Abstract—To assess the impact of California sea lions (*Zalophus californianus*) on salmon fisheries in the Monterey Bay region of California, the percentages of hooked fish taken by sea lions in commercial and recreational salmon fisheries were estimated from 1997 to 1999. Onboard surveys of sea lion interactions with the commercial and recreational fisheries and dockside interviews with fishermen after their return to port were conducted in the ports of Santa Cruz, Moss Landing, and Monterey. Approximately 1745 hours of onboard and dockside surveys were conducted—924 hours in the commercial fishery and 821 hours in the recreational fishery (commercial passenger fishing vessels [CPFVs] and personal skiffs combined). Adult male California sea lions were responsible for 98.4% of the observed depredations of hooked salmon in the commercial and recreational fisheries in Monterey Bay. Mean annual percentages of hooked salmon taken by sea lions ranged from 8.5% to 28.6% in the commercial fishery, 2.2% to 18.36% in the CPFVs, and 4.0% to 17.5% in the personal skiff fishery. Depredation levels in the commercial and recreational salmon fisheries were greatest in 1998—likely a result of the large El Niño Southern Oscillation (ENSO) event that occurred from 1997 to 1998 that reduced natural prey resources. Commercial fishermen lost an estimated \$18,031–\$60,570 of gear and \$225,833–\$498,076 worth of salmon as a result of interactions with sea lions. Approximately 1.4–6.2% of the available salmon population was removed from the system as a result of sea lion interactions with the fishery. Assessing the impact of a growing sea lion population on fisheries stocks is difficult, but may be necessary for effective fisheries management.

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Impact of the California sea lion (*Zalophus californianus*) on salmon fisheries in Monterey Bay, California

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California sea lions (*Zalophus californianus*) interact with almost all commercial and recreational fisheries along the California coast, causing entanglement and damage to fishing gear and loss of catch (Beeson and Hanan[1]; NMFS[2]). The prey of these pinnipeds has been of interest for years because pinnipeds have been viewed as competitors with humans for a variety of fish species. Historically, this competition between pinnipeds and fishermen was of limited importance because fishes and pinnipeds were harvested. However, the increasing specialization within the fishing industry during the twentieth century and changing attitudes toward pinnipeds have intensified this competition (Harwood and Croxall, 1988). Since the passage of the Marine Mammal Protection Act (MMPA) in 1972, the population of California sea lions has increased along the West Coast of North America (NMFS[2]). This increase in pinniped populations has resulted in an increase in the number of reports of pinnipeds interacting with fishing boats and depredating the catch in fisheries along the West Coast (Beeson and Hanan[1]; NMFS[2]).

The California sea lion population, found from offshore islands in Mexico north to Vancouver Island, British Columbia, has increased steadily throughout the latter part of the twentieth century (NMFS[2]). In the early 1900s, 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). Numbers of sea lions began to increase in the 1940s with curtailment of commercial harvests, but bounties were paid for seals and sea lions in Oregon and Washington until the early 1970s. Following passage of the MMPA in 1972, the California sea lion population increased at an annual average of 5.0–6.2% along the West Coast (Carretta et al.[3]). There are an estimated 204,000–214,000 sea lions in U.S. waters (Carretta et

[1] Beeson, M. J., and D. A. Hanan. 1996. An evaluation of pinniped-fisheries interactions in California. Report to the Pacific States Marine Fisheries Commission, 46 p. Pacific States Marine Fisheries Commission, 205 SE Spokane St., Portland, OR 97202.

[2] NMFS (National Marine Fisheries Service). 1997. Impacts of California sea lions and Pacific harbor seals on salmonids and the coastal ecosystems of Washington, Oregon, and California. NOAA Tech. Memo. NMFS-NWFSC-28, 150 p. Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097.

[3] Carretta, J. V., M. M. Muto, J. Barlow, J. Baker, K. A. Forney, and M. Lowry, editors. 2002. U.S. Pacific Marine Mammal Stock Assessments: 2002. NOAA/NMFS Tech. Memo., NOAA-TM-NMFS-SWFSC-346, 290 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, California 92037-1508.

al.[3]), and an additional 45,000–54,000 animals along Baja, Mexico (Aurioles-Gamboa and Zavala-Gonzalez, 1994). In the Monterey Bay region, sea lions do not breed but several important resting sites exist with a range of 3000 to 7500 animals during the nonbreeding season (Weise, 2000). 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 in riverine habitat, declines in water quality, overharvesting, changes in oceanic conditions, and the development of hydroelectric power systems that obstruct major riverine migration routes.

Chinook salmon (*Oncorhynchus tshawytscha*) stocks in the Central Valley of California probably represent 85% to 95% of the chinook salmon catches south of Pt. Arena and in Monterey Bay (PFMC[4]). Central Valley chinook originate in the Sacramento River and San Joaquin River and have 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 as endangered under the Endangered Species Act (ESA). Salmon landed in Monterey Bay during the summer fishing season are predominantly fall and late-fall run Central Valley chinook salmon. Size limits and seasonal restrictions are set to reduce retention of listed winter run Central Valley chinook and Klamath River stocks (PFMC[4]). By taking hooked fish, sea lions can affect salmon stocks because commercial and recreational fishermen continue to fish for salmon to replace those taken by sea lion and this activity of predation and compensatory fishing leads to greater numbers of fish being removed from the population. In the ocean commercial troll and recreational salmon fishery, sea lions will swim near or follow fishing boats and will depredate fish once hooked.

