8 %) and May 1998 (32.1 %), but takes did not decline in June and July 1998 as in 1997 (Fig. 14). In September 1997 and August and September 1998, surveys were conducted but little to no fishing effort was present because of the perceived threat of losing fish to sea lions. Percentage takes by sea lions below the water's surface were significantly greater in 1997 (mean=5.6 %, SE=0.79) and 1998 (mean=27.9%, SE=1.24) than surface takes in 1997 (mean=2.9 %, SE=0.56; Mann-Whitney, P=0.001) and 1998 (mean=0.6 %, SE=0.18; Mann-Whitney, P<0.000).

In the CPFV fishery, 139 boats were surveyed dockside in 1997 accounting for 5,168 hooked salmon, and 179 boats were surveyed in 1998 accounting for 4,694 hooked salmon (Table 12). Approximately 6.3% of the recreational fishery (CPFV and skiff combined) were sampled in 1997 and 15.6% in 1998. Mean percentages of takes by sea lions recorded during dockside surveys were significantly greater in 1998 than in 1997 (Mann-Whitney, P<0.000; Fig. 12). A significantly greater mean percentage of takes by sea lions occurred during the sea lion non-breeding season than the breeding season in 1997 (Mann-Whitney, P=0.010) and 1998 (Mann-Whitney, P<0.000; Fig. 13). In 1997, percentages of fish taken by sea lions declined in June (consistent with the typical sea lion breeding season), whereas in 1998 the percentages of fish taken by sea lions remained relatively high in June and July (Fig. 15). In August and September of 1997 and 1998, surveys were conducted but little to no salmon fishing effort occurred because of the perceived threat of takes by sea lions so boats targeted albacore tuna (*Thunnus alalunga*) and rockfishes (*Sebastes* sp.). Percentages of takes by sea lions below the water's surface and at the surface were not significantly different in 1997 (below surface mean=3.6 %, SE=0.65, surface mean=4.8 %, SE=0.91; Mann-Whitney, P=0.082); however, in 1998 the mean percentage of below surface takes (mean=11.8 %, SE=1.34) was significantly greater than surface takes (mean=6.5 %, SE=0.84; Mann-Whitney, P<0.000).

In the private skiff fishery during 1997, 723 boats were surveyed dockside accounting for 2,926 hooked salmon, and in 1998, 538 boats were surveyed dockside accounting for 1,564 hooked salmon (Table 13). The mean percentages of takes by sea lions recorded during dockside surveys were significantly greater in 1997 than in 1998 (Mann-Whitney, P=0.023, Fig. 12). A significantly greater mean percentage of takes by sea lions occurred during the sea lion non-breeding season of sea lions than the breeding season in 1997 (Mann-Whitney, P<0.000), whereas in 1998 there was no significant difference (Mann-Whitney, P=0.158; Fig. 13). Percentages of takes by sea lions declined following June 1997, whereas percentages of takes remained high in June and July 1998 (Fig. 16). In August and September of 1997 and 1998, surveys were conducted but there was little to no salmon fishing effort because of the perceived sea lion problem and the remaining boats targeted albacore tuna. Significantly greater percentages of takes by sea lions occurred at the surface than below the surface in 1997 (Mann-Whitney, P=0.001) and 1998 (Mann-Whitney, P<0.000).

The catch per unit of effort (CPUE: number of fish landed per boat per day) was significantly less in 1998 than in 1997 for the commercial (Mann-Whitney, P<0.000), CPFV (Student's t-test, P=0.011), and skiff fisheries (Mann-Whitney, P<0.000) in Monterey Bay (Fig. 17). The percentage of the CVI abundance for chinook salmon taken by sea lions during 1997 and 1998 ranged from 3.7% to 7.3% (Table 14).

Monetary Impact

Commercial fishers lost an estimated $54,900 (1997) to $60,570 (1998) of gear, and $373,039 (1997) to $480,989 (1998) worth of fish as a result of sea lion interactions with the fishery (Table 15 and 16). Estimates of gear and fish loss were extrapolated from observed losses to total losses based on percentages of the fisheries that were sampled. Gear types varied among commercial and recreational fisheries, and gear cost for each fishery varied greatly, therefore, average, high, and low cost estimates for each gear type were used to estimate gear loss for commercial and recreational fisheries (Table 17). Total revenue losses as a result of fish taken by sea lions in commercial fishery were equivalent to 14.3% in 1997 and 80.0% in 1998 of the total salmon fishery revenues.

DISCUSSION

Fishery Interactions

Conflicts between pinnipeds and fisheries are well documented in California (Briggs and Davis 1972, Fiscus 1979, Ainley *et al.* 1982, Miller *et al.* 1983, Hanan *et al.* 1989, Beeson and Hanan 1996, NMFS 1997). California sea lions have been the primary pinniped species involved in taking fish in ocean commercial and recreational salmon fisheries (Miller *et al.* 1983, Hanan *et al.* 1989, Beeson and Hanan 1996). In comparing present results and past studies it is imperative to distinguish between the percentage of salmon taken by pinnipeds relative to the number of legal size fish landed (i.e. legal catch) and number of pinniped takes relative to total number of fish hooked (i.e. total catch). The former value overestimates percentages by not including undersize fish caught, whereas the latter includes all fish hooked in the calculation and assumes all fish, regardless of size, have an equal probability of being taken by sea lions.

Dockside surveys were representative of the amount of interactions between sea lions and salmon fisheries because there were no significant differences in mean percentages of takes by sea lions between onboard and dockside surveys. Onboard surveys alone would not provide sufficient samples to adequately assess levels of interactions between sea lions and salmon fisheries, conversely, the validity of only dockside surveys would be questionable because of perceived biases associated with only dockside surveys. Biases include fishers not providing truthful information, fishers avoiding surveys, fishers not answering all questions, and not all fishers returning to the docks. Combining onboard and dockside surveys enabled me to verify dockside findings, obtain sufficient levels of sampling for comparisons, and directly observe and understand the nature of these interactions.

The percentage of hooked salmon taken by sea lions in the commercial salmon fishery relative to the legal catch has increased in the last several decades by at least 8% since the 1970s and 1980s. Briggs and Davis (1972) reported California sea lions took 4.1% of all salmon hooked during the 1969 commercial and sport salmon season, Miller *et al.* (1983) reported that in 1981 3.0% of the legal catch was taken during commercial salmon activities, and Beeson and Hanan (1996) found sea lions took 15% of the legal catch in commercial fisheries in 1995. In 1997, 12.5% of the legal catch was removed by sea lions in Monterey Bay and 71.1% in 1998.

Predation levels in the CPFV fishery have increased by at least 8% since 1983, and approximately 3% since 1995. Miller *et al.* (1983) reported predation rates of 5.2 % for the CPFV legal catch in Monterey Bay, and Beeson and Hanan (1996) reported predation rates of 10.5 % of the legal catch for the recreational fishery in 1995 (CPFV and private skiff combined). In Monterey Bay, 13.7 % of the legal catch was taken by sea lions in 1997 and 26.3 % in 1998.

In the skiff portion of the recreational salmon fishery, predation of the legal catch has increased by at least 26% since 1983, and 17% since 1995. Miller *et al.* (1983) reported predation levels of 1.4 % of the legal catch for skiff fisheries in Monterey Bay, and Beeson and Hanan (1996) reported predation levels of 10.5 % of the legal catch for 1995 recreational fishery season (CPFV and private skiff combined). In Monterey Bay, predation of the legal catch was 27.7 % in 1997, and 31.0% in 1998. Skiffs typically fish in large groups called the fleet. Sea lions had a greater probability of getting a hooked salmon when there were greater number of hooks in the water; therefore, sea lions most likely target the fleet. Individual skiff fishers caught fewer fish, but lost a proportionally greater number of fish to sea lions than commercial or CPFV fishers.

The greatest levels of sea lion predation in commercial and recreational fisheries occurred in spring when adult male sea lions were migrating south to breeding rookeries in southern California and Baja California, Mexico. In 1997, predation levels dropped significantly in June and July following a high level in May, corresponding to declines in numbers of sea lions in Monterey Bay as males headed southward to breeding colonies (Chapter 1). In 1998, loss of catch to sea lions was greatest in May with slight decreases during June and July because the decline in numbers of adult male sea lions during the breeding season was far less and shorter in duration than in June and July 1997. I assumed that adult male sea lions took the majority of hooked fish because animals identified taking fish during boat surveys were almost exclusively adult male sea lions and percentages of fish taken by sea lions were less during the sea lion breeding season. Briggs and Davis (1972), Miller *et al.* (1983), and Beeson and Hanan (1996) also reported greater numbers of salmon taken in spring (the non-breeding season) in the commercial and recreational salmon fisheries. Loss of catch to sea lions would most likely be greater during the northward migration of male sea lions because greater numbers of animals would be in the Monterey Bay region, however, fishing effort declined sharply and the commercial season was closed during part of that time in 1997.

Sea lions took most salmon below the water's surface in the commercial fishery and at the surface in recreational fisheries. Commercial fishers lost fish below the surface as a result of the large amount of trolling gear used, and time required for pulling gear when fish were hooked. Commercial fishers typically need 5 to 10 minutes, and as long as 20 minutes to pull hooked fish from the water, allowing ample time for sea lions to take fish. Before the 1994 amendments to the MMPA, sea lions were legally killed for endangering commercial catches, gear, and fishers, and are still at risk of harassment for taking fish off hooks today. As a result, most fish in the commercial fishery are taken below the surface and consumed at the surface some distance from the boat. Less gear and perhaps different types of gear that can be pulled faster may reduce the number of below surface takes and overall depredation levels. In recreational fisheries, fishers typically used rod and reel, which allowed fish to be reeled in within minutes. It has been illegal for recreational fishers to harass or kill sea lions since the passage of the MMPA in 1972, so it was not uncommon to see sea lions next to recreational boats in close pursuit of fish being pulled from the water, or taking a fish just before it was netted.

Increased depredation levels in the commercial and recreational salmon fisheries in 1998 were most likely the result of the large El Niño Southern Oscillation (ENSO) event that occurred in 1997-1998. The 1997-98 ENSO event created large anomalies in physical and biological conditions in the coastal waters off California resulting in above average seasonal norms in sea surface temperatures and large displacements in the distribution of many fish species (Lynn *et al.* 1998). A combination of factors during large ENSO events contribute to increased predation of salmon catches. These factors included shifts in sea lion prey composition, decreases in sea lion prey populations, increases in number of sea lions in the region, decreases in fishing effort by commercial and recreational salmon fishers, and decreases in number of salmon landed. Commercial gill net fishers reported that loss of catch to pinnipeds was more intense during ENSO events (Beeson and Hanan 1996).

Increased intensity in depredation of hooked fish by pinnipeds during ENSO events may be indicative of decreased foraging success resulting from shifts in prey availability and abundance. A significant shift in sea lion diet occurred from market squid, northern anchovy, and Pacific sardine eaten during autumn 1997 and winter 1997-98 to Pacific sardine and anchovy eaten during the ENSO (Chapter 1). Commercial catches of squid, hake, and herring fisheries, common prey of sea lions, were low or virtually nonexistent from the fall of 1997 through the summer of 1998 (CDF&G 1999). In May 1998, the catch rate of pelagic-young-of-the-year rockfish was the lowest in the history of tri-annual rockfish surveys (Lynn *et al.* 1998). It is, therefore, reasonable to assume that sea lions were probably stressed with the lack of prey and change in prey species, and would find a hooked salmon an attractive and easy meal.

Mean numbers of California sea lions recorded during the northward migration in summer and autumn 1998 were approximately 2,000 individuals greater than in summer and autumn 1997, most likely in response to poor foraging conditions in southern California resulting from ENSO conditions (Chapter 1). During the 1983 and 1992 ENSO events, numbers of sea lions increased along the central California coast due to the enhancement of the normal northward migration resulting from poor food availability in the Southern California Bight (Sydeman and Allen 1997). During the 1983-84 ENSO older juvenile sea lions migrated in greater than usual numbers from southern to central California (Trillmich *et al.* 1991). Greater numbers of female sea lions were counted on Año Nuevo Island in summer and fall 1998 presumably in response to poor foraging conditions in southern California (Morris pers. comm). Increases in numbers of sea lions in Monterey Bay during 1998 were most likely juveniles and adult females that moved northward to avoid the lack of schooling prey species in southern California resulting from ENSO.

Presumably as a result of ENSO conditions, total landings of salmon and the catch per unit effort in commercial and recreational fisheries were significantly less in 1998 than 1997. In 1998, approximately 2,000 fewer fish were landed in both commercial and recreational fisheries than in 1997, although approximately double the percentages of fisheries (total salmon landings) were sampled dockside. Numbers of salmon landed in Monterey Bay in 1998 decreased by 59.6% in the commercial fishery and 49.4% in the recreational fishery (PFMC 1999). In California during 1998, numbers of salmon landed in the commercial fishery were 55.7% less than in 1997, and 46.7% less in the recreational fishery. In 1998, CPUE of the commercial fishery declined proportionally more than other fisheries, which corresponded to proportionally greater percentages of fish taken by sea lions. In Monterey Bay, numbers of angler trips in 1998 declined by 38.6% in the commercial fishery, and 39.9% in the recreational fishery (PFMC 1999). Statewide in 1998, declines of 21% were observed in the active commercial fleet, and declines of 35% occurred in numbers of recreational angler trips (PFMC 1999).

Monterey Bay was selected for this study because it experienced the greatest levels of depredation during the 1995 commercial and recreational fisheries season (Beeson and Hanan 1996). Although Monterey Bay experienced increased levels of pinniped predation in recreational fisheries in 1997 and commercial and recreational fisheries in 1998, these levels were probably not representative of the whole California coast, but were more likely the worst-case scenario. Pinniped depredation may be increasing in other areas along the California coast as the sea lion population increases, but probably not to the degree that was observed in Monterey Bay. Pinniped predation of hooked fish in salmon fisheries is probably spatially and temporally variable. Although this variability complicates evaluating pinniped impacts on fisheries, it is important for fishery managers to take this variability into account.

