Marine Mammals: Conflicts with Fisheries, Other Management Problems, and Research Needs

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Assessment of California Sea Lion Fishery Interactions

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Introduction

The Marine Mammal Protection Act of 1972 (MMPA) dictates that all populations of marine mammals under U.S. jurisdiction have a determination made as to

whether or not they are at optimum levels. The National Marine Fisheries Service has defined optimum to mean that the population level is between the maximum net productivity level (MNPL) and the maximum population level (K). This determination is referred to as an assessment. Initially the MMPA put a complete moratorium on the taking of any marine mammal by a U.S. citizen unless specifically exempted from the moratorium. Problems immediately arose between commercial fishermen and marine mammals, where marine mammals were found to become more and more brazen in their interactions with fishermen. This has been particularly true for the California sea lion. Recently, the MMPA has been amended to allow the non-intentional take of marine mammals by commercial fishermen, as long as the impacted population is determined to be at optimum levels. Currently, the necessary information is not available to make a determination for any of the marine mammal stocks that occur off the coast of California.

Assessments of previously exploited marine mammal populations have historically been based on estimates of the maximal population level (k), where k is generally estimated by back calculating to the pre-exploitation level from a record of annual harvests and an estimate of the current population size. The MNPL is then estimated as a fixed percentage of K. A complete record of harvests does not exist for California sea lions (*Zalophus californianus*), even though the population was dramatically reduced in the early 1920s (LeBoeuf and Bonnell 1980), and therefore back-calculating the historic population level is not possible. Direct estimation of the MNPL is not possible because the current population size and the density dependent mechanisms that regulate this population are not known.

In this paper we present an analysis of the interaction between California sea lions and California fisheries. This is in terms of dollars lost to the fishermen and the number of sea lions indirectly removed from the population. Because direct management of sea lions cannot take place until an assessment has been made, an analysis procedure, referred to as the dynamic response method (DRM), is also presented. The paper ends with a discussion of management options.

California Sea Lion Interactions in California Fisheries

A summary of Miller et al. (1982) is presented here (Table 1). It should be pointed out that Table 1 represents only damage by California sea lions and not total damage by pinnipeds. California sea lions cause damage to catch or gear in seven major fisheries. The largest dollar losses occur in the following fisheries: Commercial salmon trolling fishery, commercial sport-boat fishery, the Pacific herring fishery, and the halibut gill-net fishery. Of an estimated 1,560 (range 1,285 to 1,834) sea lion mortalities per year due to fishery interactions, over 952 (range 678 to 1,277) occur in the shark gill-net fishery. The commercial salmon trolling fishery and the halibut gill-net fishery each take roughly 200 animals. Precise estimates of sea lion abundance are not available, but minimum estimates range between 45,000 and 60,000 animals (LeBoeuf and Bonnell 1980). A take of 1,800 represents an annual harvest of 3.0 to 4.0 percent. Only the gill-net fisheries experience significant gear damage. Damage by sea lions to trammel-nets that are set for halibut was particularly severe (43 percent of total dollars lost in halibut fishing). The total damage to catch by California sea lions in all fisheries was estimated to be $394,886 in 1980, and the total damage to gear was $80,350. The total dollar value of losses

Table 1. Depredation rate, dollar loss, and take of sea lions in California fisheries. (Data from Miller et al. 1982. Where species-specific losses are not given, loss is prorated according to composition of take).