Consumption of hooked salmon by sea lions may not only impact salmonid stocks but impact 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[5]). Concern over declining salmonid stocks has resulted in adjustments of fishing regulations, such as allocation of harvest between ocean and inland user groups, harvest quotas, and time and area closures (Beeson and Hanan[1]). Increasing losses of fish to California sea lions may produce further restrictions for the recreational and commercial salmon fisheries.

[4] PFMC (Pacific Fisheries Management Council). 1999. Review of 1998 ocean salmon fisheries. NOAA Award No. NA97FC0031, sections A1–A50 and B1–43. Pacific Fisheries Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

[5] PFMC (Pacific Fisheries Management Council). 1995. Review of 1994 ocean salmon fisheries. NOAA No. NA57FC0007, sections A1–A50 and B1–B43. Pacific Fisheries Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

During the last several decades only a few researchers have attempted to quantify the impact of sea lions on fisheries in California waters and, more specifically, the Monterey Bay region. According to Beeson and Hanan,[1] the recreational ocean salmon landings in 1995 were greatest in Monterey Bay and San Francisco areas and experienced the greatest amount of sea lion predation (charter passenger fishing vessels and private skiff combined). In our study, we surveyed salmon fisheries in Monterey Bay because of the particularly high rates of interactions with sea lions (Beeson and Hanan[1]) in an effort to better understand the nature and extent of these interactions in the commercial and recreational fisheries.

The purpose of this study was to estimate the percentage of salmon taken by California sea lions from commercial and recreational salmon fisheries in Monterey Bay from 1997 to 1999. We hypothesized that the percentages of fish taken by California sea lions in salmon fisheries would be greater than those taken in previous years and would be part of an increasing trend in sea lion and fisheries interactions paralleling the growth of the sea lion population. Further, we estimated the number of fish removed from the California Central Valley chinook stock from observed percentages of fish taken by sea lions in fisheries. Lastly, we estimated the monetary losses associated with sea lions interacting with commercial and recreational salmon fisheries in Monterey Bay from 1997 to 1999 by quantifying the value of fish lost and the type and amount of gear lost or damaged.

Methods

From 1997 to 1999, observations of interactions between pinnipeds and salmon fisheries were conducted onboard boats, and interviews with fishermen were performed at dockside at the three major ports in the Monterey Bay region: Santa Cruz, Moss Landing, and Monterey (Fig. 1). Salmon fishing operations included commercial troll fishery and recreational fisheries consisting of commercial passenger fishing vessels (CPFVs) and private skiffs. The timing of the commercial and recreational salmon fishery seasons varied each year of the study, and sampling was conducted from the beginning to the end of each season (Table 1). The commercial troll fishery included day boats (i.e., a one-day fishing trip) and multiple-day boats. Fishing areas included in our study ranged from Pt. Sur north to Año Nuevo Island. Data regarding fisheries interactions collected at the three different ports were pooled because fishermen from all three ports often fish as a fleet.

Dockside surveys were conducted to achieve a greater sampling effort than could be obtained from onboard observations alone. 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

Table 1

Commercial and recreational salmon fishery seasons in the Monterey Bay region from 1997 to 1999.

	Commercial	Recreational
1997	1–31 May, 23 June–18 July, 1–30 September	15 March–19 October
1998	1–31 May, 16 June–30 September	14 March–7 September
1999	1 May – 21 August, 1–30 September	14 March–6 September

onboard sampling in areas where interaction was more prevalent (Miller et al.[6]). During this study, captains were requested during onboard observations to conduct normal fishing operations and not to intentionally seek out areas with greater or lesser rates of interaction between sea lions and fishery operations.

Sampling of commercial and recreational salmon fisheries was stratified by month and approximately equal numbers of onboard and dockside surveys were 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. Each onboard survey in the commercial fishery took a full fishing day onboard one boat, and dockside interviews were conducted during four-hour periods in the middle to late afternoon during the peak time that vessels returned 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 took a full fishing day aboard one vessel, and dockside surveys took 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 (for the sampling day) all CPFVs targeting salmon and that had returned to port. In the skiff fishery, greater numbers of fishing trips occurred on weekends; therefore approximately three-quarters of sampling days occurred on weekends, and one-quarter occurred on weekdays. Onboard surveys in 1997 aboard one skiff took a full fishing day, and dockside surveys from 1997 to 1999 were conducted during two-hour sampling periods in late morning and early afternoon during the peak return time for private skiffs.

In 1997, four onboard surveys were conducted in the commercial and CPFV fishery, and five onboard private skiff surveys were conducted. Whereas in 1998 and 1999, in an effort to increase onboard sample size, survey effort was concentrated in the commercial and CPFV fisheries; 22 surveys conducted each year in each fishery.