Estimated levels of depredation reported for the commercial and recreational salmon fisheries in Monterey Bay may be affected by many assumptions. Lack of direct validation for information received during dockside surveys had unknown impacts on estimates of predation levels, but concurrent onboard sampling appeared to alleviate this concern. Sampling the recreational fisheries began late in April of 1997, resulting in approximately five weeks of the recreational season that were not sampled. The greatest depredation of catch occurred in the spring in all fisheries, therefore, missing the early part of the season might have decreased estimates of predation levels. Commercial and private skiff salmon boats bypass the sampling docks when no fish are landed or they dock in a harbor slip. Boats that bypass sampling docks may have no fish because of predation by sea lions, and not sampling these boats would decrease predation levels, but the magnitude of this decrease was difficult to evaluate. Although no statistical difference in dockside and onboard sampling was detected in 1997, increased onboard sampling and no significant difference between onboard and dockside surveys in 1998 increased my confidence that dock surveys were reflective of what was happening in the fisheries. Boat surveys were limited by crew cooperation, therefore, not all fishing styles and locations were sampled with unknown impacts on predation levels. Boat surveys also were limited to day trips because multiple-day boats often fished outside the study area during the course of a trip; however, multiple day boats were surveyed dockside so any biases of onboard samples would have been detected when comparing dockside and onboard predation levels.

Greater depredation levels in 1998 were most likely anomalous, resulting from the ENSO conditions. Impacts of sea lion predation on prey populations during these ENSO events may be substantial. In addition to an increasing sea lion population, percentages of fish taken by sea lions may be affected by oceanographic conditions, sea lion prey availability, and desirability of the fish species targeted by fisheries. Anecdotal information gathered from CPFV operators seems to be consistent with the inference that sea lions prey on more desirable sport and commercial fish such as salmon, yellowtail (*Seriola lalandi*), barracuda (*Sphyraena argentea*), and bonita (*Sarda chiliensis*), but not rockfishes and flatfish. This inference is further supported by sea lion diet information in Monterey Bay during 1997 and 1998, indicating that sea lions ate commercially important prey species such as sardines, anchovies, market squid, rockfishes, mackerel, and hake (Chapter 1).

Sea lions and salmon fisheries in Monterey Bay experienced operational interactions that could negatively impact salmon populations along the Central California coast. Pinniped depredation of hooked salmon from the California Central Valley chinook salmon population went from a low of approximately 3.8% during a non- ENSO year to an estimated 7.9% during an ENSO season, and possibly as great as 37.3% according to consumption models based on sea lion food habits (Chapter 1). High harvest levels coupled with high natural depredation of salmon during an ENSO year could be devastating for the Central Valley chinook salmon population. Further, when sea lions take fish in the fishery, fishers continue fishing to replace depredated fish, further impacting the salmon population. Hooked salmon lost to sea lions are losses to the population and need to be considered when determining allotments, quotas, and area closures. To better estimate impacts of sea lion predation on the CVI, concurrent studies of sea lion and salmon fishery interactions and sea lion food habits need to be conducted along the entire Central California coast, including Half Moon Bay, San Francisco Bay, and the Farallon Islands. Sea lions are only one of many natural predators of commercially important fish species. Identifying other natural predators and assessing their impact on prey populations is difficult, but necessary for effective fisheries management.

While operational interactions between salmon fisheries and sea lions may negatively impact salmon populations and fishers, it is important to recognize that these interactions also negatively impact sea lions. California sea lions are killed incidentally in set and drift gillnet fisheries, and as a result of firearms use in gillnet and non-gillnet fisheries (Barlow *et al.* 1997). From 1986 to 1998, of the 6,196 pinnipeds live stranded along the central California coast, 7.5% had human-related injuries (Goldstein *et al.* 1999). Approximately 5% of the animals admitted to a rehabilitation center had lesions caused by gunshots, 1.7% had lesions caused by entanglement with manmade marine debris, 0.7% had injuries caused by fishing tackle, and 0.1% had boat propeller injuries. Mortality of sea lions and other marine mammals resulting from fisheries interactions is difficult to quantify without direct observations of the fisheries, and has the potential to significantly affect marine mammal populations.

It is likely that only a small proportion of the sea lion population, particularly adult males, were responsible for salmon taken off hooks in salmon fisheries. Percentages of fish taken off the hook declined in both years when adult males moved south during the breeding season. Greater number of takes, however, occurred in the fisheries in August and September when lower numbers of animals were present in the region. On any given fishing day, peak numbers of sea lions were counted at ground survey locations during late-morning to early afternoon, which is also the period when most fishing occurred.

Miller *et al.* (1983) suggested that the total damage to fisheries by California sea lions was not proportional to the number of sea lions in the area. It is likely that takes on a given day in Monterey Bay were repeat occurrences by the same animals. I agree with Demaster et al. (1982) that a reduction in the number of animals or culling of the population would probably not reduce sea lion depredation levels unless the few animals responsible were identified and removed. Instead, there is a need for non-lethal deterrents to keep sea lions from taking hooked fish in open-ocean fisheries. Changing fishing gear types, limiting the amount of gear in water, various harassment techniques, area closures, and tolerance most likely encompass other possible management options.

Monetary Impacts

An increasing sea lion population and increased interactions with salmon fisheries resulting in salmon and gear losses will certainly impact negatively individual fishers and possibly California's economy (Beeson and Hanan 1996). Comparisons of monetary losses between years and among studies must consider average fish weight, ex-vessel price per year, and definitions of fishing regions. For example, if greater numbers of fish were lost in a given year but ex-vessel prices were low, the overall monetary impact would be less than during a year when fewer fish were taken but the ex-vessel price was high. Exact numbers of commercial trollers were unavailable, but based on my observations, there were possibly 100 vessels in Monterey Bay, and of those, perhaps 50 vessels actively fished in 1997 and 1998.

Depending on the exact number of fishers in Monterey Bay, estimates of economic impacts from sea lion interactions on individual fishers ranged from approximately $4,279 to $10,831 per year. Past researchers often included all ports in California, and analyzed impacts by port, but included different fishing areas under the same port names. Miller *et al.* (1983) estimated annual losses resulting from sea lion interaction in 1980 at $274,000 for California, and an estimated $21,536 for Monterey Bay. It is unclear, however, if these figures included fishing areas south of Monterey, such as Morro Bay, and fishing areas north, such as Half Moon Bay. Beeson and Hanan (1986) estimated 86,900 fish or $1,734,000 was lost in 1995 because of sea lion interactions, and 48,000 fish were taken in Monterey, representing approximately $960,000. Beeson and Hanan (1986) included the Port of Princeton in Half Moon Bay in figures reported for Monterey. Therefore, it was not possible to make direct comparisons among studies, but it appears that economic losses per individual fisher have increased since the 1980's, and will probably continue to increase if sea lion population and interactions with salmon fisheries increase. Assessment of economic impacts of salmon fisheries in Monterey Bay in this study was limited to gear and fish loss, however, impacts are most likely more widespread affecting the local economy of the region.

Discussing the competition between sea lions and fisheries tends to arouse controversy because of the complex mix of biological, economic, social, political, and moral factors involved (Harwood and Croxall 1988). Fishers claim regularly that their activities are regulated while predation by marine mammals is unrestricted (Harwood 1992). Although losses in Monterey Bay in 1998 were most likely anomalously large because of ENSO conditions, this offered little reassurance to those fishers whose livelihoods were threatened. Growing sea lion populations have undoubtedly intensified competition with fisheries, but greater fishing effort, sophisticated fish equipment, fisheries methods, and less than rigorous fisheries management is equally responsible. Segments of the American public find marine mammals appealing and demand that populations be protected, whereas other segments demand protection from economic ruin resulting from marine mammal-fishery interactions. Clearly, demands from both segments of the public must be addressed (Everitt and Beach 1982). Continued research assessing and refining our understanding of food habits of marine mammals is essential, and incorporating this information into fisheries management is equally important. When conflicts between fisheries and marine mammals are identified, population management strategies and non-lethal deterrent solutions need to be developed. Any management solutions need to consider not only the specific interactions, but also the ecosystem as a whole and the viewpoints of all segments of the American public.

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Table 1. Counts of California sea lions on eight main haulout sites based on monthly aerial surveys in 1997 and 1998, listed south to north along the central California coast. Common name is listed for each haul-out site.

	Hurricane Point	Lobos Rocks	Big Sur Rocks	Sea Lion Rocks	Bird Rock	Monterey Jetty	Lighthouse Rock	Ano Nuevo Island
May-97	103	68	50	31	0	580	167	2,298
June-97	0	1	0	7	20	50	5	510
July-97	72	351	338	870	706	160	104	2,966
August-97	0	683	32	531	434	39	166	3,267
September-97	62	235	0	155	610	300	195	3,039
December-97	53	481	196	533	1,336	849	10	4,064
January-98	73	153	60	424	700	777	73	1,958
February-98	4	18	16	61	261	612	4	2,250
March-98	0	0	0	175	236	330	25	3,096
April-98	52	99	141	672	219	186	48	2,831
May-98	24	131	70	510	255	371	112	2,825
June-98	0	88	0	274	167	171	55	5,963
July-98	0	116	0	237	127	93	49	3,252
September-98	84	91	0	510	351	163	50	5,712
Average	38	180	65	356	387	334	76	3,145
SD	37.5	197.9	98.7	261.1	355.0	268.3	63.5	1401.1

Table 2. Seasonal comparison of prey species composition from California sea lion fecal samples collected during 1997 and 1998 in Monterey Bay, California based on percent similarity index (PSI). Asterick (*) indicates redundant comparisons.

	Winter 1997-98	Spring 1998	Summer 1998	Autumn 1998
Autumn 1997	72.2	83.2	35.4	43.4
Winter 1997-98	*	73.3	18.4	22.8
Spring 1998	*	*	37.3	42.1
Summer 1998	*	*	*	80.5

Table 3. Mean percentage number (%N), mean percentage mass (%M), percentage frequency of occurrence (%FO), and mean index of relative importance (IRI) of prey species identified in sea lion scats collected in Monterey Bay, California during autumn (August - October; n=87) 1997. Standard error is also shown. Listed in order of decreasing IRI.

	% N		% M			IRI	
Prey Species	Mean	SE	Mean	SE	%FO	Mean	SE
Engraulis mordax	18.83	4.43	13.66	3.96	31.34	1018.40	262.95
Merluccius productus	18.14	4.37	19.19	4.61	25.37	947.11	227.74
Loligo opalescens	16.72	4.23	13.96	3.89	23.88	732.79	193.92
Sardinops sagax	11.90	3.80	10.57	3.57	14.93	335.44	109.95
Sebastes sp.	8.16	2.95	8.33	3.07	13.43	221.53	80.90
Oncorhynchus sp.	3.79	1.93	6.61	2.91	5.97	62.06	28.93
Leptocottus armatus	2.21	1.56	3.86	1.99	7.46	45.26	26.46
Octopus sp.	3.10	2.10	3.00	2.09	4.48	27.33	18.76
Citharichthys stigmaeus	1.74	0.88	1.36	0.67	7.46	23.09	11.54
Elasmobranch	1.55	1.05	3.51	2.14	4.48	22.66	14.26
Citharichthys sordidus	2.07	1.18	2.16	1.30	4.48	18.93	11.11
Cymatogaster aggregata	1.93	1.53	2.58	1.83	2.99	13.44	10.03
Trachurus symmetricus	1.72	1.51	2.33	1.70	2.99	12.11	9.58
Porichthys notatus	1.49	1.49	1.49	1.49	2.99	8.91	8.91
Eptatretus sp.	0.37	0.37	1.21	1.21	1.49	2.35	2.35
Lampetra tridentata	0.75	0.75	0.02	0.02	1.49	1.15	1.15
Symphurus atricauda	0.24	0.24	0.17	0.17	1.49	0.61	0.61

Table 4. Mean percentage number (%N), mean percentage mass (%M), percentage frequency of occurrence (%FO), and mean index of relative importance (IRI) of prey species identified in sea lion scats collected in Monterey Bay, California during winter (November - January; n=70) 1997-98. Standard error is also shown. Listed in order of decreasing IRI.

	% N		% M			IRI	
Prey Species	Mean	SE	Mean	SE	%FO	Mean	SE
Loligo opalescens	39.78	5.11	31.33	4.94	51.43	3657.28	516.87
Sardinops sagax	23.28	4.67	27.36	5.05	31.43	1591.58	305.22
Elasmobranch	11.95	3.54	16.43	4.23	20.00	567.56	155.49
Engraulis mordax	6.35	2.35	4.50	2.12	17.14	185.92	76.55
Citharichthys sordidus	2.53	1.16	3.19	1.55	11.43	65.40	30.93
Scomber japonicus	3.19	1.76	5.35	2.51	7.14	61.02	30.45
Citharichthys stigmaeus	2.98	1.81	2.53	1.68	5.71	31.49	19.98
Sebastes sp.	1.90	1.14	2.96	1.72	5.71	27.80	16.32
Octopus sp.	1.56	0.64	0.37	0.17	10.00	19.32	8.13
Merluccius productus	1.38	0.87	0.87	0.79	4.29	9.63	7.11
Atherinops affinis	1.43	1.00	1.60	1.16	2.86	8.65	6.18
Cymatogaster aggregata	0.74	0.71	1.22	1.19	2.86	5.59	5.43
Chilara talori	0.76	0.72	0.25	0.24	2.86	2.89	2.73
Oncorhynchus sp.	0.71	0.71	0.83	0.83	1.43	2.21	2.21
Clupea pallasi	0.20	0.20	0.81	0.81	1.43	1.45	1.45
Symphurus atricauda	0.71	0.71	0.16	0.16	1.43	1.25	1.25
Microgadus proximus	0.02	0.02	0.14	0.14	1.43	0.23	0.23
Porichthys notatus	0.06	0.06	0.06	0.06	1.43	0.18	0.18
Ptychocheilus sp.	0.05	0.05	0.03	0.03	1.43	0.12	0.12

Table 5. Mean percentage number (%N), mean percentage mass (%M), percentage frequency of occurrence (%FO), and mean index of relative importance (IRI) of prey species identified in sea lion scats collected in Monterey Bay, California during spring (February - April; n=100) 1998. Standard error is also shown. Listed in order of decreasing IRI.

