Interactions of Northern Fur Seals and Commercial Fisheries

Charles W. Fowler
National Marine Mammal Laboratory

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National Marine Mammal Laboratory
Seattle, Washington

Introduction

Under international agreement, the northern fur seal (*Callorhinus ursinus*) is managed with the objective of obtaining a maximum sustainable yield. Currently the harvest is restricted to subadult males; however, between 1956 and 1968 the fur seal population of the Pribilof Islands was subjected to a harvest of females. This harvest was justified, in part, as an attempt to stimulate the production of greater quantities of harvestable animals (Chapman 1981). A reduction in the population occurred during this period as can be seen in Figure 1. As described in York and Hartley (1981), the female harvest itself provides an explanation for part of this reduction, but cannot account for more than about 70 percent of the decline in the numbers of pups born. It was expected that the population would increase following the termination of the harvest of females in 1968, yet no increase occurred.

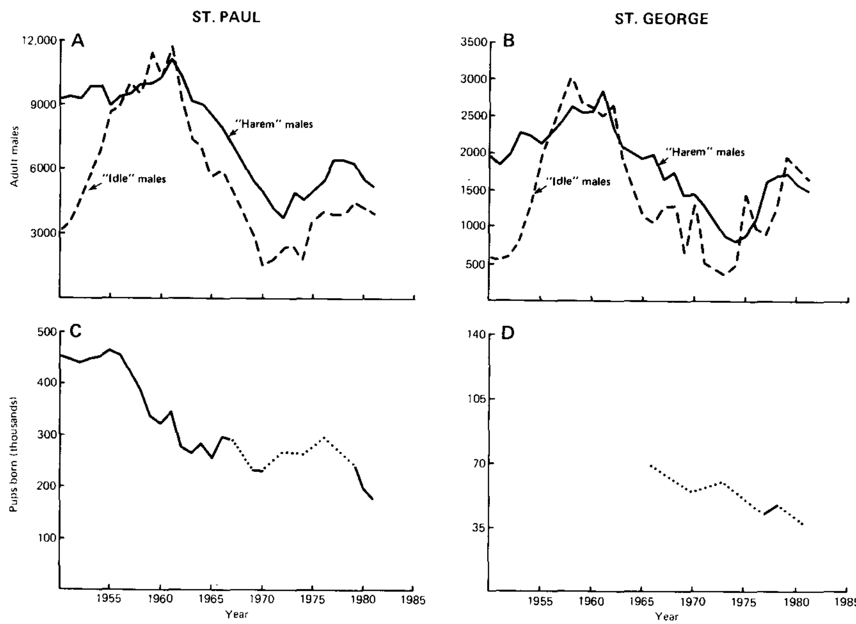

Figure 1. Observed declines in the fur seal population of the Pribilof Islands as indicated by numbers of pups and large males for both St. Paul and St. George Island, 1950–1981. Dotted lines are for periods during which data are not available for consecutive years. (From Lander 1980, Kozloff in preparation).

Currently the entire Pribilof population is declining as evidenced by declines in numbers of pups, harvestable males, and adult males on both islands. Other populations of this species in the western Pacific are also showing evidence of a decline, based on data published in the annual proceedings of the North Pacific Fur Seal Commission in recent years. In summary, the Pribilof population has shown (1) a greater decline between 1956 and 1968 than can be easily explained by the female harvest alone, (2) no increase following the termination of the female harvest, and (3) a current trend toward smaller population levels. In view of these dynamics, both managers and scientists are faced with the problem of providing an explanation.

Several explanations for the decline in the Pribilof fur seal population have been advanced. Over time, minor changes have occurred in the management regime, giving rise to the possibility that modifications in the harvest strategy may provide an explanation. Most of these modifications have involved relatively small changes in the length limits and season length applied in the harvest and would thus have affected only the male component of the population.

It is possible that increasing levels of toxic substances in the environment may explain the decline. However, current information indicates that the level of measured toxic substances in the tissues of fur seals have not increased. The incidence of disease appears to have remained the same or declined, but increases in predation may have occurred.

During the years over which the fur seal population declined (1956 to the present), the Bering Sea became subject to the effects of relatively intense fishing pressure (see Bakkala et al. 1979). Of particular importance is the pollock (*Theragra chalcogramma*) fishery, which became large and economically important between about 1964 and 1972. Data from this fishery indicated that the pollock population underwent significant changes during this period (Smith 1981). It is because of such changes and the presence of other fisheries in the eastern North Pacific that the decline in the fur seal population is often explained as an effect of commercial fisheries.