	% depredation	Value of fishery losses		*Zalophus* mortality
		Catch loss	Gear loss	
1. Commercial salmon troll fishery (1980)	1.90%	274,000	12,200	300
2. Salmon partyboat fishery (1980)	0.32%	6,000	360	0
3. Salmon recreational skiff fishery (1980)	0.02–0.18%	2,300	0	0
4. Recreational salmon fishery (river) (1979/80)	0	0	0	0
5. Partyboat fishery for bottomfish (1980)	?	27,000	10,730	0
6. Pacific herring fishery (1979/80)	0.46–0.62%	40,600	4,550	0
7. Gill net fisheries (1980)				
a. Shark	0	0	792	952
b. Halibut	6.94%	32,368	24,071	242
c. White seabass	2.00%	3,740	0	0
d. Rockfish	1.4%	2,600	0	15
e. White croaker	7.1%	2,978	1,000	0
f. Barracuda	2.2%	330	0	0
g. Bonito	6.5%	1,270	382	0
h. Flyingfish	6.4%	200	0	0
		43,486	26,245	1,487
8. Market squid fishery	0	0	0	10
9. Round-haul net fishery for anchovy and mackerel	0	0	0	20
10. Hook and line fishery (1980)	0.44%	1,500	0	0
11. Commercial trawl fishery	0	0	0	25
12. Klamath River gill-net fishery	?	?	?	7
Totals		$394,886	$80,350	1,571

due to fishery interaction with sea lions was $475,236. The annual total dollar value of losses due to all marine mammals in California was reported to be $598,690 (Miller et al. 1982).

One of the best series of data obtained in Miller et al.'s (1982) interaction study was in the commercial and recreational salmon fisheries. These fisheries are conducted during the peak of southern migratory movement (April–May) of sea lions along the nearshore area and when these animals are returning to central and northern California during the fall months. During spring, the salmon are spread throughout the area from Monterey to the Oregon border with some heavier

California Sea Lion

aggregations of salmon moving about in relation to their food supply. The May salmon catch and California sea lion depredation indicate a more widespread but close to shore migratory pattern of sea lions, with depredation reported from 32 (57%) of the 50 catch block areas reported as high yield areas by salmon fishermen. During the spring southward migration there are more salmon taken off hooks by sea lions at a farther distance from hauling grounds than during the northward movement.

The post-breeding northern movement of sea lions is more spread out in both time and space. Interaction with salmon trollers, however, was primarily within 15 km (9.3 miles) of major hauling grounds. The juxtaposition of the hauling grounds of Little Jackass Creek, California (35 km [21.7] miles north of Fort Bragg) and the usual annual fall concentration of maturing salmon near that area results in significant losses of salmon due to depredation by sea lions. Over 43 percent of the total salmon taken off hooks by California sea lions along the California coast were lost in this area. When the number of fish stolen or damaged by catch block area is compared with the number of fish caught in these blocks, there is no clear-cut relationship between the occurrence of heavy catches and the degree of depredation. The only possible cause and effect relationship appears to be that high depredation rates occur when dense fish aggregates are near major hauling grounds.

The high concentration of southern migrating California sea lions during April–June in Monterey Bay occurring during intensive salmon fishing effort presents an opportunity to investigate relationships between number, size composition, and behavior of California sea lions and the catch and depredation rates. One of the more significant findings is that the number of California sea lions hauling out at the Monterey Coast Guard breakwater reached all time peaks in the 1980 and 1981 counts. Counts made at the breakwater by the Department of Fish and Game and Alan Baldridge (Hopkins Marine Station, pers. comm.) from 1967 through 1971 ranged from 400 to 800 animals during the spring peak. The 1980 May maximum count was 1,521 California sea lions, 914 of which were yearlings. The peak count in 1981 was in April and May with over 2,000 California sea lions tallied. About 500 of these were rafting in the water adjacent to the breakwater, precluding accurate determination of size composition. Large numbers were yearlings as in 1980.

Subadults in 1980 and 1981 were reported by local fishermen and researchers to be more abundant than previously observed in the Monterey Bay area. These young animals were exceptionally tame and curious and showed little fear of fishing boats. By July 1 all but a few of the adult California sea lions had departed for the rookery areas. Some of the yearlings remained for about two weeks before also moving out, presumably to the south. Ainley et al. (1977) reported concentrations of yearling California sea lions at the Farallon Islands for the first time in 1971 and subsequently recorded increasing numbers annually.