	% N		% M			IRI	
Prey Species	Mean	SE	Mean	SE	%FO	Mean	SE
Sardinops sagax	26.41	3.55	30.39	4.07	50.00	2840.11	380.63
Loligo opalescens	31.89	3.98	22.62	3.90	47.00	2562.14	370.19
Elasmobranch	7.78	2.03	18.47	3.49	24.00	629.87	132.71
Sebastes sp.	8.05	1.81	5.24	1.85	25.00	332.26	91.48
Engraulis mordax	7.69	1.56	3.99	1.42	27.00	315.35	80.41
Merluccius productus	4.41	1.48	1.80	1.03	13.00	80.77	32.74
Clupea pallasi	1.87	0.75	2.23	1.14	8.00	32.78	15.12
Cymatogaster aggregata	2.24	0.94	0.98	0.63	9.00	28.95	14.13
Citharichthys sordidus	2.14	1.19	1.96	1.22	6.00	24.64	14.45
Oncorhynchus sp.	1.51	0.68	2.50	1.14	6.00	24.09	10.91
Octopus sp.	1.74	0.82	0.35	0.25	7.00	14.64	7.48
Atherinops californiensis	1.12	0.55	1.69	0.75	5.00	14.06	6.48
Trachurus symmetricus	0.78	0.52	1.52	0.77	4.00	9.19	5.16
Porichthys notatus	0.35	0.22	0.56	0.38	3.00	2.74	1.80
Chilara talori	0.48	0.25	0.12	0.08	4.00	2.39	1.30
Citharichthys stigmaeus	0.49	0.33	0.07	0.04	3.00	1.69	1.11
Ptychocheilus sp.	0.60	0.45	0.37	0.36	1.00	0.97	0.80
Atherinops affinis	0.13	0.08	0.04	0.03	4.00	0.71	0.45
Spirinchus thaleichthys	0.50	0.50	0.01	0.01	1.00	0.51	0.51
Leptocottus armatus	0.20	0.15	0.02	0.01	2.00	0.42	0.33
Sculpin	0.16	0.11	0.04	0.04	2.00	0.39	0.30
Scomber japonicus	0.04	0.04	0.23	0.23	1.00	0.27	0.27
Lyopsetta exilis	0.14	0.14	0.12	0.12	1.00	0.26	0.26
Phanerodon furcatus	0.04	0.04	0.09	0.09	1.00	0.13	0.13
Eptatretus sp.	0.08	0.08	0.01	0.01	1.00	0.09	0.09
Pleuronichthys vetulus	0.06	0.06	0.03	0.03	1.00	0.08	0.08

Table 6. Mean percentage number (%N), mean percentage mass (%M), percentage frequency of occurrence (%FO), and mean index of relative importance (IRI) of prey species identified in sea lion scats collected in Monterey Bay, California during summer (May - July; n=72) 1998. Standard error is also shown. Listed in order of decreasing IRI.

	%N		%M			IRI	
Prey Species	Mean	SE	Mean	SE	%FO	Mean	SE
Sardinops sagax	47.16	5.02	48.33	5.22	66.67	6366.34	683.03
Engraulis mordax	15.33	3.57	9.41	2.96	29.17	721.42	190.43
Merluccius productus	9.15	2.68	8.53	2.95	22.22	392.93	125.08
Oncorhynchus sp.	8.70	2.94	11.48	3.62	18.06	364.45	118.44
Sebastes sp.	5.58	2.39	6.08	2.63	9.72	113.37	48.75
Elasmobranch	3.06	1.62	7.51	2.78	9.72	102.70	42.79
Loligo opalescens	3.42	1.69	2.11	1.43	11.11	61.48	34.63
Citharichthys sordidus	0.77	0.70	1.21	1.20	2.78	5.50	5.26
Sculpin	1.39	1.39	1.39	1.39	1.39	3.86	3.86
Cymatogaster aggregata	0.43	0.22	0.21	0.10	5.56	3.55	1.80
Octopus sp.	0.50	0.46	0.20	0.19	2.78	1.94	1.83
Ophiodon elongatus	0.05	0.05	0.99	0.99	1.39	1.46	1.46
Trachurus symmetricus	0.28	0.28	0.74	0.74	1.39	1.42	1.42
Citharichthys stigmaeus	0.69	0.69	0.19	0.19	1.39	1.23	1.23
Scomber japonicus	0.08	0.08	0.47	0.47	1.39	0.76	0.76
Porichthys notatus	0.35	0.35	0.14	0.14	1.39	0.68	0.68
Clupea pallasi	0.23	0.23	0.01	0.01	1.39	0.34	0.34
Atherinops californiensis	0.16	0.16	0.07	0.07	1.39	0.32	0.32
Chilara talori	0.07	0.07	0.01	0.01	1.39	0.11	0.11
Genyonemus lineatus	0.05	0.05	0.01	0.01	1.39	0.09	0.09

Table 7. Mean percentage number (%N), mean percentage mass (%M), percentage frequency of occurrence (%FO), and mean index of relative importance (IRI) of prey species identified in sea lion scats collected in Monterey Bay, California during autumn (August - October; n=68) 1998. Standard error is also shown. Listed in order of decreasing IRI.

	%N		%M			IRI	
Prey Species	Mean	SE	Mean	SE	%FO	Mean	SE
Sardinops sagax	54.17	5.07	56.13	5.20	75.36	8312.25	773.47
Engraulis mordax	11.00	2.63	3.76	1.17	24.64	363.45	93.63
Loligo opalescens	6.79	1.92	2.92	1.50	27.54	267.45	94.27
Merluccius productus	7.18	2.51	5.56	2.23	18.84	240.10	89.25
Sebastes sp.	7.15	2.63	5.38	2.25	15.94	199.76	77.75
Elasmobranch	3.86	2.05	11.19	3.55	13.04	196.25	73.11
Trachurus symmetricus	0.88	0.51	3.03	1.53	7.25	28.36	14.84
Oncorhynchus sp.	3.19	1.77	5.32	2.61	2.90	24.67	12.70
Citharichthys stigmaeus	1.09	0.47	0.35	0.16	11.59	16.72	7.23
Scomber japonicus	0.64	0.51	2.02	1.44	1.45	3.87	2.82
Porichthys notatus	0.41	0.26	0.23	0.14	4.35	2.77	1.76
Citharichthys sordidus	0.36	0.25	0.44	0.38	2.90	2.33	1.83
Genyonemus lineatus	0.32	0.25	0.42	0.32	2.90	2.15	1.67
Chilara talori	0.23	0.12	0.11	0.07	5.80	2.00	1.10
Atherinops californiensis	0.18	0.18	1.10	1.10	1.45	1.86	1.86
Clupea pallasi	0.16	0.12	0.12	0.09	2.90	0.80	0.61
Ptychocheilus sp.	0.07	0.07	0.46	0.46	1.45	0.77	0.77
Eptatretus sp.	0.12	0.12	0.01	0.01	1.45	0.19	0.19
Lepidogobius lepidus	0.07	0.07	0.04	0.04	1.45	0.17	0.17
Cymatogaster aggregata	0.07	0.07	0.01	0.01	1.45	0.12	0.12
Atherinops affinis	0.02	0.02	0.02	0.02	1.45	0.06	0.06
Pleuronichthys vetulus	0.02	0.02	0.00	0.00	1.45	0.04	0.04

Table 8. Estimate of mass (in 1000s kilograms) of prey species consumed by California sea lions in Monterey Bay in 1997 and 1998. Biomass reconstruction model estimates are based on the proportion of prey species in the total reconstructed biomass.

Prey Species	Autumn 1997	(CV)	Winter 1997-98	(CV)	Spring 1998	(CV)	Summer 1998	(CV)	Autumn 1998	(CV)
Loligo opalescens	150.7	(4.3)	301.2	(2.6)	58.1	(8.5)	4.8	(133.5)	16.4	(0.01)
Engraulis mordax	29.8	(21.5)	102.6	(7.6)	5.5	(89.1)	26.3	(24.6)	37.4	(0.00)
Sardinops sagax	76.8	(8.3)	136.2	(5.7)	76.2	(6.5)	272.5	(2.4)	726.6	(0.00)
Sebastes sp.	655.5	(1.0)	627.8	(1.2)	103.1	(4.8)	228.6	(2.8)	180.9	(0.00)
Oncorhynchus sp.	671.3	(1.0)	70.6	(11.0)	126.4	(3.9)	403.4	(1.6)	357.3	(0.00)
Merluccius productus	173.9	(3.7)	32.3	(24.1)	48.3	(10.2)	45.0	(14.3)	78.5	(0.00)
Elasmobranch	249.6	(2.6)	754.7	(1.0)	430.9	(1.1)	231.5	(2.8)	650.2	(0.00)
Citharichthys sordidus	9.4	(68.3)	16.9	(46.1)	7.5	(65.6)	0.8	(801.0)	9.1	(0.01)
Citharichthys stigmaeus	9.9	(64.5)	7.2	(107.6)	0.9	(534.5)	0.2	(3,203.9)	7.0	(0.02)
Porichthys notatus	14.0	(45.8)	0.4	(2,064.3)	2.8	(177.2)	1.7	(379.4)	2.5	(0.05)
Octopus sp.	1.4	(464.4)	2.1	(363.2)	1.7	(287.8)	0.4	(1,601.9)	-	-
Cymatogaster aggregata	15.7	(40.7)	0.8	(968.4)	0.7	(729.3)	1.5	(427.2)	0.1	(2.49)
Trachurus symmetricus	20.5	(21.0)	-	-	16.2	(30.4)	4.0	(161.8)	79.5	(0.00)
Scomber japonicus	-	-	102.3	(7.6)	5.0	(99.5)	9.9	(65.4)	29.4	(0.00)
Leptocottus armatus	27.0	(23.8)	-	-	0.2	(3,216.4)	-	-	-	-
Eptatretus sp.	3.8	(169.0)	-	-	0.2	(2,450.6)	-	-	0.5	(0.24)
Symphurus atricauda	1.1	(580.5)	0.3	(2,905.3)	-	-	-	-	-	-
Atherinops californiensis	-	-	-	-	33.9	(14.6)	11.9	(54.3)	10.5	(0.01)
Atherinops affinis	-	-	1.6	(484.2)	0.3	(1,559.0)	-	-	0.4	(0.31)
Chilara taylori	-	-	0.8	(1,032.1)	0.7	(664.6)	0.3	(2,276.4)	2.9	(0.04)
Clupea pallasi	-	-	5.5	(141.8)	8.2	(60.2)	-	-	1.8	(0.07)
Genyonemus lineatus	-	-	-	-	-	-	1.3	(483.4)	12.0	(0.01)
Lyopsetta exilis	-	-	-	-	0.4	(1,247.2)	-	-	-	-
Ophiodon elongatus	-	-	-	-	-	-	166.7	(3.9)	-	-
Pleuronichthys vetulus	-	-	-	-	0.7	(748.3)	-	-	0.1	(1.25)
Phanerodon furcatus	-	-	-	-	1.0	(498.9)	-	-	-	-
Sculpin	-	-	-	-	0.2	(3,216.4)	-	-	-	-
Spirinchus thaleichthys	-	-	-	-	-	-	-	-	-	-
Lampetra sp.	1.4	(456.3)	-	-	-	-	-	-	-	-
Microgadus proximus	-	-	1.7	(447.8)	-	-	-	-	-	-
Total	2,121.8		2,165.2		928.9		1,410.8		2,203.0	

Table 9. Estimate of mass (in 1000s kilograms) of prey species consumed by California sea lions in Monterey Bay in 1997 and 1998. Mean percentage mass model estimates are based on mean percentage mass of prey species per fecal sample. Because one aerial survey was conducted in autumn 1998 no coefficient of variation (CV) could be estimated.