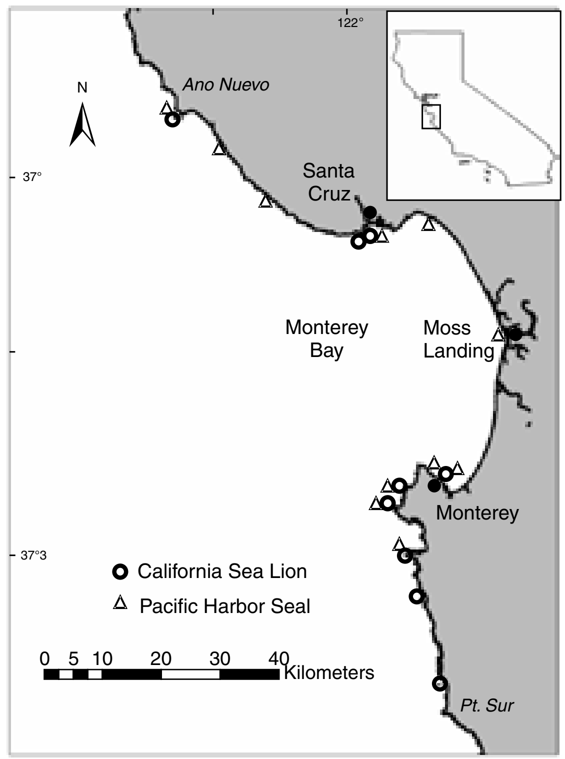

Figure 1

Primary fishing ports used by commercial and recreational salmon vessels, and pinniped haul-out sites in Monterey Bay, California.

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

Commercial troll and recreational salmon fisheries use different types of fishing gear, which can affect the nature and magnitude of their interactions with pinnipeds. Commercial salmon trolls are designed to catch fast-swimming fishes by using flashy lures that are trolled behind the moving vessel on heavily

[6] Miller, D. J., M. J. Herder, and J. P. Scholl. 1983. California marine mammal-fishery interaction study, 1979-1981. NMFS Southwest Fish. Cent., Admin. Rep. LJ-83-13C, 233 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037-1508.

weighted fishing lines. Multiple lines are mounted on outrigger poles to ensure separation of the lines and are controlled by small hydraulic winches (Starr et al., 1998). Depending on conditions, commercial fishermen use three to fifteen lures per line and two to six lines per boat, totaling six to ninety lures with hooks per boat. In recreational boats each fisherman traditionally uses one rod, reel, line, and hook with bait.

Surface takes, also termed "definite takes," were defined as takes when pinnipeds took a hooked salmon (and when the species and number of marine mammals involved could be determined). Surface takes were also 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 takes when fish were removed from the hook (and when the species and number of marine mammals involved could not observed directly). Evidence that indicated the occurrence of below-surface takes was in the form of 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. However, fishermen and researchers recognized that takes by pinnipeds, specifically by sea lions, differed from takes by sharks and other predators by the action of the line, effect on the hook or lure (or both), and type of bite on fish parts remaining on the hook.

Number of salmon and percentage of catch taken by pinnipeds were compared with the total catch and the legal catch in commercial and recreational fisheries. Total catch was defined as numbers of fish hooked, including all legal-size fish, fish taken by pinnipeds, and all undersize fish. Legal catch represented only fish of legal size landed by anglers. Our rationale for using total catch was that all fish, regardless of size, have an equal probability of being taken by pinnipeds; therefore, comparisons with total catch were a more accurate metric for quantifying the impact of pinnipeds on the salmon fishery. Comparisons with the legal catch inflated the percentage of fish taken by pinnipeds and exacerbated the perception of the problem of pinnipeds interacting with salmon fisheries. However, previous researchers have compared percentage takes by pinnipeds with legal catch; therefore we also made the comparison with legal catch to place our results in a historical context.

Mean percentages of fish taken by sea lions in relation to total catch (referred to as "mean percentage of fish taken by sea lions") for the commercial, CPFV, and skiff fisheries for onboard and dockside surveys from 1997 to 1999 were non-normal in distribution and were transformed by 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, among years (1997 to 1999), between seasons (sea lion breeding and nonbreeding seasons), and between takes (surface and below surface) using a Students t-test and ANOVA or a Mann-Whitney U-test and Kruskal-Wallis test for data that were non-normal and heteroscedastic after transformation.

Sea lion breeding and nonbreeding seasons from 1997 to 1999 were determined by using aerial and ground counts from Weise (2000). The breeding season was designated as the time when a significant decline in the number of breeding adult males was recorded at haul-out sites in the Monterey Bay region, when animals where presumably heading for the breeding rookeries in southern California. Typically the breeding season is from June and July, and the nonbreeding season occurs during the months of March, April, May, August, and September.

Mean catch per unit of effort, or the numbers of fish hooked per day per boat, in commercial, CPFV, and skiff fisheries data were non-normal and heteroscedastic, therefore, were they were transformed by using $\sqrt{count+1}$ (Harvey, 1987; Zar, 1996). Mean catch per unit of effort for the three fisheries was compared among years with an ANOVA.

To estimate the impact of California sea lion depredation on salmon populations in Monterey Bay we compared estimated numbers of hooked salmon taken by sea lions and the Central California Valley index (CVI) for chinook salmon abundance. The CVI is the numbers of ocean- and inland-harvested Chinook salmon and the sum of all runs of chinook on the Sacramento Rivers (PFMC[4]) and represents presumably the population of salmon passing through the Monterey Bay region during the fishery season. The estimated number of salmon taken was calculated from the observed number of takes in the commercial and recreational fishery multiplied by the percentage of the total catch that was sampled. Percentage of the total catch sampled was estimated by dividing the number of observed legal-size fish landed by the total number of legal-size fish landed (CDF&G, unpubl. data[7]).