Depredation rates on salmon do not closely follow trends in the total number of salmon lost. The highest depredation rates for the entire California coastline on salmon trollers were recorded in Monterey Bay, yet greatest numbers of lost fish were off northern California where there was a greater proportion of salmon in relation to numbers of sea lions. The Monterey Bay depredation rates were 3.31 percent, 4.26 percent, and 7.60 percent of the legal catch for May, August, and September, 1980 respectively.

There is a greater concentration of salmon in Monterey Bay during spring months than in fall. The total number of salmon taken off hooks by sea lions in May was higher than in September, but not in relationship to the numbers of animals present. There was twice the rate of depredation per fishing boat in Monterey Bay in September as in May, but only about one-tenth as many sea lions were present in September as in May. It appears that only a few of the California sea lions present may be involved in fishery interactions. During the intensive salmon trolling taking place in Monterey Bay in May, 1980, large numbers of sea lions did not leave the hauling grounds near the harbor in the morning to follow the vessels heading for the fishing areas. In fact, nearly all the sea lions had returned from their nighttime foraging bouts and were hauling out as the fishing vessels were passing by. On any given day when complaints were being voiced over the marine radio about sea lion problems, no more than about a dozen interactions could be accounted for, and some of these could have been repeated occurrences by the same animals. Therefore, a reduction in the number of animals present would probably not reduce depredation unless most of the animals present are removed or unless the few animals responsible for the damages could be identified and removed.

The Dynamic Response Method

The interaction between sea lions and California fisheries is expected to generate interest in management related activities that will mitigate losses by fishermen due to sea lions. However, the newly amended MMPA dictates that populations must be at optimum levels before mitigating measures can be taken. The return of pinniped management to the State of California can only proceed if the proposed populations are considered to be at optimum, and if the replacement yield has been determined. Because an assessment based on back-calculating historical population levels is not possible (historical harvest records are not available), and because direct estimates of the maximum population level are not available, alternate methodologies must be developed. The next section describes an assessment method that is based on a time series of population indexes.

A. Harvesting Dynamics and MNPL

The MNPL is a reasonable lower limit for the optimum sustainable population level because the MNPL is a breakpoint in the range of the population levels. At levels greater than the MNPL, a stock will come to a stable equilibrium under a quota harvest. Below the MNPL, a stock will not equilibrate under a quota harvest, but will decline to extinction or grow to exceed MNPL, depending on harvest rate, production, and the population size.

B. Direct Assessment of Current Dynamics

For the same reasons that make the MNPL a division line between favorable and unfavorable dynamic regimes, it should be possible to detect whether a population is above or below its MNPL from examination of its dynamics. We term this analysis a dynamic response assessment. The theoretical feasibility of a dynamic response assessment should be obvious from the fact that observations of the dynamics of the population could be described in terms of a stock/recruitment

relationship. Furthermore, if the observations were used to establish the production curve, the peak of which is located at the MNPL, we could then ask whether the present level is above or below that estimate of MNPL. Thus, the dynamic response assessment is a special case of the general procedure of deducing the stock recruitment relationship from observations on dynamics.

There are two basic advantages to restricting the analysis to a qualitative dynamic response assessment, rather than answering the management question as a by-product of a complete program of estimating the stock/recruitment curve. The first advantage is that estimates of the full stock/recruitment curve involve extrapolations beyond the range of available observations. If our sole objective is to arrive at a qualitative "above or below" determination rather than actually to arrive at a quantitative estimate of what the value of the MNPL is, it is not necessary to postulate on the shape of the production curve outside of the observed range of population levels.

The second advantage is that the estimation of the stock/recruitment relation involves absolutely scaled estimates of population density (or estimates scaled in units of carrying capacity), whereas the simpler qualitative question can be addressed with data on rates alone. Thus the proposed assessment can be carried out with fewer data.