Prey Species	Autumn 1997	(CV)	Winter 1997-98	(CV)	Spring 1998	(CV)	Summer 1998	(CV)	Autumn 1998
Loligo opalescens	335.0	(318.0)	599.5	(318.2)	220.5	(474.9)	27.2	(1,457.4)	63.8
Engraulis mordax	327.6	(330.0)	86.1	(823.5)	38.9	(909.9)	121.8	(697.0)	81.8
Sardinops sagax	253.6	(378.4)	523.7	(357.9)	296.2	(390.7)	625.6	(307.0)	1,222.6
Sebastes sp.	200.0	(410.9)	56.8	(1,006.6)	51.0	(904.0)	78.8	(937.7)	117.2
Oncorhynchus sp.	158.5	(485.6)	15.9	(1,728.3)	24.4	(1,156.4)	148.6	(697.7)	115.9
Merluccius productus	460.3	(279.6)	16.7	(1,560.4)	17.6	(1,444.9)	110.4	(760.6)	121.2
Elasmobranch	84.1	(664.5)	314.3	(472.6)	180.0	(513.6)	97.1	(811.7)	243.8
Citharichthys sordidus	51.9	(654.8)	61.2	(847.3)	19.1	(1,568.2)	15.7	(2,095.0)	9.8
Citharichthys stigmaeus	32.6	(541.3)	48.6	(1,149.2)	0.7	(1,593.7)	2.4	(2,204.5)	7.7
Porichthys notatus	35.7	(1,083.3)	1.1	(1,777.0)	5.4	(1,726.3)	1.7	(2,293.3)	4.9
Octopus sp.	72.0	(758.0)	7.0	(826.1)	3.4	(1,800.9)	2.6	(2,049.9)	-
Cymatogaster aggregata	61.7	(771.7)	23.3	(1,676.4)	3.6	(4,289.2)	2.7	(1,058.6)	0.1
Trachurus symmetricus	55.9	(792.4)	-	-	14.8	(1,272.0)	9.6	(2,122.0)	65.9
Scomber japonicus	-	-	102.4	(820.1)	2.9	(1,894.6)	8.0	(1,615.6)	44.1
Leptocottus armatus	92.4	(566.0)	-	-	0.2	(1,963.0)	-	-	-
Eptatretus sp.	28.9	(1,082.3)	-	-	0.1	(3,262.1)	-	-	0.2
Symphurus atricauda	4.1	(1,068.3)	3.2	(1,656.7)	-	-	-	-	-
Atherinops californiensis	-	-	-	-	16.5	(1,121.9)	1.0	(1,951.7)	24.1
Atherinops affinis	-	-	-	-	0.5	(1,611.9)	-	-	0.4
Chilara taylori	-	-	4.9	(1,620.0)	1.1	(1,700.0)	-	-	2.5
Clupea pallasi	-	-	1.6	(17,245.8)	23.6	(1,194.7)	0.1	(2,397.4)	2.6
Genyonemus lineatus	-	-	-	-	-	-	-	-	9.2
Lyopsetta exilis	-	-	-	-	1.2	(2,468.6)	-	-	-
Ophiodon elongatus	-	-	-	-	-	-	12.8	(2,146.9)	-
Pleuronichthys vetulus	-	-	-	-	0.3	(2,363.7)	-	-	-
Phanerodon furcatus	-	-	-	-	0.8	(2,624.9)	-	-	-
Sculpin	-	-	-	-	0.5	(2,008.0)	18.1	(2,119.7)	0.0
Spirinchus thaleichthys	-	-	-	-	0.1	(2,825.3)	-	-	-
Lampetra sp.	0.6	(1,093.7)	-	-	-	-	-	-	-
Microgadus proximus	-	-	2.7	(1,694.9)	-	-	-	-	-
Total	2,255.1		1,869.0		923.3		1,284.4		2,138.5

Table 10. Estimate of annual fish consumption (in 1000's kg) by California sea lions in Monterey Bay during 1998 based on mean percentage mass model (MPM) and biomass reconstruction model (BR; in 1000's kg), commercial fisheries catches (in 1000's kg) for 1998, and the equivalent percentage of fish consumed by sea lions compared to the commercial fisheries catches. Coefficient of variation listed in parenthes

	Consumption Estimates for 1998				Commercial	Equivalent % Commercial Catch	
Prey Species	MPM	(CV)	BR	(CV)	Catch (1998)	MPM	BR
Sardinops cauruleus	2,668.1	(1,055.6)	1,211.5	(14.6)	10,030.0	26.6	12.1
Loligo opalescens *	911.1	(2,250.5)	380.6	(144.6)	8,297.3	11.0	4.6
Engraulis mordax	328.7	(2,430.3)	171.8	(121.2)	903.2	36.4	19.0
Oncorhynchus sp.	304.8	(3,582.5)	957.5	(16.5)	193.6	157.4	494.5
Sebastes sp.	303.8	(2,848.3)	1,140.4	(8.8)	1,442.3	21.1	79.1
Scomber japonicus	157.5	(4,330.2)	146.5	(172.4)	1,494.1	10.5	9.8

* Commercial squid catch is for 1997 because no landings were reported for 1998.

Table 11. Monthly catch statistics and estimates of the number and percentage of salmon taken by pinnipeds in the commercial salmon fishery during dockside surveys in Monterey Bay during 1997 and 1998.

			Catch Statistics			Number Takes		Percentage Takes	
		Number boats sampled	Total number fish hooked	Number legal fish landed	Number undersize fish	Number fish taken at surface	Number fish taken below surface	Total % of legal catch lost	Total % of total catch lost
1997	May	117	5,722	4,226	245	346	905	29.6	21.9
	June	72	4,705	3,318	1345	14	28	1.3	0.9
	July	108	7,516	4,744	2534	162	76	5.0	3.2
	TOTAL	297	17,943	12,288	4124	522	1,009	12.5	8.5
1998	May	181	10,741	4,376	2910	71	3,384	79.0	32.2
	June	55	2,296	955	817	22	502	54.9	22.8
	July	57	2,409	875	1102	4	428	49.4	17.9
	TOTAL	293	15,446	6,206	4829	97	4,314	71.1	28.6

Table 12. Monthly catch statistics and estimates of the number and percentage of salmon taken by pinnipeds in the CPFV salmon fishery during dockside surveys in Monterey Bay during 1997 and 1998.

			Catch Statistics			Number Takes		Percentage Takes	
		Number boats sampled	Total number fish hooked	Number legal fish landed	Number under size fish	Number fish taken at surface	Number fish taken below surface	Total % of legal catch lost	Total % of total catch lost
1997	April	12	220	150	17	44	9	35.3	24.1
	May	25	266	229	12	13	12	10.9	9.4
	June	44	2,184	1,738	387	37	22	3.4	2.7
	July	50	2,325	980	1,097	130	118	25.3	10.7
	August	8	173	60	64	23	26	81.7	28.3
	TOTAL	139	5,168	3,157	1,577	247	187	13.7	8.4
1998	March	27	244	190	15	29	10	20.5	16.0
	April	48	1,175	830	115	89	141	27.7	19.6
	May	32	970	687	63	49	171	32.0	22.7
	June	30	1,241	742	204	116	179	39.8	23.8
	July	40	1,062	818	170	22	52	9.0	7.0
	August	2	2	0	2	0	0	0.0	0.0
	TOTAL	179	4,694	3,267	569	305	553	26.3	18.3

Table 13. Monthly catch statistics and estimates of the number and percentage of salmon taken by pinnipeds in the skiff salmon fishery during dockside surveys in Monterey Bay during 1997 and 1998.

			Catch Statistics			Number Takes		Percentage Takes	
		Number boats sampled	Total number fish hooked	Number legal fish landed	Number undersize fish	Number fish taken at surface	Number fish taken below surface	Total % of legal catch lost	Total % of total catch lost
1997	April	248	1,003	635	181	126	61	29.4	18.6
	May	256	751	443	105	138	65	45.8	27.0
	June	83	399	263	123	6	7	4.9	3.3
	July	82	669	277	353	20	19	14.1	5.8
	August	43	97	22	62	13	0	59.1	13.4
	September	11	7	3	4	0	0	0.0	0.0
	TOTAL	723	2,926	1,643	828	303	152	27.7	15.6
1998	March	98	199	150	24	23	2	16.7	12.6
	April	111	399	205	112	27	55	40.0	20.6
	May	71	192	122	41	11	18	23.8	15.1
	June	132	453	244	98	37	74	45.5	24.5
	July	108	302	148	128	1	25	17.6	8.6
	August	18	19	13	6	0	0	0.0	0.0
	TOTAL	538	1,564	882	409	99	174	31.0	17.5

Table 14. Indices of annual chinook salmon abundance and impacts of Monterey Bay pinniped predation on California Central Valley chinook in 1997 and 1998.

	Estimated Pinniped Takes			Abundance Index	Pinniped Predation
Year	Commercial	Recreational	Total	(Ocean + River totals)	Index (%)
1997	25,805	14,137	39,942	1,055,300	3.8
1998	40,880	7,236	48,116	611,800	7.9

Table 15. Total number of salmon taken by pinnipeds and economic impacts of pinniped takes in the commercial and recreational salmon fisheries in Monterey Bay, California during 1997 and 1998.

Fishery	Year	# Observed Pinniped Takes	% Fishery Sampled	Total # Pinniped Takes	Average Fish Weight	Average Ex-vessel Price/Pound	Total Revenue Lost	Total Revenue in Monterey Bay	% of Total Revenue Lost (Fish & gear)
Commercial	1997	1,531	5.93	25,805	10.4	$1.39	$373,039	$2,994,054	14.3
	1998	4,411	10.79	40,880	7.4	$1.59	$480,989	$676,722	80.0
Recreational *	1997	889	6.29	14,137	10.4	$1.39	$204,367	n/a	n/a
	1998	1,131	15.63	7,236	7.4	$1.59	$85,146	n/a	n/a

* Recreational Fishery includes CPFV and skiff fisheries

n/a - not applicable

Table 16. Monetary impact of pinniped predation resulting in gear loss in the commercial and recreational salmon fisheries in Monterey Bay, California in 1997 and 1998. Estimates of the value of gear loss use average, maximum, and minimum costs for gear.

Fishery	Year	Value of Observed Gear Loss			% Fishery	Value of Total Gear Loss		
		Average ($)	Max. ($)	Min. ($)	Sampled	Average ($)	Max. ($)	Min. ($)
Commercial	1997	3,257	4,453	2,192	5.93	54,900	75,056	36,946
	1998	6,530	8,778	4,551	10.78	60,570	81,426	42,211
Recreational*	1997	1,130	1,818	565	6.29	17,975	28,904	8,986
	1998	1,889	3,232	839	15.63	12,089	18,858	7,194

* Recreational Fishery includes CPFV and private skiffs

Table 17. Gear types and average, maximum, and minimum estimates of gear cost ($) lost during pinniped predation in the commercial and recreational fisheries in Monterey Bay, California during 1997 and 1998.

Gear type	Commercial Fishery			Recreational Fishery		
	Average ($)	Max. ($)	Min. ($)	Average ($)	Max. ($)	Min. ($)
Flasher	6.84	10.00	5.00	7.71	9.95	4.95
Hoochie (incl. hook, swivel, and skirt)	2.00	2.50	1.50	2.49	3.00	2.00
Spoon (incl. hook)	2.92	4.00	1.50	4.75	5.95	3.50
Plugs or Lures	3.40	5.00	1.00	10.33	11.50	9.50
Cable Baiter or crowbar hook	1.86	2.25	1.25	2.50	2.99	2.00
Weights or lead (avg. 4-8 oz. weight)	-	-	-	0.99	1.38	0.60
Leader	-	-	-	1.25	1.50	1.00
Hooks	-	-	-	0.69	1.00	0.38
Mooching set-up (used in rec. fish.)	-	-	-	2.71	1.09	5.00

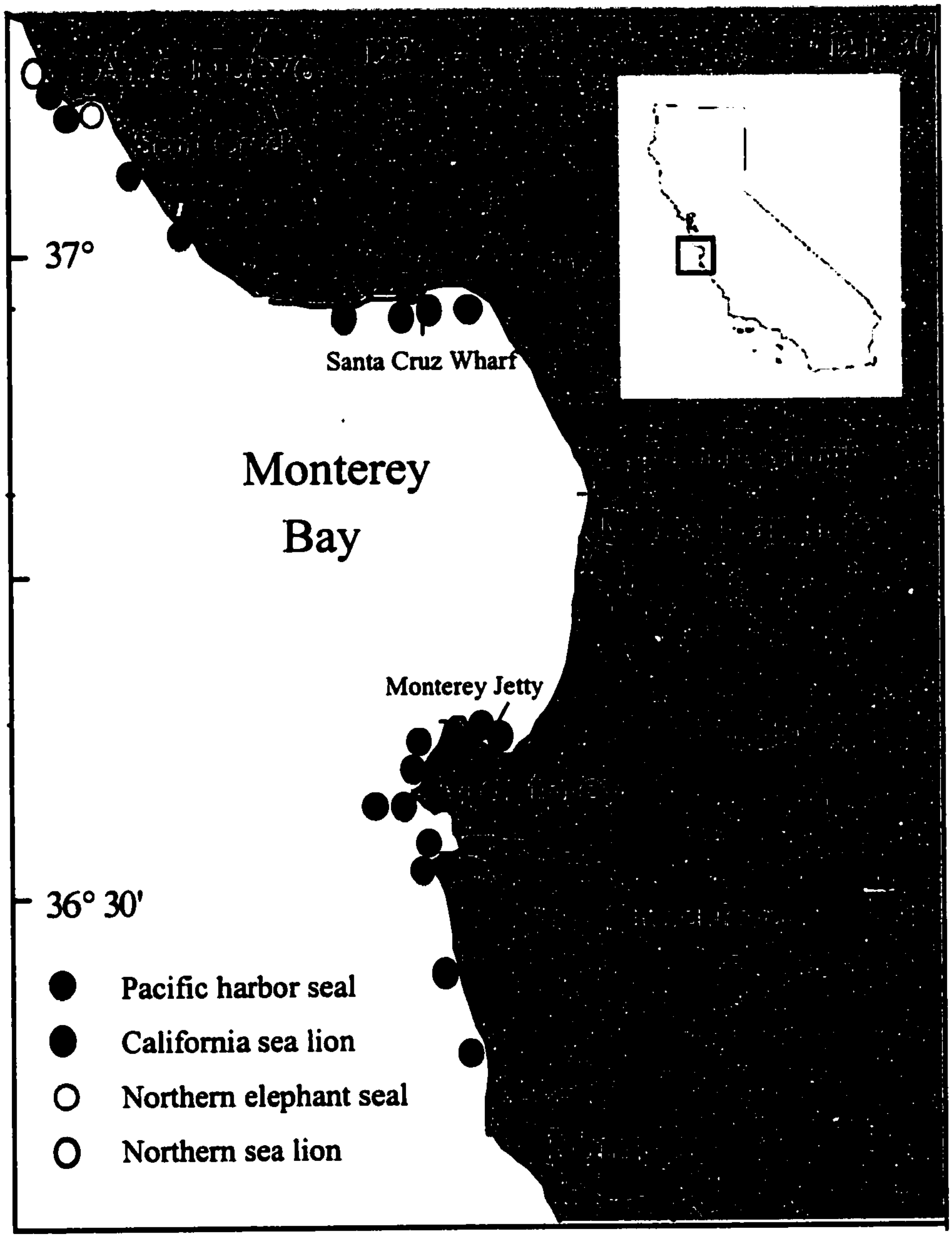

Figure 1. Pinniped haul-out sites and main ports in Monterey Bay, California. Fecal samples were collected at the Santa Cruz Wharf and the Monterey jetty during 1997 and 1998.