The ways in which commercial fisheries may have affected the fur seal population fall into several categories. The decline may have occurred as a result of a reduction in the amount of prey consumed by fur seals (i.e., through reduction in numbers or changes in size composition of the prey). It may have happened as a result of a restructuring of the ecosystem in response to developing fisheries, especially if this resulted in the reduction of prey species consumed by fur seals. Finally, the decline may be a result of the direct impact of fisheries on the fur seals, such as through entanglement and incidental taking. Entanglement is a term that refers to fur seals becoming wrapped or caught in debris that has been discarded or lost. A large part of this debris involves trawl net material. Incidental taking involves the capture of fur seals in fishing gear while it is being actively fished.

In this paper I review information related to the indirect effects of commercial fisheries on fur seals (i.e., through the reduction of food resources available to fur seals) and compare it with information concerning the direct impact of fisheries on fur seals (the issue of entanglement and incidental take). The indirect effects will be evaluated through a review of the feeding ecology of fur seals and of information dealing with changes that have occurred within the population. The direct effects will be addressed through a review of information on direct taking and through a review and analysis of information on net debris and entanglement rates. In all cases the review is restricted to information on the population of northern fur seals of the Pribilof Islands.

Indirect Interactions

Diet

From 1958 to 1974, Canada and the United States cooperated in pelagic field research to study the distribution, migration, and feeding habits of northern fur seals in the Bering Sea and eastern North Pacific Ocean. These investigations established that fur seals feed upon well over 100 species of fishes and cephalopods in the eastern North Pacific and Bering Sea (Kajimura 1982). Added to this is the list of prey species found in the western North Pacific. Within this large list of prey species, a smaller subset forms the principal prey species of importance to the fur seal. Table 1 shows a list of the principal prey species utilized by fur seals in the eastern Bering Sea and eastern North Pacific Ocean from 1958 through 1974. There is a strong tendancy for the composition of the fur seal diet to be related to geographic location.

Kajimura (1982) shows that time (time of day or season) is also an important factor in determining the composition of the fur seal diet. At any one time, for any particular location, however, it is not uncommon to find that one species comprises a relatively large portion of the stomach contents in sampled fur seals. For example, anchovy (*Engraulis mordax*) off the coast of California often comprised 50 percent (by volume) of the sampled stomach contents. For those fur seals that remain off California into May, however, it is not uncommon for Pacific whiting (*Merluccius productus*) to comprise over 50 percent of the stomach contents. In the Bering Sea, capelin (*Mallotus villosus*) and pollock were found to be the most prevalent species in July and August. These two species often accounted for over 25 percent of the contents of fur seal stomachs, at times comprising as much as 75 percent.

Consumption Rates

McAlister (1981) estimated that 476 thousand metric tons of fish are consumed by fur seals each year in the Bering Sea and Aleutian Island area of Alaskan waters. This estimate is based on information concerning the metabolic rates of fur seals combined with information concerning the fur seal's population characteristics such as the age structure, migratory patterns, and distribution. Further analysis of the information presented in McAlister (1981) reveals that fur seals consume approximately 21 percent of all fish consumed by marine mammals in the eastern Bering Sea and Aleutian Island area; this translates to approximately 1.2 percent of the standing stock biomass of fishes in this area.

Opportunistic Feeding

As has been shown by Kajimura (1982), the feeding behavior of fur seals is opportunistic in nature. As fur seals follow their migratory route from the Pribilof Islands to waters off Washington, Oregon, and California, their diet changes. These

Table 1. Principal forage species utilized by fur seals in the eastern North Pacific Ocean and the eastern Bering Sea, 1958–74 (from Kajimura 1982).

	Area						
Forage Species	California	Oregon	Washington	British Columbia	Gulf of Alaska	Western Alaska	Bering Sea
Fish:							
Clupea harengus pallasi	—	—	x	x	x	x	x
Engraulis mordax	x	x	x	—	—	—	—
Oncorhynchus spp.	—	—	x	x	x	x	—
Mallotus villosus	—	—	x	—	x	x	x
Thaleichthys pacificus	—	—	x	x	—	—	—
Cololabis saira	x	x	—	x	—	—	—
Gadidae	—	—	—	—	—	—	x
Gadus macrocephalus	—	—	—	x	—	—	—
Merluccius productus	x	x	x	x	—	—	—
Theragra chalcogramma	—	—	—	x	x	x	x
Trachurus symmetricus	x	—	—	—	—	—	—
Sebastes spp.	x	x	x	x	x	—	—
Anoplopoma fimbria	x	—	x	x	—	x	—
Pleurogrammus monopterygius	—	—	—	—	x	x	x
Ammodytes hexapterus	—	—	—	—	x	x	x
Cephalopods:							
Loligo opalescens	x	x	—	x	—	—	—
Onychoteuthis sp.	x	x	x	—	—	—	—
Onychoteuthis borealijaponicus	—	—	—	—	x	—	—
Gonatus sp.	—	—	—	—	x	—	—
Berryteuthis magister	—	—	—	—	x	x	x
Gonatopsis borealis	—	—	—	—	—	—	x
unidentified squid	—	—	—	—	x	—	—

changes appear to be in direct response to the availability and abundance of prey species in the areas through which the fur seal passes.