C. Principles of the Analysis

A fundamental feature of population models that are used to make assessments is a density dependence relationship that results in the per capita population growth rate being a decreasing function of population density. The production curve is a product of population density and per capita population growth, so the production curve is unimodal where the peak, the MNPL, corresponds to the point where the product of two functions—density, an increasing function of density, and per capita growth, a decreasing function of density—is maximal. Since the two functions are oppositely related to density, the product will be maximum at some intermediate density.

Another way of describing the unimodality of the production curve is in terms of its slope. At densities below MNPL, the slope is positive and at densities above the MNPL, the slope is negative. This relationship, when translated to a plot of time versus population level, dictates that the population growth curve is dependently convex up in the region below MNPL, so that the population will exhibit an acceleration in its growth rate in the approach to MNPL from below. It also means that the growth curve is convex down in the region above the MNPL, and the population will exhibit a deceleration in the growth away from MNPL in the direction of the unharvested equilibrium level.

Analysis of Pup Counts from San Miguel Island

These modes of describing the qualitative differences in the production curve above and below MNPL form the basis for the method of estimating, from recent dynamics, whether a given population is above or below its current MNPL. We will illustrate this method by considering an assessment of the San Miguel Island population of California sea lions over the past decade.

Most pinniped populations along the coast of California were drastically reduced

by the early twentieth century. These populations have begun recovering under government protection, and most pinniped populations are currently thought to be increasing. Except for an incidental kill owing to fishery interactions, these populations are not harvested directly. Therefore, the population trajectories are those of free running populations that were initially far from the equilibrium and are now presumably approaching the equilibrium. Accordingly, there is reason to hope that the trajectories exhibit rather clearly the density dependent dynamics of population growth and are not dominated by environmental noise about an equilibrium.

Pup production of California sea lions has been annually estimated by counting neonates on breeding beaches. Their relationship to the size of the entire population depends on the nature of the density dependence of reproduction. We assume that, over the range of densities exhibited in our data, the fecundities are not dependent on density. Instead, we posit that the major mechanism of density dependence is through juvenile mortality, which expresses itself at some time after the pup census. Under this assumption, the pup counts may be interpreted as relative measures of population size.

Our criterion for dynamics above or below MNPL in a free running system not near equilibrium is simply acceleration or deceleration in the population growth rate. This is detected as upward or downward convexity in the relationship between a relative measure of population size (such as pup counts) and time. Given a minimal number of censuses, we may test for curvature by fitting a second-order polynomial and inquiring into the sign of the second-order term (i.e., if positive, population is below MNPL; and if negative, population is above MNPL).

This simple procedure is premised on the population not crossing from one side of the MNPL to the other during the period of observations. If the population does make that crossing, then one segment of the density-time plot will be convex up and the other will be convex down. If the shape is reasonably symmetrical, this will yield a zero or very small curvature measure in a second order fitting, but of course we will be hard pressed to detect zero curvature due to:
1. Excessive sampling error in the censuses;
2. Excessively slow acceleration or deceleration relative to the duration of the data record; and
3. Populations genuinely at or near MNPL.

It should be noted that this approach is conservative because a population that has only recently passed the MNPL will be assigned a positive second derivative. In fact, the second derivative will on average only be negative when there are as many years of data after the MNPL has been reached as before. This shortcoming can be circumvented by using the most recent data, but a minimum number of counts is necessary to provide a reasonable degree of precision in the assessment.