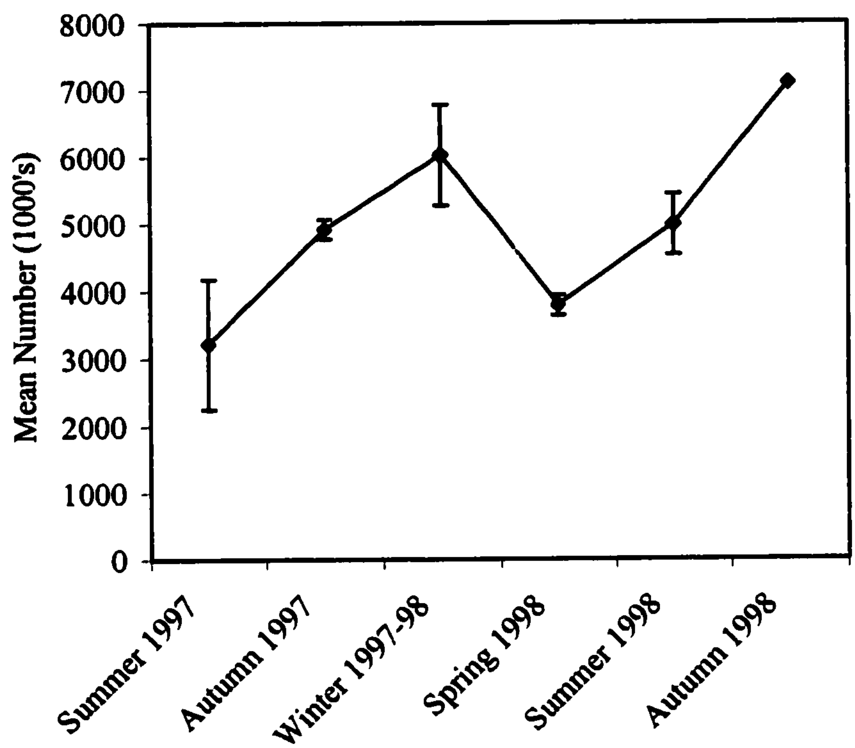

Figure 2. Seasonal mean abundance of California sea lions at haul-out site in Monterey Bay, California during 1997 and 1998. Error bars indicate one standard error.

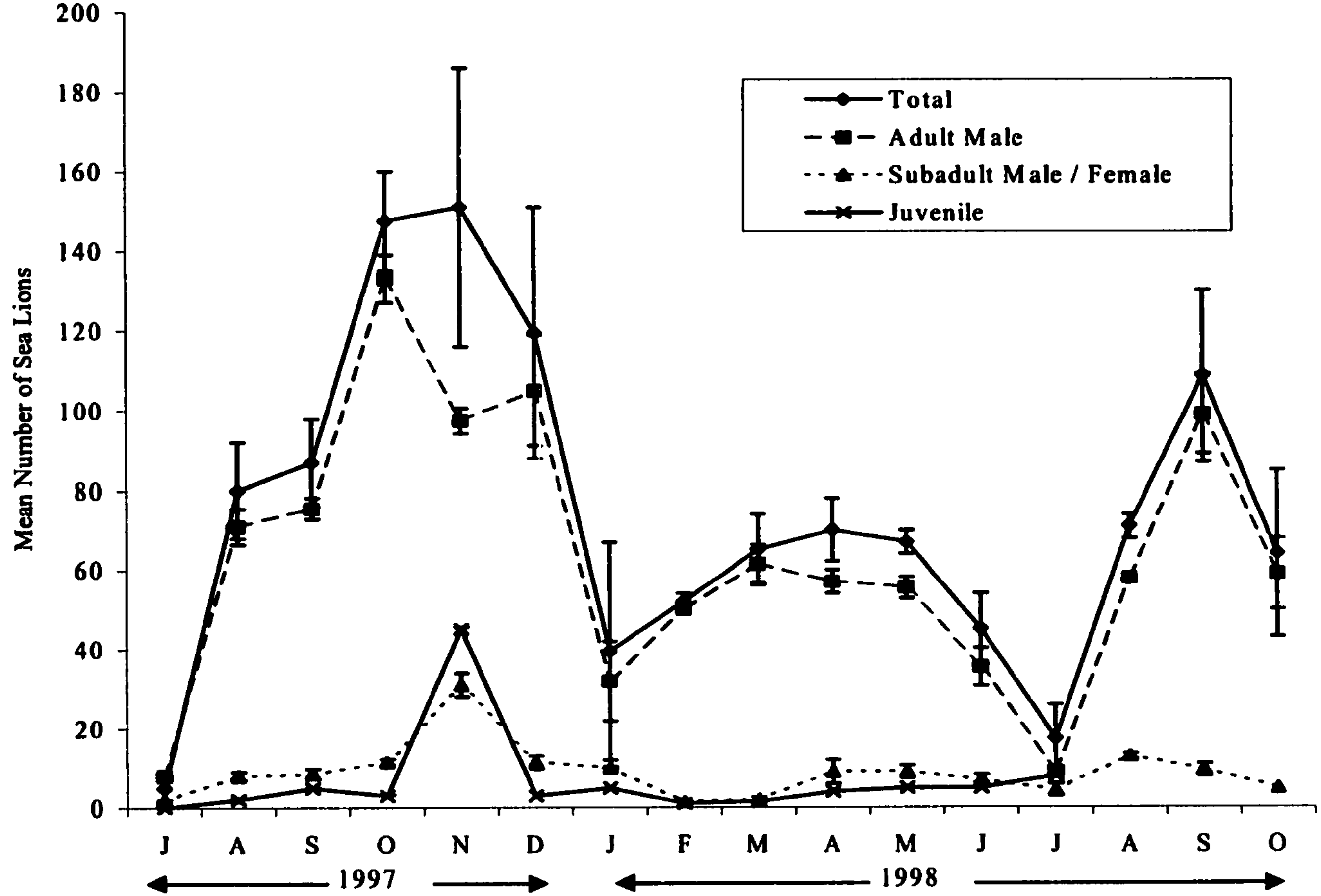

Figure 3. Monthly mean number of adult male, sub-adult male/female, and juvenile California sea lions at the Santa Cruz wharf based on 33 land-based surveys conducted from July 1997 to October 1998. Error bars indicate one standard error.

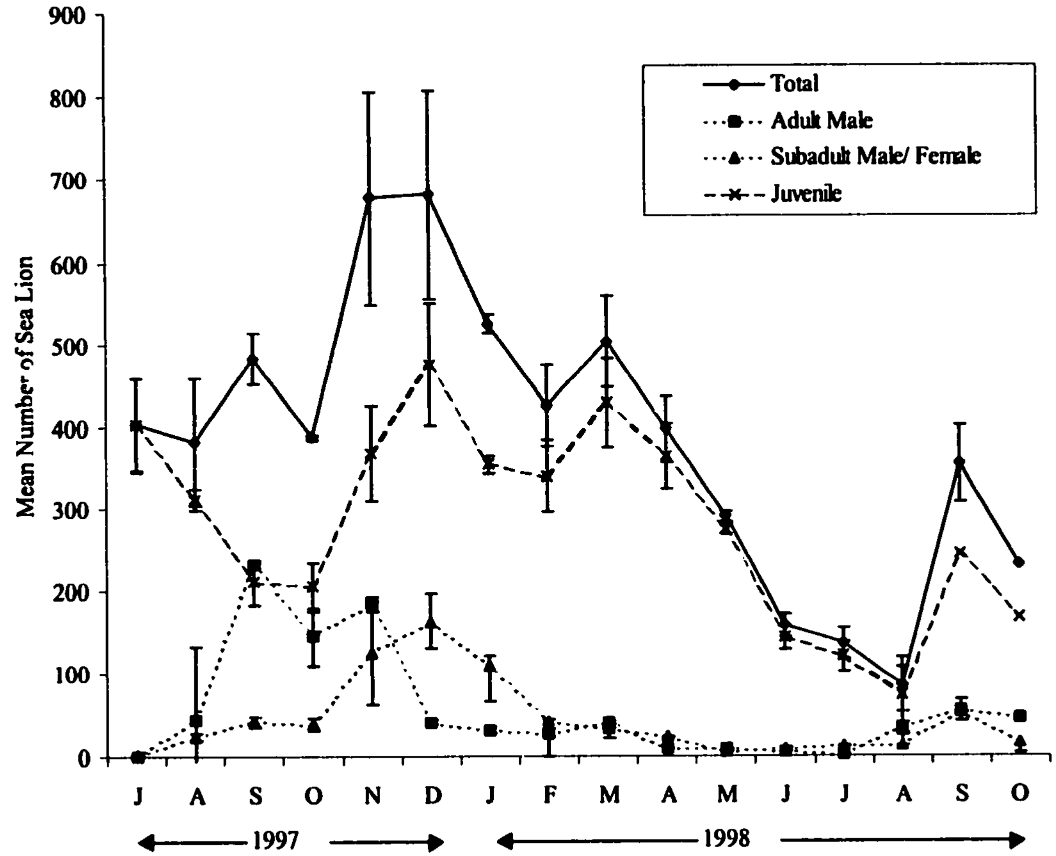

Figure 4. Monthly mean number of adult male, sub-adult male/female, and juvenile California sea lions at the Monterey jetty based on 33 land-based surveys conducted from July 1997 to October 1998. Error bars indicate one standard error.

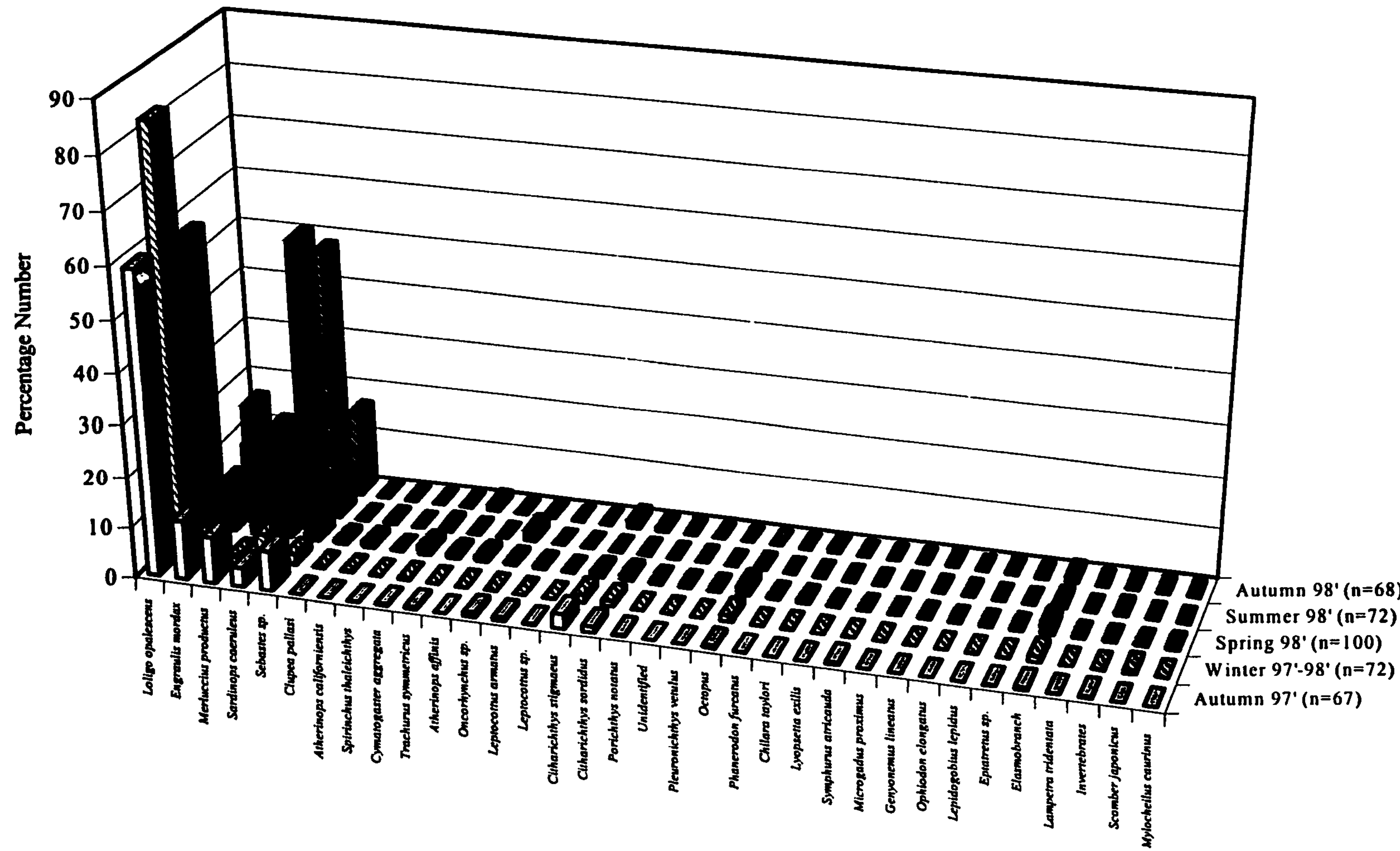

Figure 5. Comparison among seasons of percentage number of prey species identified in California sea lion fecal samples collected in Monterey Bay, California in 1997 and 1998.