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 loses was collected during dockside and onboard surveys for commercial and recreational salmon fisheries.

Annual monetary losses resulting from fish taken by sea lions were calculated by using total numbers of estimated takes by sea lions, average dressed mass (mass of gutted and cleaned fish) of salmon landed in Monterey from 1997 to 1999, and average exvessel price (wholesale price per pound of fish paid to fishermen) for chinook salmon in California from 1997 to 1999 (PFMC[4]). Estimated numbers of takes by sea lions in Monterey Bay from 1997 to 1999 were a function of

[7] CDF&G (California Department of Fish and Game). 2004. Ocean Salmon Project database. CDF&G Ocean Salmon Project, 475 Aviation Blvd., Suite 130, Santa Rosa, CA 95403.

numbers of observed takes (based on dockside samples) and proportions of the total catch sampled.

Estimates of lost and damaged gear were calculated by using average costs for each type of gear used in commercial and recreational salmon fishing operations. A survey of the 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 fishermen from the three ports in Monterey Bay. Commercial fishermen buy the majority of their gear in bulk, and often by mail order to reduce costs.

Results

From 1997 to 1999, 1745 hours of onboard surveys and dockside interviews were conducted in the commercial and recreational salmon fisheries. In 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. In 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. During 1999, 704 hours of onboard and dockside surveys were conducted, 410 hours in the commercial fishery, 258 hours in the CPFV fishery, and 36 hours in the skiff fishery. Increased sampling effort in 1998 and 1999 were the result of increased onboard survey effort in the commercial and CPFV fisheries.

During this study 101 onboard surveys and 2780 dockside interviews (number of boats sampled) were conducted in the commercial and recreational salmon fisheries. There were no significant differences in mean percentages of fish taken by sea lions between onboard and dockside surveys in the commercial (1997, P=0.329; 1998, P=0.623; 1999, P=0.653), CPFV (1997, P=0.276; 1998, P=0.660; 1999, P=0.327) and skiff fisheries (1997, P=0.052; Fig. 2). We assumed, therefore, that dockside surveys provided a representative measure of pinniped takes in the salmon fisheries and onboard survey data were pooled with dockside interview data for subsequent analysis.

A total of 967 interviews with commercial fishermen and 1813 interviews with recreational fishermen were were conducted at dockside in Monterey Bay, accounting for 41,895 and 15,115 hooked salmon, respectively (Table 2). In the commercial fishery a similar number of interviews were conducted in 1997 and 1998, whereas in 1999 approximately 21.2% greater numbers of interviews were conducted with the same effort. However, the number of fish landed in 1999 was significantly less than in 1997 and 1998. In the CPFV fishery, the trend

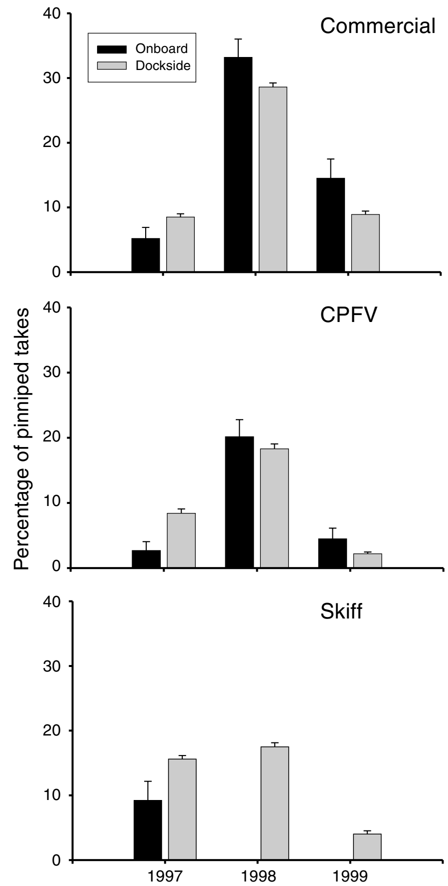

Figure 2

Percentage of pinniped takes in relation to the total number of salmon hooked as determined from dockside and onboard surveys for the commercial, commercial passenger fishing vessel (CPFV), and personal skiff fisheries in Monterey Bay, California, from 1997 to 1999. Onboard survey effort concentrated in CPFV and commercial fisheries during 1998 and 1999. Error bars indicate one standard error.

was similar to the commercial fishery, but the number of fish landed and the number of boats surveyed was significantly fewer overall. In the skiff fishery, there was a steady decline in the number of fishermen surveyed and the number of fish landed from 1997 to 1999.

Onboard observations combined with dockside interviews revealed that California sea lions were almost exclusively responsible for the depredation of hooked salmon in the commercial and recreational fisheries in Monterey Bay, taking 98.4% of the 1199 observed hooked salmon from 1997 to 1999. Of the estimated 2420 takes in 1997, 1072 were directly observed surface takes and sea lions were identified in 98.6% of the takes (Table 2). In 1998, approximately 501 of 5542 takes

Table 2

Yearly catch statistics and estimates of the number and percentage of salmon taken by pinnipeds in the commercial, commercial passenger fishing vessel (CPFV), and skiff salmon fisheries during dockside surveys in Monterey Bay in 1997, 1998, and 1999.