Results

The series of pup counts from San Miguel Island extends from 1971 through 1981 (Figure 1). Pup counts from the other pupping colonies in the Channel Islands are available (Table 2), but are not adequate for this type of analysis because they represent too short a time series or are composed of counts that are not comparable due to technique differences. Because the pup counts in DeLong et al. (1982) are
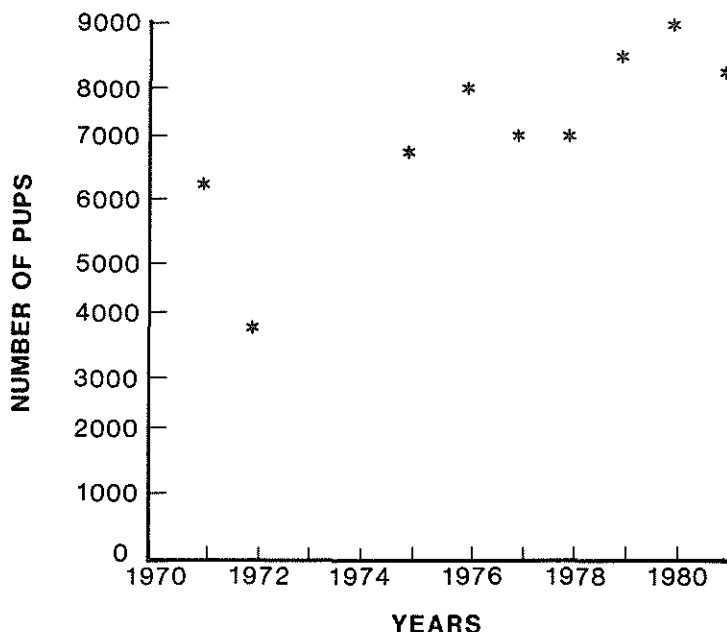
SEA LION PUP COUNTS

Figure 1. California sea lion pup counts from San Miguel Island (1971–1981). All counts are of live pups from censuses made during the last week of July.

composed of both single counts and averages of multiple counts, it it necessary to analyze the individual counts to get the proper weighting in the regression (Table 3). It is also conceivable that neonatal mortality or pre-parturient fetus mortality is density dependent, and therefore these sources of pup lossess should be included in an index where pup counts are used to index changes in the total population size. Information from DeLong et al. (1982) was used to construct three types of population indexes: total number of live pups in July, totals of pups plus neonatal deaths, and pups plus neonatal deaths plus premature births (Table 3). An analysis of the three population indexes in Table 3 is complicated by the unusually large number of premature pups in 1972. This is not considered to be a density dependent response. In the analysis, a second order polynomial was fitted to each of the three counts. Models were fitted both with and without the 1972 data (indicated by presence of asterisk in Table 4). The results (Table 4) indicate that the second derivative is negative in all but one case. The one model where the second derivative was positive is also the model that is the poorest indicator of trends in population growth. This is because estimates of total neonatal mortality are negatively biased. Therefore, our analysis indicates that at least the San Miguel population of California sea lions is past the MNPL and is exhibiting a detectable amount of growth rate retardation due to density dependent effects. If an expo-

Table 2. Peak pup production figures for *Zalophus californianus* in the Southern California Bight area.

	SMI	SNI	SBI	SCI	Other
1969		2697(1)			
1970		2271(1)			
1971	5285(6)	3500(6)			
1972	3501(6)				
1973					
1974					
1975	6236(2)	3800(2)	648(2)	608(2)	
	7103(6)				
1976	7130(2)	3533(2)	515(2)	413(2)	2(2) S. Cruz
	8084(6)				
1977	5304(2)	3773(2)	493(2)	351(2)	
	7413(6)				
1978	7100(6)		465(3)		
1979	8476(6)		625(3)		
1980	9279(6)	6288(4)	730(3)		
1981	8255(6)	6824(4)		666(5)	

SMI = San Miguel Island
SNI = San Nicolas Island
SBI = Santa Barbara Island
SCI = San Clemente Island
(1) = Odell 1971, Ground counts
(2) = LeBoeuf et al. 1978, Aerial surveys
(3) = Heath 1982, Ground counts
(4) = Stewart pers. comm., Ground counts
(5) = Oliver pers. comm., Ground counts
(6) = DeLong et al. 1982, Ground counts
Counts were made in July–August and do not include those pups that did not survive until the census.

nential equation is fit to the series of pup counts in Table 3, the resulting values of r vary between .04 and .06 (Table 4), which indicates that the annual rate of population change (λ) is between 1.04 and 1.06 from 1971 through 1981. If our assertion is correct, and the population growth rate is currently being reduced by density dependent effects, a growth rate of 5 percent per year must be considered a minimum estimate of the maximum rate of population change.