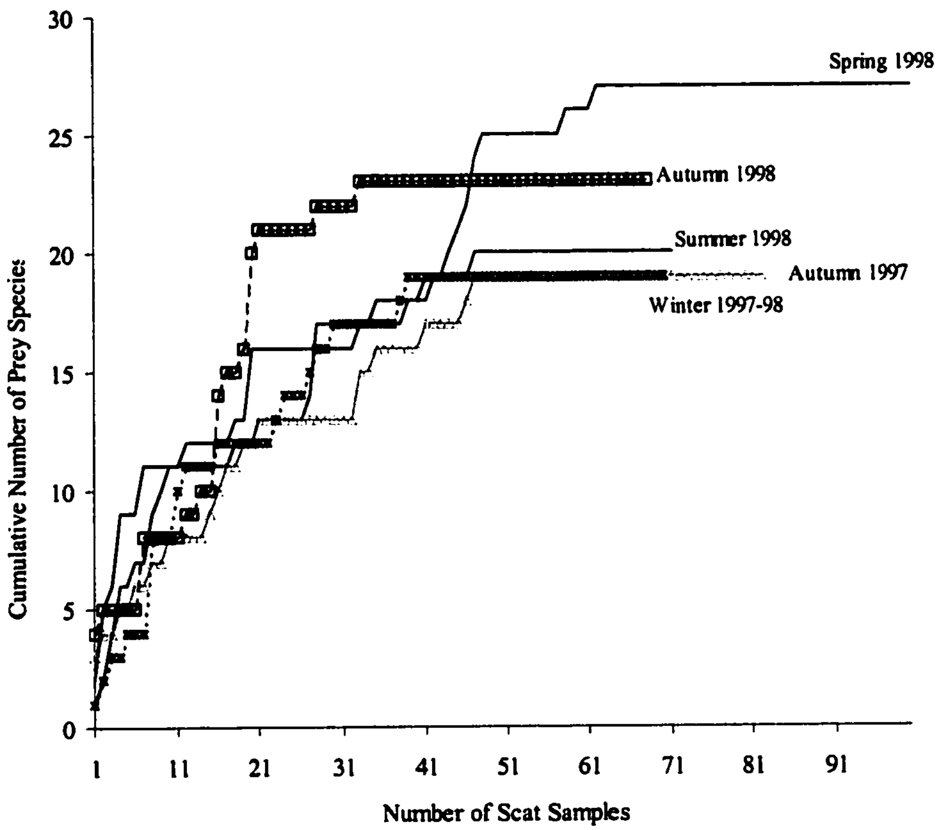

Figure 6. Cumulative number of prey species per fecal sample collected during autumn 1997, winter 1997-98, spring 1998, summer 1998, and autumn 1998 in Monterey Bay, California.

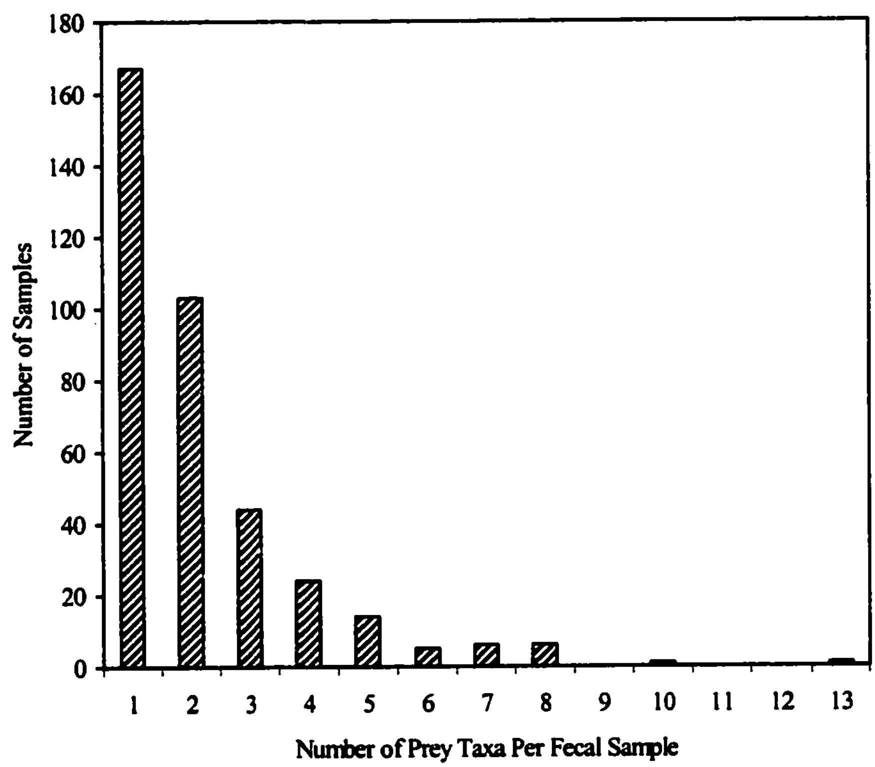

Figure 7. Frequency of number of prey taxa per California sea lion fecal sample collected in Monterey Bay during 1997 and 1998.

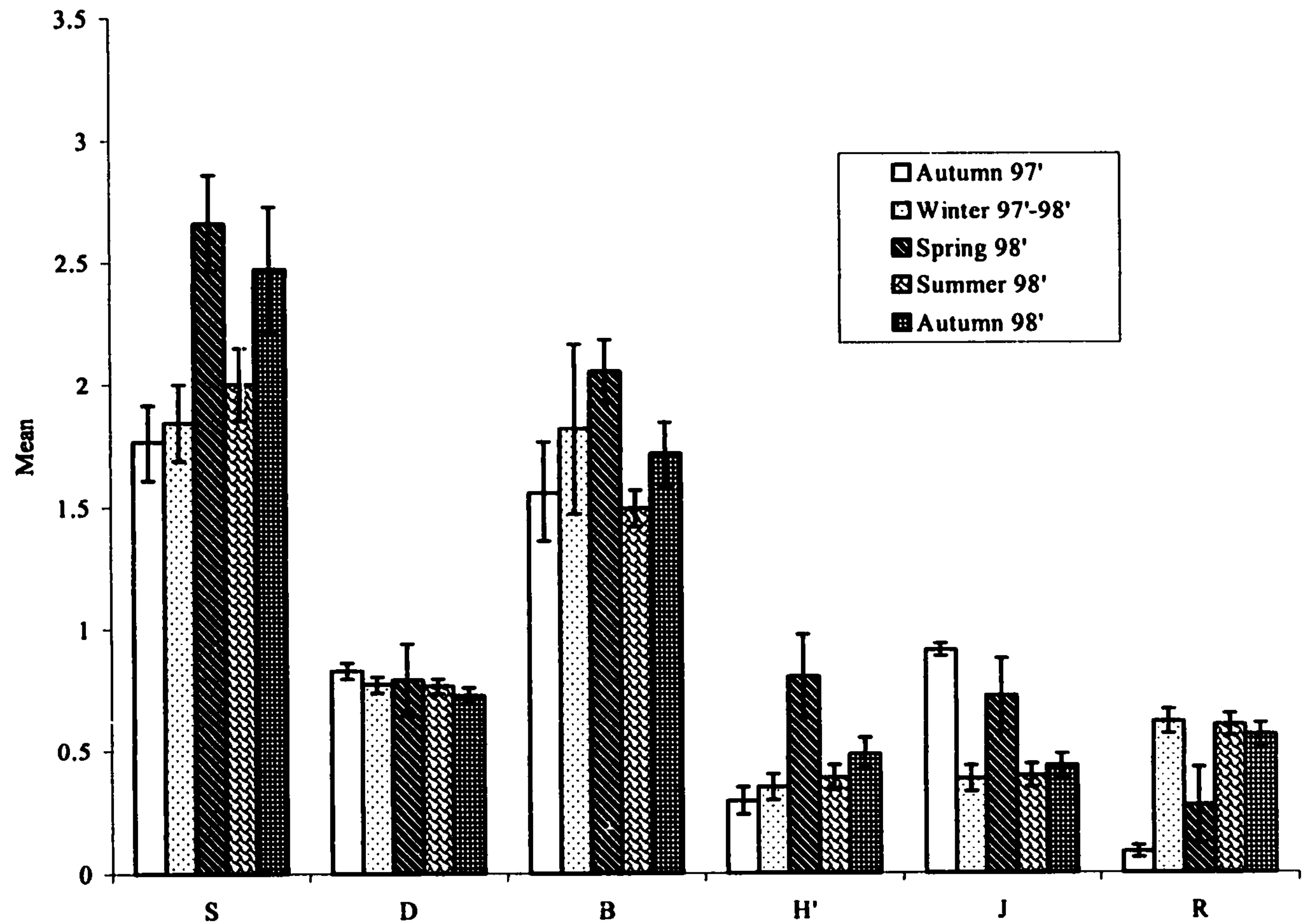

Figure 8. Mean seasonal variation of prey array indices calculated from California sea lion fecal samples collected in Monterey Bay, California during 1997 and 1998.

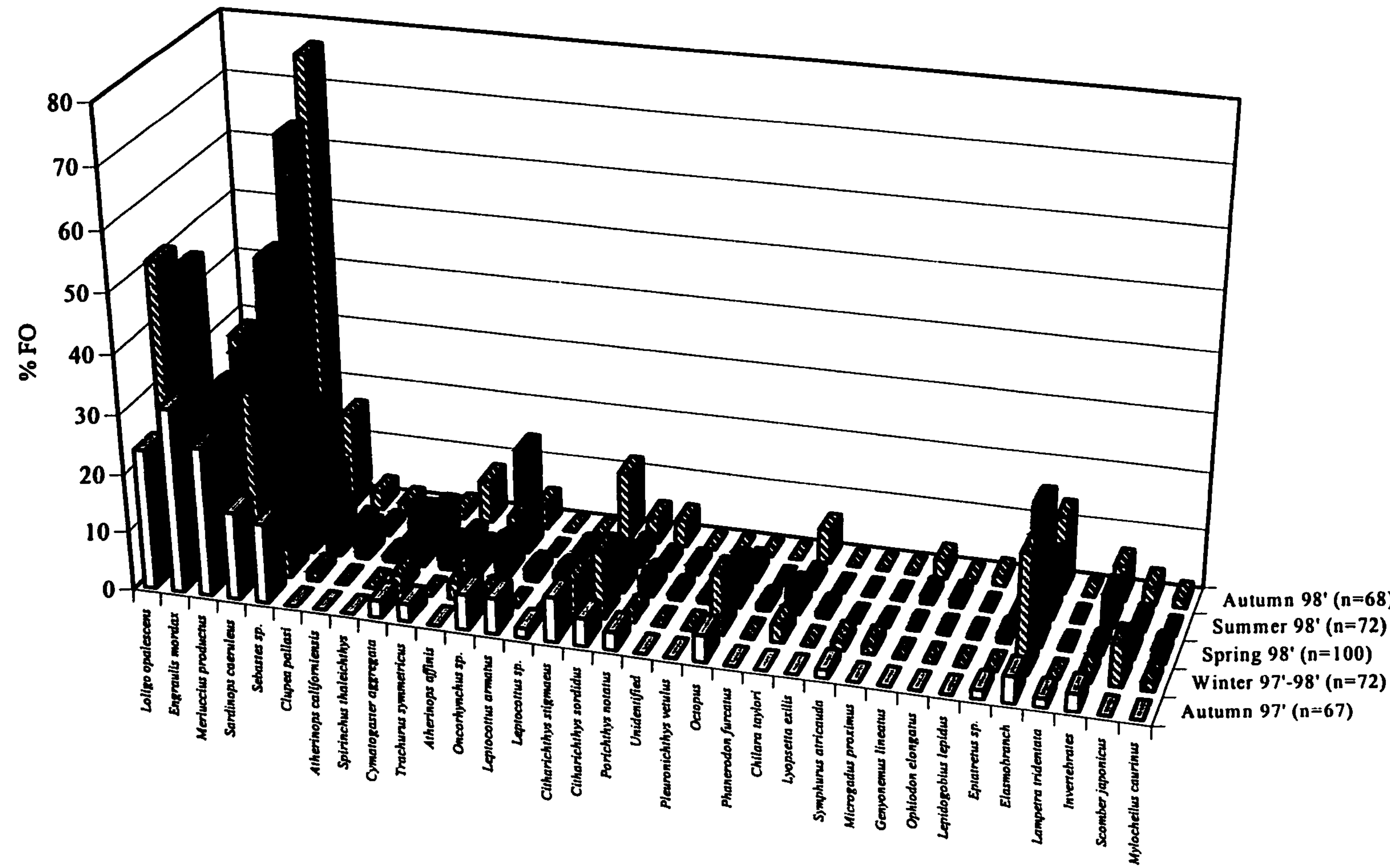

Figure 9. Comparison among seasons of percentage frequency occurrence of prey species identified in California sea lion fecal samples collected in Monterey Bay, California in 1997 and 1998.