			Catch statistics			Number of takes		Percentage of takes	
Fishery	Year	Number dockside interviews	Total number of fish hooked	Number of legal-size fish landed	Number of under-size fish	Number of fish taken at surface	Number of fish taken below surface	Total % of legal catch lost	Total % of total catch lost
Commercial	1997	297	17,943	12,288	4124	522	1009	12.5	8.5
	1998	293	15,446	6206	4829	97	4314	71.1	28.6
	1999	377	8506	6785	966	37	718	11.1	8.9
	Total	967	41,895	25,279	9919	656	6041	26.5	16.0
CPFV	1997	139	5168	3157	1577	247	187	13.7	8.4
	1998	179	4694	3267	569	305	553	26.3	18.3
	1999	58	362	319	35	6	2	2.5	2.2
	Total	376	10,224	6743	2181	558	742	19.3	12.7
Skiff	1997	723	2926	1643	828	303	152	27.7	15.6
	1998	538	1564	882	409	99	174	31.0	17.5
	1999	176	401	315	70	8	8	5.1	4.0
	Total	1437	4891	2840	1307	410	334	26.2	15.2

occurred at the surface, and sea lions were identified in 98.4% of those takes. In 1999, 51 of the 779 takes occurred at the surface, and sea lions were responsible for 96.1% of the takes. We assumed sea lions took similar percentages of fish below the surface. As evidence of takes below the surface, sea lions would come to the surface within minutes with a fish. Pacific harbor seal (*Phoca vitulina richardsi*) was responsible for other observed takes.

Percentages of the catch taken by sea lions, based on pooled dockside and onboard surveys, were significantly different among years in the commercial (P<0.000), CPFV (P<0.000), and skiff fishery (P<0.000; Fig. 3). During 1998, significantly greater percentages of salmon were taken in the commercial (Tukey HSD multiple comparison, P<0.000), CPFV (Tukey HSD multiple comparison, P<0.000), and skiff fisheries (Tukey HSD multiple comparison, P<0.000). Whereas during 1999, the CPFV (Tukey HSD multiple comparison, P<0.000) and skiff fisheries (Tukey HSD multiple comparison, P<0.000) experienced significantly smaller percentages of sea lion takes. In the commercial fishery there was no difference in the percentage of fish taken between 1997 and 1999.

Although the timing of the sea lion migration varied by year (Weise, 2000), the percentages of takes by sea lions were greater during the nonbreeding season than during the breeding season in all three years (Fig. 4). In the commercial fishery, those differences were significant for all three years (1997, P<0.000; 1998, P=0.001; 1999, P=0.041). In the CPFV fishery, significantly more takes occurred during the nonbreeding season in 1997 (P=0.010), and 1998 (P<0.000); however, there was no significant difference in 1999 (P=0.358). In the skiff fishery, significantly more takes by sea lions occurred during the non-

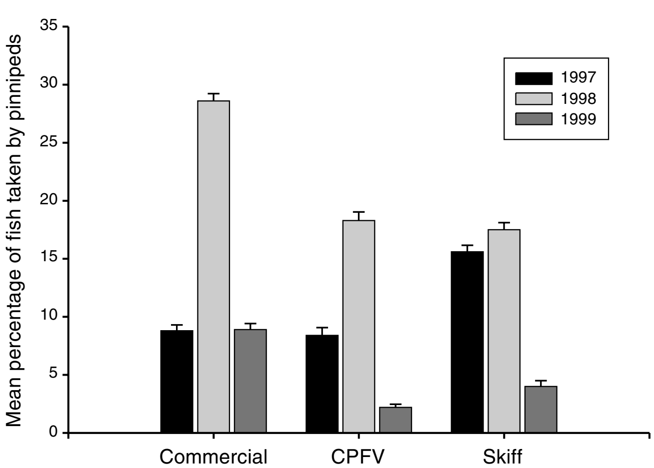

Figure 3

Mean percentage of salmon taken by California sea lion (*Zalophus californianus*) as determined from onboard and dockside surveys of the commercial, commercial passenger fishing vessel, and skiff fisheries in Monterey Bay, California, from 1997 to 1999. Error bars indicate one standard error.

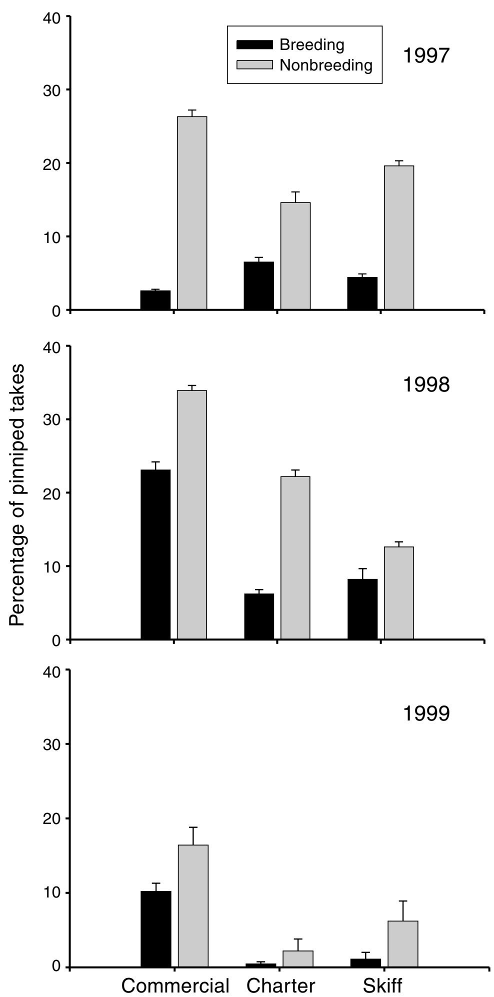

Figure 4

Mean percentage of fish taken by pinnipeds during the California sea lion (*Zalophus californianus*) breeding and nonbreeding seasons in the commercial, commercial passenger fishing vessel (CPFV), and personal skiff fisheries in Monterey Bay, California, from 1997 to 1999. Error bars indicate one standard error.