Management Implications

Until an assessment of the entire California sea lion population is made, it is doubtful whether management action will be taken to reduce or mitigate the impact of sea lions on fisheries in California. Even with an assessment that found sea lions above their MNPL, it is not clear what measures would be effective. Miller et al. (1982) present evidence that the total damage by California sea lions is not proportional to the number of sea lions in an area. They reported that an order of magnitude difference in the number of animals was associated with only a doubling of fishery interaction rates. They further suggest that fishery interactions are greatly affected by seasonal movement and hauling patterns. Therefore, reduction in

California Sea Lion 261

Table 3. Counts of live pups, neonatal deaths, and premature births for California sea lions on San Miguel Island from 1969 through 1981. (Data are from DeLong et al. 1982). If more than one count is available, both counts are given.

Year	A Pups	B A + neonatal deaths	C B + premature births
1971	5285	6633[a]	6981
1972	3501	4157[a]	5159
1975	7323	7416	7745
	6702	6795	7124
1976	8359	8505	8811
	7808	7954	8260
1977	7664	7766	8262
	7162	7264	7760
1978	7268	7462	7723
	6932	7126	7387
1979	8710	9032	9302
	8245	8567	8837
1980	9279	9307	9704
1981	8937	9218	9317
	7573	7854	7953

[a]Mortality studies were conducted on sample areas throughout the breeding season. Results indicated that most dead pups disappear within 21 hours after death. Therefore, neonatal mortality is far in excess of what is assessed from a single census taken at the time live pups are censused. Estimates of neonatal mortality for 1975 through 1981 are therefore substantially below actual mortality.

population size would likely have to be drastic to have any effect at all. Currently, most fishermen seem to consider the loss to marine mammals as overhead, or they simply avoid areas where marine mammals concentrate. Current research on mitigating marine mammal-fishery interactions is directed at developing non-lethal, acoustic deterrents; results are not yet available. In the future, a combination of harassment techniques, area closures, and tolerance will most likely encompass the management tools that are available. An important point raised by Miller et al. (1982) is that increased disturbance of rookery areas may result in a redistribution of sea lions, and areas currently not used for hauling or feeding may experience increased use. This may result in higher rates of marine mammal/fishery interactions in areas currently not experiencing such interactions. With this in mind, it is important to document existing movement patterns of sea lions and their changes in response to increasing disturbance from researchers, recreational enthusiasts, and commercial fishermen.

Acknowledgments

Table 4. Analysis of second degree polynomial and exponential functions fitted to counts of pups (A), pups plus neonatal deaths (B), and pups plus neonatal deaths plus premature births (C). Data are from Table 2.

			A			B			C
2° polynomial	y	$=$	$3511 + 847x - 36x^2$	$\overset{*}{y}$	$=$	$6461 + 147x + 6x^2$	y	$=$	$5616 + 450x - 13x^2$
	r^2	$=$	.70	r^2	$=$	.50	r^2	$=$	.56
	$\overset{*}{y}$	$=$	$4846 + 543x\text{-}19x^2$						
	r^2	$=$	.62						
Exponential	$\overset{*}{y}$	$=$	$4610\, e^{.06x}$	$\overset{*}{y}$	$=$	$5361.25\, e^{.05x}$	y	$=$	$6050.67\, e^{.04x}$
	r^2	$=$	.60	r^2	$=$	.54	r^2	$=$	.54

*1972 counts not included.

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