As further evidence for opportunistic feeding, Kajimura (1982) examined the occurrence of various prey species in the stomachs of fur seals and compared them with the abundance of the prey species as indicated by fishery surveys in the waters off California and in the Bering Sea. The species found to be most abundant in the fur seal stomachs were most abundant in the areas where the fur seals were collected. Within areas, but over time, as the composition of the prey community changed, so also did the composition of the fur seal diet as indicated by the contents of fur seal stomachs sampled.

Response by Fur Seals

It is difficult to reconstruct the response of fur seals to changes that may have occurred in the North Pacific and Bering Sea ecosystems resulting from the development of commercial fisheries. It is possible, however, to look for the effects of such changes. To examine existing information for evidence of competition with fisheries we must assume that if food resources are reduced to the point of producing a decline in the rate of consumption, fur seals will exhibit responses manifested in various attributes such as growth rates, size at birth, age at maturation, or survival. This is a safe assumption since we know that, in general, when faced with reduced consumption rates, animals are negatively affected. We would thus expect that a reduction in available food resources by commercial fisheries would result in a negative impact on the population of seals and probably cause a decline in their numbers. The available information on northern fur seals, however, does not support this explanation for the decline.

For example, as demonstrated by Lander (1979a), fur seal pups, born during the period following the first major reduction of the fur seal population were born at greater weights than pups born during the period when the population was at its peak. The weight of pups born during the 1950s was approximately 10 percent less than the weight of pups born during 1958 and 1975. As shown in Figure 2A, current data indicated that pups continue to be born at heavier weights than in the 1950s.

As also shown in Figure 2A, the weight of pups at approximately 7 weeks of age has remained relatively constant over the years 1957 to 1980 with a possible tendency to increase between 1961 and 1980.

As found by Bigg (1979), females that were sampled during the pelagic research between 1958 and 1974 showed a tendency to grow more rapidly during years following the decline created by the female harvest. The highest growth rates occurred during the period of peak growth of the pollock fisheries in the Bering Sea. The growth rates are particularly high during this period when compared to those years during which the fur seal population was at its peak in numbers and production.

Work by Hartley (in Kozloff in preparation) indicates that the growth rate of males also increased. Based on data concerning the length of 3-year-old males taken in the harvest during the third week of July on St. Paul Island, there appears to have been an increase in body lengths of animals of this age over the period 1962 to 1971.