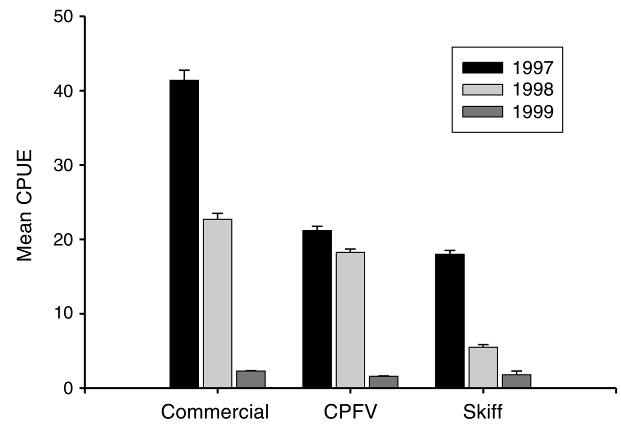

Figure 5

Mean catch per unit of effort (mean number of fish caught per day) in commercial, commercial passenger fishing vessel (CPFV), and skiff fisheries in Monterey Bay, California, from 1997 to 1999. Error bars indicate one standard error.

breeding season of 1997 ($P<0.000$), whereas in 1998 ($P=0.158$) and 1999 ($P=0.358$) there was no significant difference. During all three years, surveys were conducted on commercial, CPFV, and skiff fisheries during August and September; however, there was little to no salmon fishing effort because of the perceived sea lion problem and because the remaining fishermen targeted albacore tuna or rockfishes (or both).

Because of the different styles of hook-and-line fishing in the commercial troll and recreational salmon fisheries, sea lions were more likely to take fish below the surface from commercial trollers but to take fish at and below the surface from recreational vessels. In the commercial fishery, according to dockside interviews and onboard surveys combined, percentages of takes by sea lions below the surface of the water varied throughout the season and were significantly greater than surface takes in 1997 ($P=0.001$), 1998 ($P<0.000$), and 1999 ($P<0.000$; Table 2). In contrast, in the recreational fishery the percentages of takes by sea lions below the water's surface and at the surface varied by year. During 1997, greater percentages of takes by sea lions occurred at the surface than below the surface on CPFVs ($P=0.082$) and skiffs ($P=0.001$; Table 2). Whereas in 1998, significantly greater percentages of takes occurred below the surface in the CPFV ($P<0.000$) and skiff fisheries ($P<0.000$; Table 2). And in 1999, no differences between surface and below surface takes were detected for CPFV ($P<0.972$) or skiff fisheries ($P<0.310$); however this lack of significance was likely due to small sample sizes.

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 ($P<0.000$), CPFV ($P=0.011$), and skiff fisheries ($P<0.000$) in Monterey Bay (Fig. 5). In 1999, significantly fewer fish were caught than in 1998 and 1997 in the commercial ($P<0.000$) and CPFV ($P<0.000$) fisheries; however, there was no significant difference in the skiff fishery. The percentage of the CVI abundance for chinook salmon taken by sea lions from 1997 to 1999 ranged from 1.4% to 6.2% (Table 3).

From 1997 to 1999, commercial fishermen lost an estimated \$22,333–\$60,077 of gear, and \$224,011–\$504,548 worth of fish as a result of interactions with sea lions (Table 4). The recreational fisheries lost between \$172 and \$18,533 worth of gear as a result of sea lion interactions from 1997 to 1999. 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

Table 3

Estimates of the pinniped predation index derived from estimates of observed takes of salmon by sea lions (*Zalophus californianus*) in Monterey Bay in relation to the California Central Valley chinook abundance index from 1997 to 1999. Data for Central Valley chinook abundance index were obtained from Pacific Fisheries Management Council, 1999.

	Estimated pinniped takes				
Year	Commercial	Recreational	Total	Central Valley chinook abundance index (Ocean + river totals)	Pinniped predation index (%)
1997	24,258	14,576	24,258	1,055,300	2.2
1998	40,585	9868	40,585	611,800	6.2
1999	8780	269	8780	636,500	1.4

Table 4

Estimates of monetary impact of California sea lion interactions with commercial and recreational salmon fisheries resulting in gear and fish loss in Monterey Bay from 1997 to 1999. Recreational fishery includes commercial passenger fishing vessels and private skiffs. Value of commercial fishery revenues were obtained from the California Department of Fish and Game ocean salmon database. n/a=not applicable.