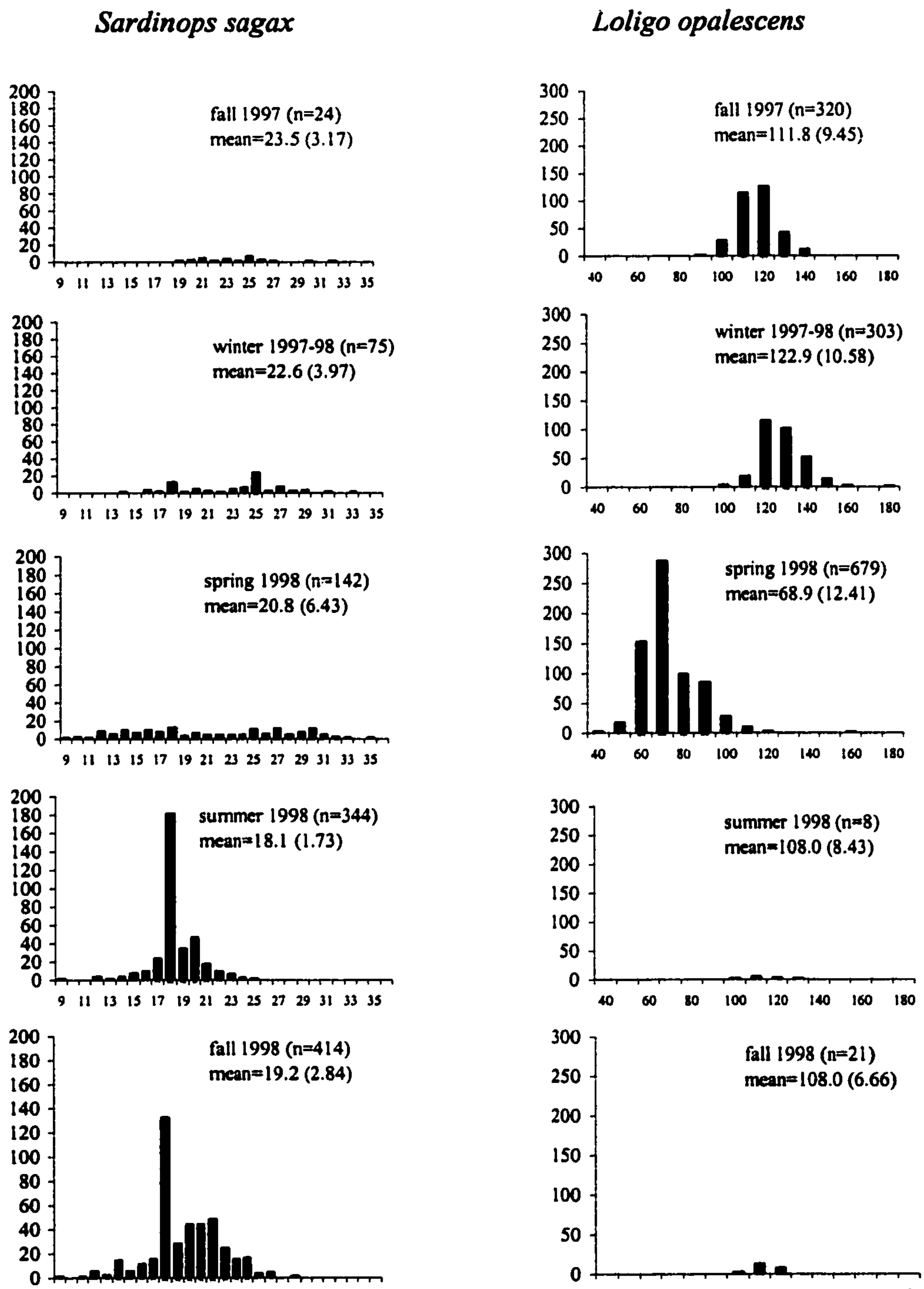

Figure 10. Frequency histograms of estimated length of *S. caeruleus* (in cm) and *L. opalescens* (in mm) recovered from California sea lion fecal samples collected in Monterey Bay, California in 1997 and 1998. Standard deviation given in parenthesis

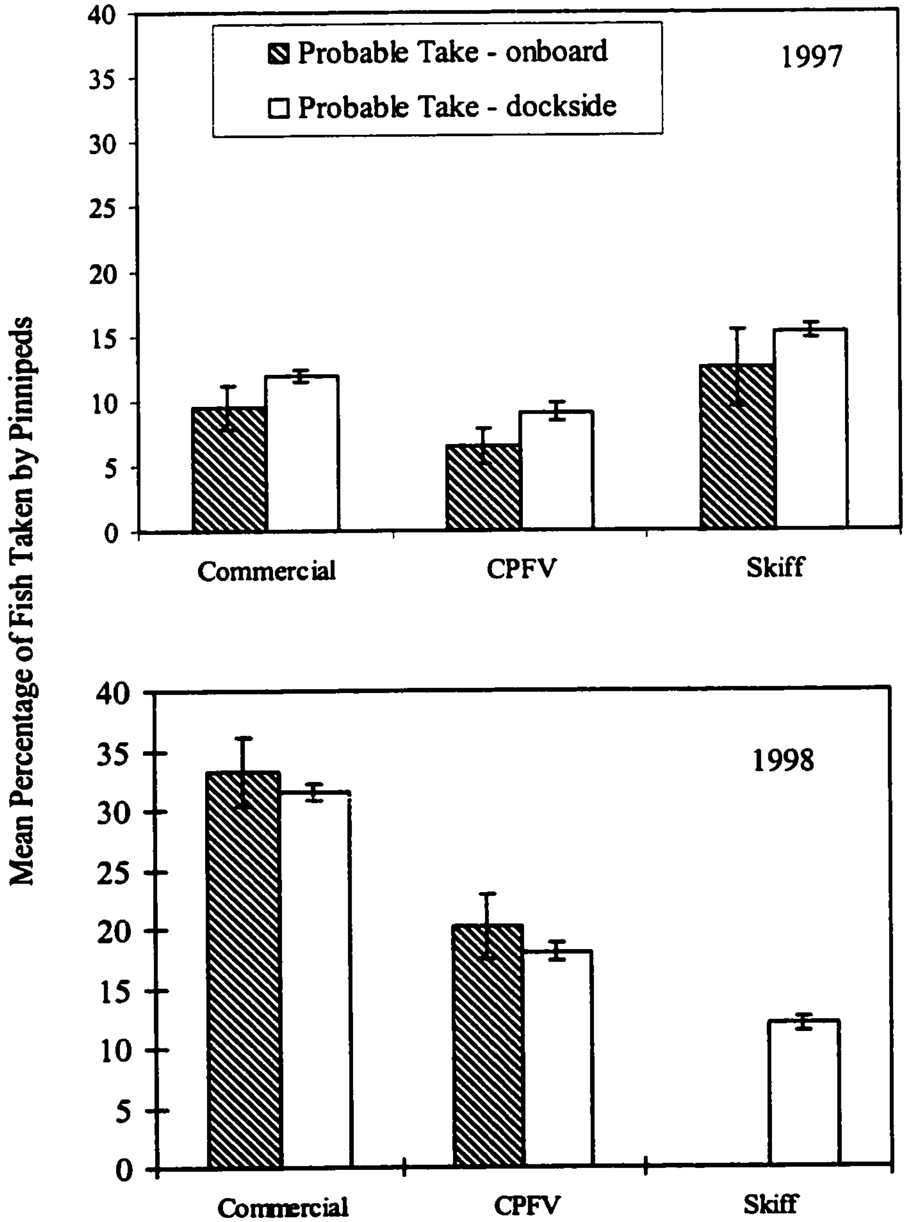

Figure 11. Mean percentage of fish taken by pinnipeds during onboard and dockside surveys in commercial, CPFV, and skiff fisheries in Monterey Bay, California in 1997 and 1998. Error bars indicate one standard error. Skiffs were not surveyed onboard during 1998.

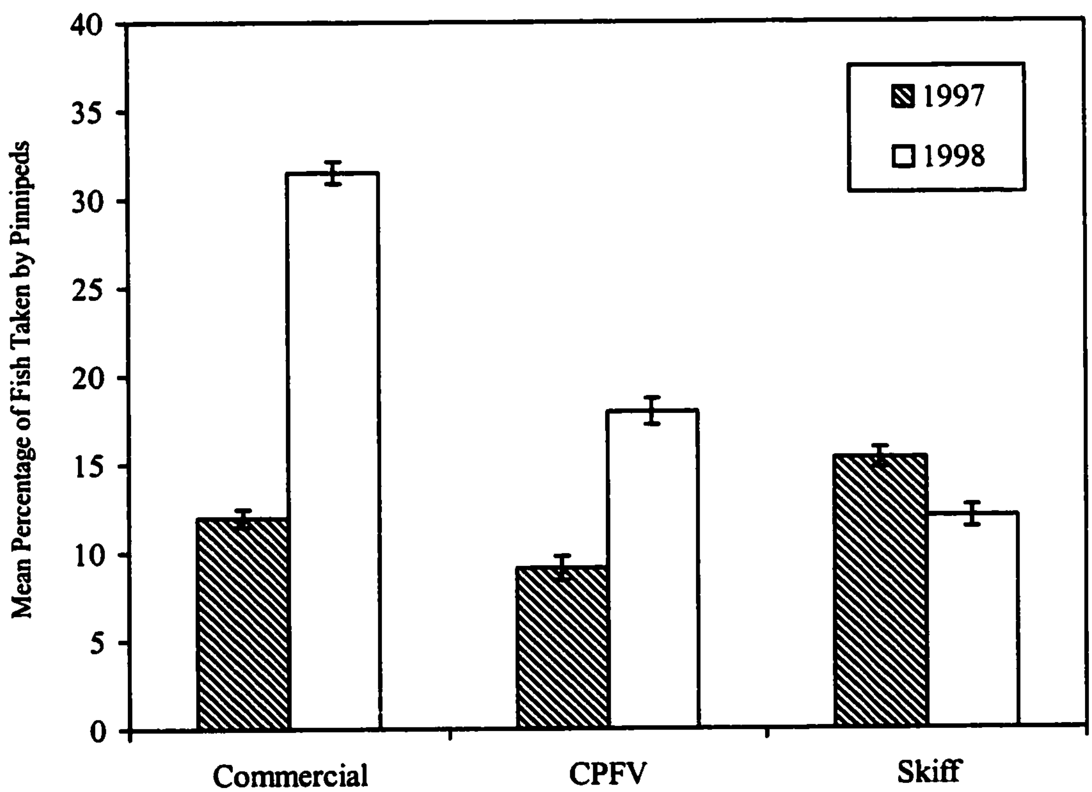

Figure 12. Mean percentage of fish taken by California sea lions in Monterey Bay, California for commercial, CPFV, and skiff fisheries during 1997 and 1998. Error bars indicate one standard error.

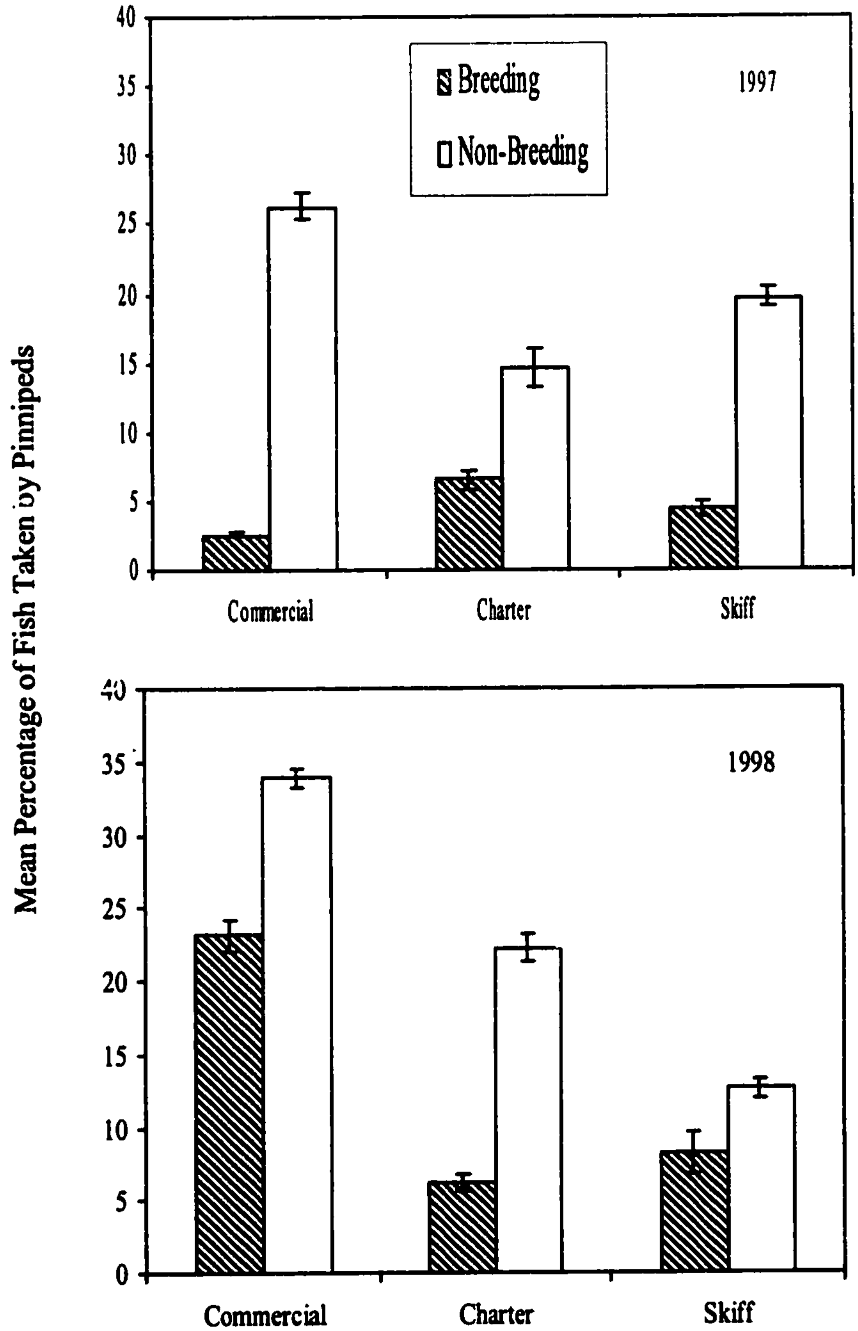

Figure 13. Mean percentage of fish taken by pinnipeds in commercial, CPFV, and skiff fisheries in Monterey Bay during California sea lion breeding and non-breeding seasons in 1997 and 1998. Error bars indicate one standard error.