Changes in growth that occurred between 1948 and 1979 are also shown in the

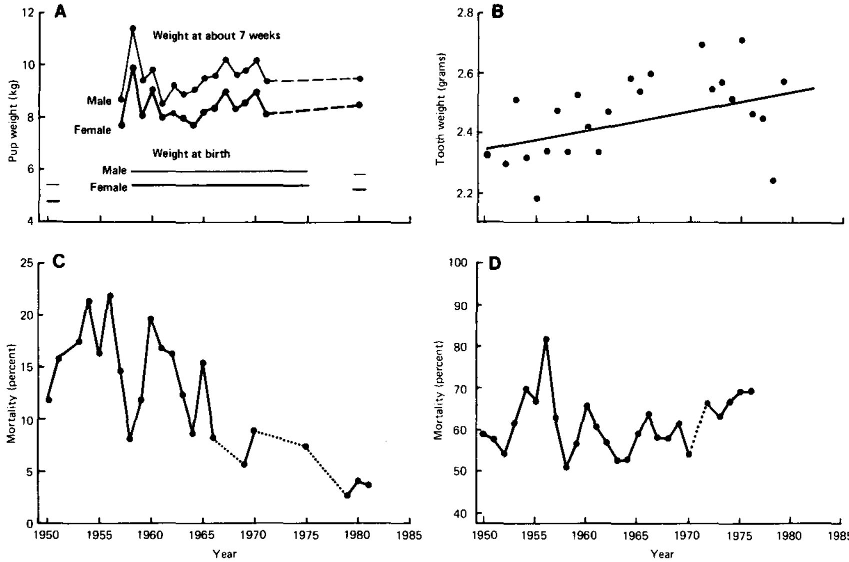

Figure 2. A. Mean weight of pups on St. Paul Island on or about 1 September from 1957 to 1971 and 1980 (National Marine Fisheries Service 1972, and Mike Goebel, personal communication) and mean weight at birth for several periods (from Lander 1979a and Mike Goebel, personal communication). B. Mean maxillary canine tooth weight for 3-year-old males sampled on, or about, 15 July 1950 to 1979 (based on work by Hartley as reported in Kozloff in preparation). C. Pup mortality on St. Paul Island prior to leaving land as calculated from data in Lander (1979b). D. Mortality of males after leaving land but prior to the age of 2 years from data in Lander (1979b). Dashed and dotted lines are for periods during which data were not available for consecutive years.

weight of teeth. Maxillary canine teeth were sampled randomly from 3-year-old males in the harvest on or about 15 July. Using a subsample of eight teeth for each year, a significant increase in tooth weight was found during this period (Figure 2B). The underlying assumption that tooth weight and body size are correlated was verified by Hartley through an analysis of tooth weight as regressed upon body length (Kozloff in preparation). Similar work by Antonelis, York, and Kajimura (also in Kozloff) supports this conclusion.

Mortality of pups on land shows a decline in parallel with the decline in pup abundance (Figure 2C). This apparent density-dependent change covers the period of years during which any effect of a fishery on resource levels would be thought to cause an increased mortality rather than a decline.

Any reduction in available food resources might be expected to result in an increase in the time required for foraging. Such a relationship cannot be established from data on female fur seal feeding cycles. Data from several years between 1962 through 1976 show only the possibility of a slight decline in the duration of feeding cycles (Gentry et al. 1977). This, along with the changes reviewed above, does not support the hypothesis that a lack of food created by the commercial fisheries has caused the decline.

By contrast, however, mortality between the time pups leave the islands and the time they reach 2 years of age shows signs of having increased recently. There is no indication of change up through the 1970 year class except for the high levels of the mid 1950s (shown by year class in Figure 2D as based on Lander 1979b). However, the most current data (provided by Anne York, personal communication) indicate an increase in mortality in year classes following 1970. Further analyses indicate that this mortality of young males at sea may have progressively changed over time. In this analysis, estimated mortality due to natural causes is shown to have declined while estimated mortality due to other causes has increased (Fowler 1982). The decline in natural mortality would have been expected as a density dependent phenomenon following a reduction in the population. The increase in observed mortality may be due to entanglement as one of the potential direct interactions with fisheries as explained below.

Synthesis

If the ecosystem inhabited by a population is subject to a disturbance that has a negative effect at the population level, it is natural to expect that the individuals within that population will show parallel signs of negative effects. Such effects would be manifested in reduced pregnancy rates, reduced growth rates, reduced weight at birth, and increased mortality. As reviewed above, most of the information that bears on the reaction of fur seals to the indirect effects of commercial fisheries indicated that individual fur seals show signs of better environmental conditions now than they did prior to the development of the fisheries. That is, neonatal survival is much higher following the development of fisheries than it was before. An increase in weight at birth may have occurred. Feeding cycles have either not changed or show small declines in length, and growth rates have increased. Survival at sea seems to be the only factor that has declined. But this change is inconsistent with increased growth rates (as well as the several other factors) as an indicator of resource levels and must be kept in mind as a possible cause of the decline independent of any lack of food resources.

Given the diversity of species that serve as alternative prey for fur seals, it is rather difficult to argue that a reduction in the populations of a few species would create problems for seals. This is especially true if reductions in one species result in increases in others through reduced competition. Since fur seals are opportunistic (Kajimura 1982), it seems reasonable to expect them to be able to shift the composition of their diet within the size range of prey consumed. If this is a valid line of reasoning, it is not unexpected that there is little evidence to support the hypothesis that there has been a reduction in food resource levels.

Given the lack of evidence for a negative influence through competition with commercial fishing as reviewed above, the possibility that fisheries have improved conditions for fur seals cannot be ruled out. Swartzman and Harr (1980), in fact, argue that changing the age structure of the pollock population increased the availability of smaller pollock, thus increasing food resource levels (i.e., the numbers of the preferred size) available to fur seals.