Fishery	Year	Percentage fishery sampled	Value of gear loss	Value of fish loss	Commercial revenues	Equivalent percentage of commercial revenue lost
Commercial	1997	6.3	$51,609	$375,470	$2,651,499	14.2
	1998	10.9	$60,077	$504,548	$598,062	84.4
	1999	8.6	$22,333	$224,011	$874,100	25.6
Recreational	1997	6.1	$18,533	n/a	n/a	n/a
	1998	11.5	$16,485	n/a	n/a	n/a
	1999	8.9	$172	n/a	n/a	n/a

and recreational fisheries, and gear cost for each fishery varied greatly; therefore, an average estimate for each gear type was used to estimate gear loss for commercial and recreational fisheries. Total revenue losses as a result of fish taken by sea lions in the commercial fishery were equivalent to between 14.2% and 84.4% of the total salmon fishery revenues.

Discussion

Conflicts between pinnipeds and fisheries are well documented in California (Briggs and Davis, 1972; Fiscus, 1979; Ainley et al., 1982; Miller et al.[6]; Hanan et al., 1989; Beeson and Hanan[1]; NMFS[2]). California sea lions have been the primary pinniped species involved in taking fish in ocean commercial and recreational salmon fisheries (Miller et al. [6]; Hanan et al., 1989; Beeson and Hanan[1]). 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 inflates 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 magnitude 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 dockside surveys alone would be questionable because of biases associated with dockside surveys. Biases included fishermen not providing truthful information, fishermen avoiding the survey, fishermen not answering all questions, and not all fishermen returning to the docks. Combining onboard and dockside surveys enabled us to verify dockside findings, obtain sufficient levels of sampling for comparisons, and directly observe and understand the nature of the interactions.

The percentage of hooked salmon taken by sea lions in the commercial salmon fishery in relation to the legal catch has increased by at least 8% since the 1970s and 1980s. Briggs and Davis (1972) reported that California sea lions took 4.1% of all salmon hooked during the

1969 commercial and sport salmon season, Miller et al.[6] reported that in 1981 sea lions took 3.0% of the legal catch during commercial salmon activities, and Beeson and Hanan[1] found that sea lions took 15% of the legal catch in commercial fisheries in 1995. In Monterey Bay in 1997, 12.5% of the legal catch was taken by sea lions, 71.1% in 1998, and 11.1 % in 1999.

Predation levels in the CPFV fishery have increased by at least 8% since 1983, and approximately 3% since 1995. Miller et al.[6] reported predation rates of 5.2 % for the CPFV legal catch in Monterey Bay, and Beeson and Hanan[1] 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, 26.3 % in 1998, and 2.5 % in 1999.

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.[6] reported predation levels of 1.4% on the legal catch for skiff fisheries in Monterey Bay, and Beeson and Hanan[1] reported predation levels of 10.5% on the legal catch for the 1995 recreational fishery season (CPFV and private skiff combined). In Monterey Bay, predation on the legal catch was 27.7% in 1997, 31.0% in 1998, and 5.1% in 1999. Skiff fishermen typically fish in large groups called "the fleet." Sea lions had a greater probability of getting a hooked salmon when there were greater numbers of hooks in the water; therefore, sea lions most likely target a fleet of fishing boats. Skiff fishermen caught fewer fish than did commercial or CPFV fishermen, but lost a proportionally greater number of fish to sea lions.

The greatest levels of sea lion predation in commercial and recreational fisheries occurred in spring when the greatest numbers of adult male sea lions were migrating south to breeding rookeries in southern California and Baja California, Mexico. In 1997 and 1999, 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 (Weise, 2000). In 1998, loss of catch to sea lions was greatest in May; slight decreases occurred in percentages of fish taken 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 of 1997 and 1999.

We concluded 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. [6], and Beeson and Hanan[1] also reported greater numbers of salmon taken in spring (the nonbreeding 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 a portion of that period in 1997.

Sea lions took most salmon below the water's surface in the commercial fishery and both at and below the surface in recreational fisheries. Commercial fishermen lost fish below the surface as a result of the large amount of trolling gear used, and the time required for pulling gear when fish were hooked. Commercial fishermen typically need five 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 fishermen, and are still at risk for harassment for taking fish off hooks today. Consequently, most fish in the commercial fishery are taken below the surface and consumed at the surface some distance from the boat because of a combination of the time required to bring a fish to the surface and the threat of harassment. Less gear and perhaps different types of gear that can bring a fish to the surface faster may reduce the number of takes below the surface and overall predation levels. In recreational fisheries, fishermen typically used rod and reel, which allowed fish to be reeled in within minutes. It has been illegal for recreational fishermen to harass or kill sea lions since the passage of the MMPA in 1972; therefore it is not uncommon to see sea lions swimming next to recreational boats in close pursuit of fish that are pulled from the water or that are taken just before they are 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 during 1997–98. 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 the large ENSO event contributed to increased predation on 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 fishermen, and decreases in number of salmon landed. Intensified depredation of catch has been reported during past ENSO events by commercial gillnet fishermen (Beeson and Hanan[1]).

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 between 1997 and 1998 from market squid, northern anchovy, and Pacific sardine to Pacific sardine and anchovy (Weise, 2000). Concurrently, commercial catches of squid, hake, and herring, common prey of sea lions, were low or virtually nonexistent from the fall of 1997 through the summer of 1998 (CalCOFI, 1999). In May 1998, the catch rate for 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 nutritionally stressed by the lack of prey and change in prey species and found a hooked salmon an attractive and easy meal.