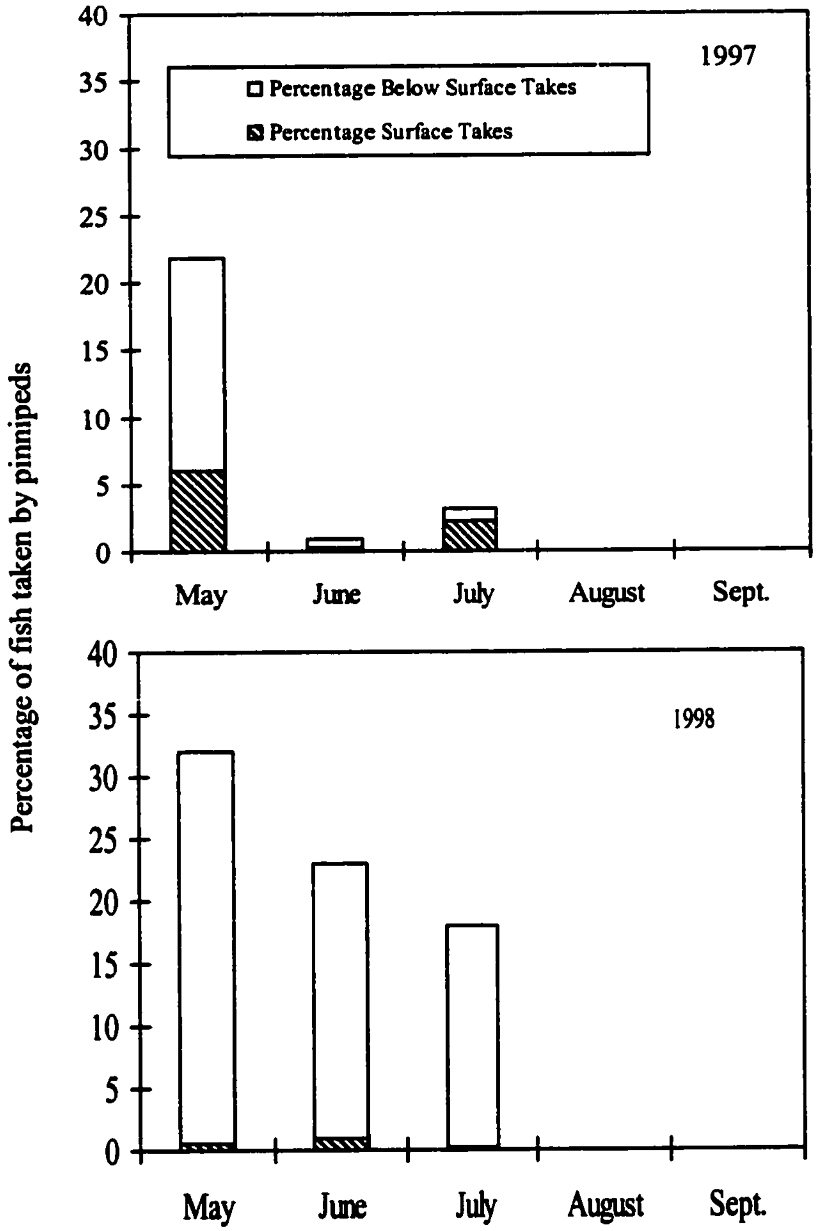

Figure 14. Percentages of fish taken by pinnipeds at surface and below surface in the commercial fishery in Monterey Bay during 1997 and 1998.

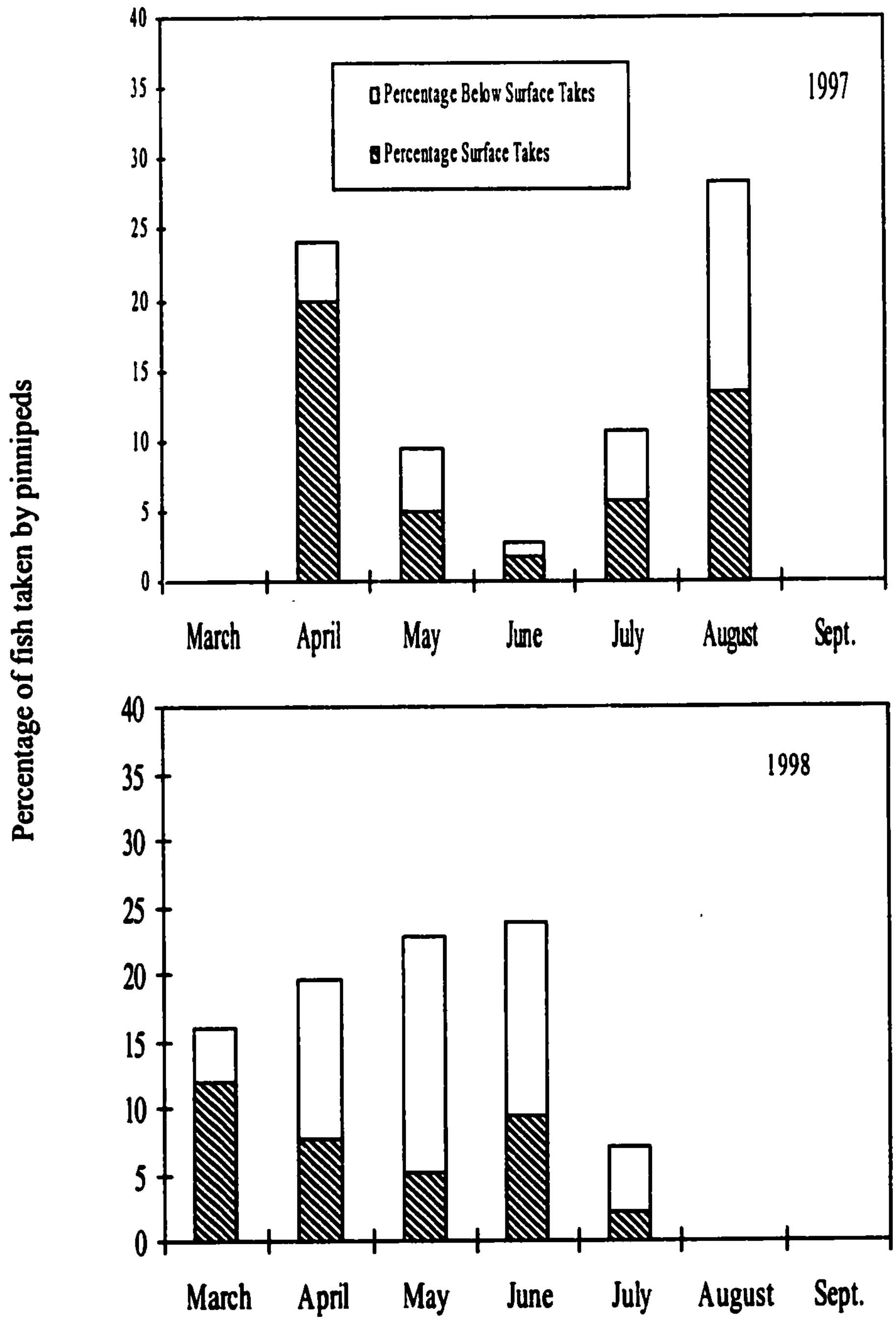

Figure 15. Percentages of fish taken at surface and below surface in the CPFV fishery in Monterey Bay, California in 1997 and 1998.

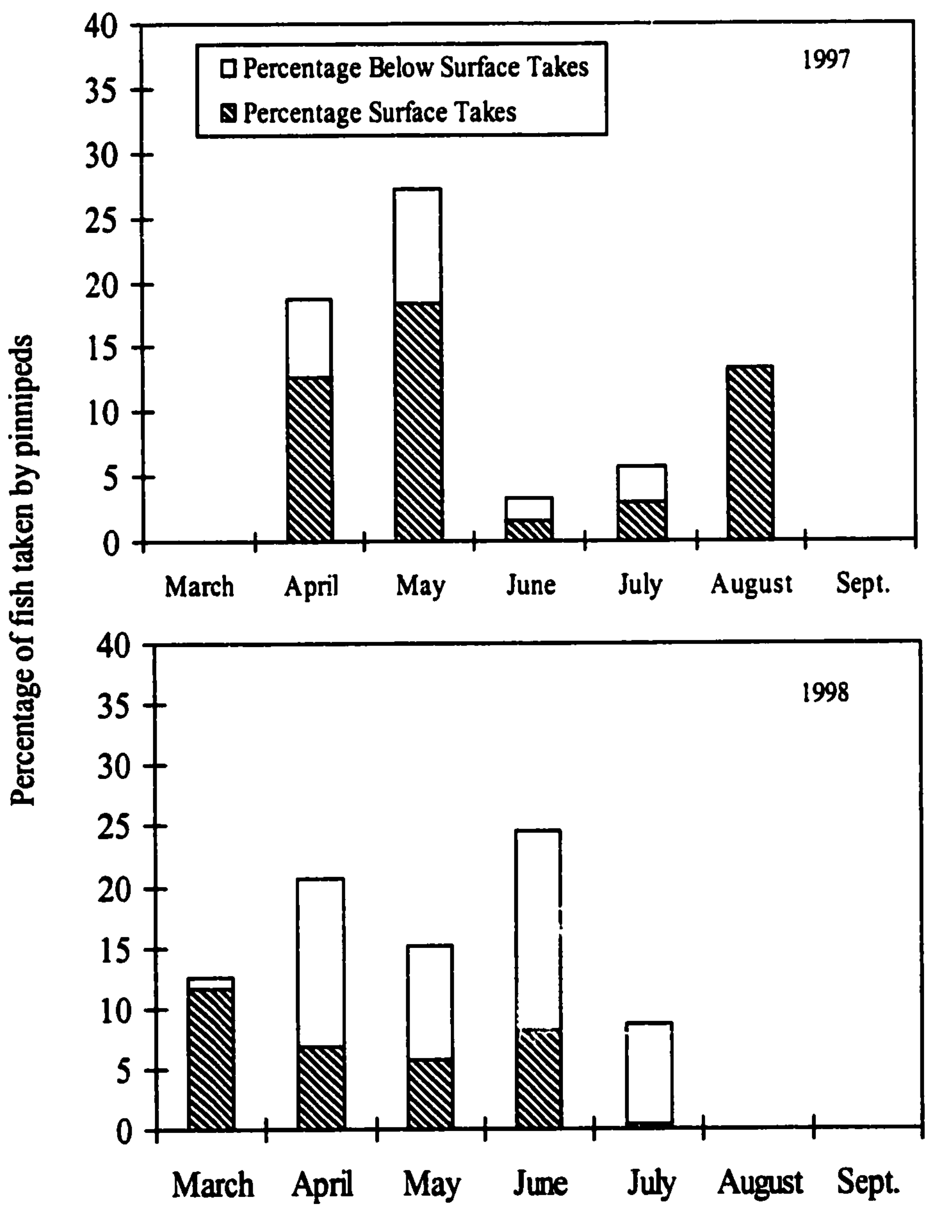

Figure 16. Percentages of fish taken at surface and below surface in the skiff fishery in Monterey Bay, California in 1997 and 1998.

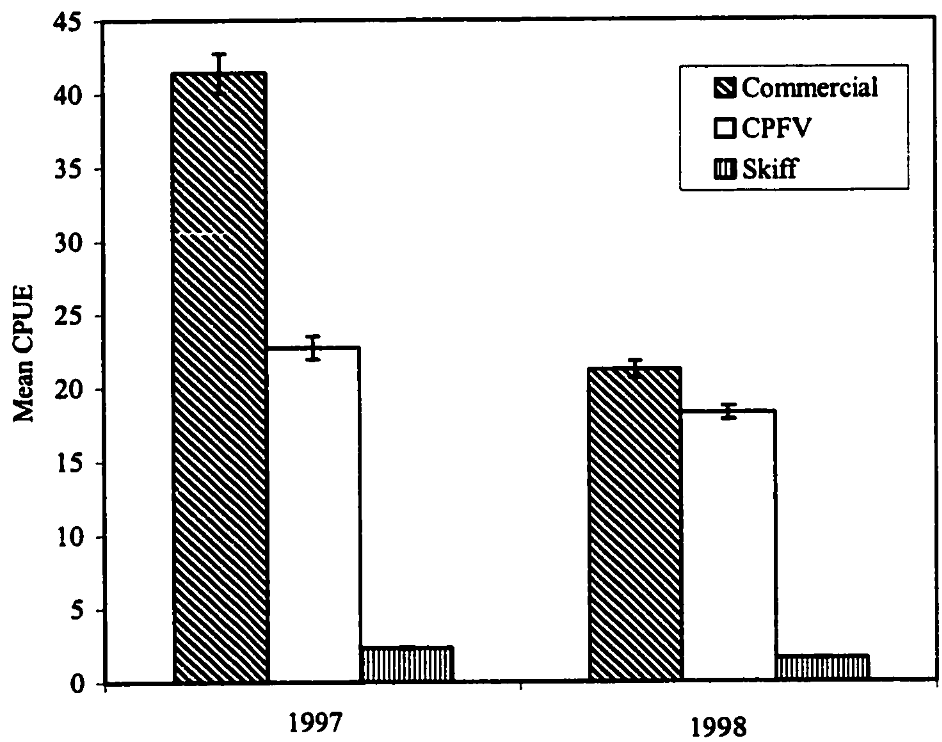

Figure 17. Mean catch per unit of effort (mean number of fish caught per day) in commercial, CPFV, and skiff fisheries in Monterey Bay, California during 1997 and 1998. Error bars indicate one standard error.