Mean numbers of California sea lions recorded during the northward migration in summer and autumn of 1998 were approximately 2000 individuals greater than in the summer and autumn of 1997 and 1999, most likely in response to poor foraging conditions in southern California resulting from ENSO conditions (Weise, 2000). During the 1983 and 1992 ENSO events, numbers of sea lions increased along the central California coast owing to the enhancement of the normal northward migration of sea lions resulting from poor food availability in the Southern California Bight (Sydeman and Allen, 1999). 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, unpubl. data[8]). Increases in numbers of sea lions in Monterey Bay during 1998 were most likely due to increases in numbers of juveniles and adult females that moved northward because of the lack of schooling prey species in southern California resulting from the ENSO.

Presumably as a result of ENSO conditions, total landings of salmon and the catch per unit of effort in commercial and recreational fisheries were significantly less in 1998 than in 1997. During our sampling effort in 1998, approximately 2000 fewer fish were landed in 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[4]). 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 in 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[4]). Therefore, there were fewer boats actively fishing, fewer fish being landed, and greater numbers of sea lions in the area, under these conditions, when a fish was hooked, it was more likely to be depredated.

Conversely, in 1999 the depredation levels in the commercial and recreational salmon fisheries in Monterey Bay were significantly less as a result of cool and highly productive La Niña oceanographic conditions. Following one of the strongest ENSO events on record during 1997–98, there was a dramatic transition to highly productive cool-water La Niña conditions and anomalous, upwelling-favorable, wind forcing along the West Coast (Schwing et al., 2000). Upwelling anomalies off the central California coast during 1999 were the greatest in the 54-year record of the upwelling index (Schwing et al., 2000). Record harvest levels of Pacific sardines (CalCOFI, 2000) and greater frequency of occurrence of sardine in the diet of sea lions in central California during the 1999 La Niña (Weise, 2000) indicated that ample prey fishes were available for foraging California sea lions; therefore, depredation pressure on the salmon fisheries was reduced.

Monterey Bay was selected for the present study because it experienced the greatest levels of depredation during the 1995 commercial and recreational fisheries season (Beeson and Hanan[1]). 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. Whereas 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 bias. 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 result in underestimates of predation levels, but the magnitude of this decrease was difficult to evaluate. Surveys of fishermen were limited by crew cooperation and therefore, not all fishing styles and locations were sampled. The lack of some data would have an impact on predation levels. Surveys of fishermen also were limited to boats fishing for one day because boats fishing for multiple days often fished outside the study area during the course of a trip; however, boats fishing for multiple days were surveyed at dockside so that any biases of onboard samples would have been detected in comparisons of dockside and onboard predation levels.

Depredation of salmon by California sea lions in Monterey Bay could negatively impact salmon populations along the Central California coast. Pinniped depredation of hooked salmon from the California Central

[8] Morris, P. A. 1999. Abstract. 13th Biennial conference on the biology of marine mammals; Maui, HI, 131 p. The Society for Marine Mammology. http://www.marinemammology.org/

Valley chinook salmon population went from a low of approximately 1.4% during a non-ENSO year to an estimated 6.2% during an ENSO season. 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, fishermen continue to fish 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 Farrallon 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.

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 all years when adult males moved south during the breeding season in June and July. However, greater percentages of takes occurred in the fisheries in August and September when lesser numbers of adult male sea lions were present in the region. On any given fishing day peak numbers of sea lions were counted at haul-out sites from late-morning to early afternoon, which is also the period when most fishing occurred (Weise, 2000). Miller et al.[6] 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. We 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 nonlethal deterrents to keep sea lions from taking hooked fish in open-ocean fisheries. A change in types of fishing gear, a limit in the amount of gear in the water, use of various harassment techniques, as well as area closures and a tolerance for sea lion predation most likely encompass other possible management options.

An increasing sea lion population and increased interactions with salmon fisheries resulting in salmon and gear losses will certainly affect individual fishermen negatively and possibly California's economy (Beeson and Hanan[1]). Comparisons of economic losses between years and among studies must consider average fish weight, exvessel price per year, and definitions of fishing regions. For example, if greater numbers of fish were lost in a given year but exvessel prices were low, the overall economic impact would be less than during a year when fewer fish were taken but the exvessel prices were high.

In past studies, all ports in California were surveyed, and impacts were analyzed by port, but these studies encompassed different fishing areas under the same port names. For example, Miller et al.[6] estimated annual losses resulting from sea lion interactions 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[1] 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[1] 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 fisherman have increased since the 1980s and will probably continue to increase if the sea lion population and interactions with salmon fisheries increase. Assessment of economic impacts of salmon fisheries in Monterey Bay in the present study was limited to gear and fish loss; however impacts are most likely widespread. For example, during the salmon season when interactions with sea lions are great, CPFV operators report that customers will cancel or postpone trips, which decreases the amount of money infused into the local economy from trip expenditures, including hotel stays, restaurants meals, and gas. Estimating the economic impact of sea lion interactions on the local economy of Monterey Bay was beyond the scope of our study.

Discussions about the competition between sea lions and fisheries tend to arouse controversy because of the complex mix of biological, economic, social, political, and moral factors involved (Harwood and Croxall, 1988). Fishermen claim regularly that their activities are regulated, whereas 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 anomaly offered little reassurance to those fishermen whose livelihoods were threatened. Growing sea lion populations have undoubtedly intensified competition with fisheries, but greater fishing effort, more sophisticated fish equipment and 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 to assess and refine 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 nonlethal 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 public.

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