Direct Interactions

The information presented above leaves us with a dilemma. How can conditions show signs of apparent improvement for individual fur seals while the population itself shows evidence of a decline? If the increase in mortality at sea is extrinsic to the population, and is causing the decline, the responses of individuals can be interpreted as density dependent changes expected at reduced population levels. In other words, the decline itself may be caused by mortality that is unrelated to the levels of food resources. Such factors as entanglement or incidental take, for example, would reduce the population in the face of abundant resources. This could result in there being more resources per individual and local densities of prey might even increase. Such changes would then be expected to elicit density dependent responses having precisely the nature of those described above. As reviewed by Fowler et al. (1980), populations of large mammals in general tend to show changes such as these in response to reduced population levels.

In the following sections I review information indicating that the fur seal population is declining as a result of direct interactions with fisheries in the form of mortality caused primarily by becoming entangled in debris, especially fragments of trawl nets.

Incidental Mortality

Incidental mortality (or incidental take) is a common problem in many fisheries and is subject to governmental regulations. Examples include the dolphins caught in the yellowfin tuna fishery, porpoise caught in the Japanese high seas salmon gillnet fishery, and sea turtles caught in shrimp fisheries. As has been outlined by Kajimura (1976) and Jones (1980, 1981, 1982) fur seals are also taken incidentally in some commercial fisheries. At this time it is impossible to produce a reliable estimate of the total mortality rate caused by the incidental taking of fur seals. However, Jones (1980, 1981, 1982) has estimated that between 100 and 1,000 fur seals are currently taken each year in the Japanese high seas salmon gillnet fishery. The numbers taken in this fishery may be declining due to shifts in the areas fished relative to the fur seals' distribution.

There are many other fisheries involved in the North Pacific and Bering Sea and further work is needed to determine the degree to which fur seals are killed as a result of incidental taking. Reviews of this general problem (Northwest and Alaska Fisheries Center 1980, Kajimura 1976, Jones 1982) indicated that, although the incidental take of fur seals in fisheries is a problem, there is doubt that it is a primary contributing factor in observed declines.

Entanglement in Debris

Since the early 1960s, fur seals on the Pribilof Islands have been observed with pieces of debris caught on their bodies. Presumably this occurs as a result of encounter at sea with floating materials enhanced by play behavior, curiosity, feeding on other attracted species or by attempts to use such debris in haulouts (Fiscus and Kozloff 1972).

Since 1965 the incidence of fragments of nets on animals taken in the harvest of subadult males on the Pribilof Islands has been monitored (Figure 3). The portion of these animals that exhibit entanglement in such debris has remained fairly constant over the past several years. These data alone, however, do not allow for an estimate of the rate at which animals actually die due to entanglement. Since a large portion of the entangled animals are caught in net debris, it is possible to entangled seals and for fragments that wash up on beaches. As demonstrated in Fowler (1982), these data can be used to estimate the proportion of entangled animals that become entangled in large fragments. In this case, the mean weight of fragments on animals observed on the Pribilof Islands in 1973 was 370 grams (13 ounces) (Sanger 1974). The mode for these fragments was 150 grams (5.3 ounces) and the maximum was about 2 kg (4.4 lbs.). Approximately 60 percent (by count) of the material washed up on the beaches of Amchitka Island was of greater size than the maximum observed by Sanger (1974) (Merrell 1980 and personal communication, 1982). Additionally, approximately half of the larger weight categories of net material observed both on beaches and seals were proportionately underrepresented in the fragments found on seals (again by count). If the net material on beaches is representative of that at sea, this implies that about 80 percent (60 percent plus 1/2 of 40 percent) of the entangled seals die and are not represented in the population of entangled seals observed on the islands.

If we assume that the probability of entanglement is independent of net fragment size, then the portion of the population that becomes entangled in large fragments is at least four times as high as for small fragments. From $c = 0.0111$ this rate is then: $4c = 0.0444$ or over 4 percent of the population each year. These are animals that become entangled and cannot make it back to the islands. Adding to these the animals that become entangled in small fragments and eventually die (0.011 of the population), we see that about 5.5 percent of the population will be estimated to die each year due to net fragments alone. About one-third of the observed entangled animals are entangled in plastic bands. If they exhibit mortality rates comparable to those entangled in small net debris, the total entanglement rate will be almost 5.9 percent.

The weakest assumption in these calculations is that of the time over which a 75 percent mortality would occur (corresponding to the 75 percent injured animals). Table 2 shows calculations based on alternative periods, including those outlined above (time = 6 months). Given the severity of the wounds created by entanglement, the actual mortality rates are probably higher than assumed above, making it likely that 75 percent of the entangled animals die in as few as 2–4 months.

Discussion

The analysis above is based on several assumptions that need further study. But there are many reasons why the assumptions behind the estimates in column 5 of Table 2 are conservative and make them lower bounds to the estimated mortality due to entanglement. For example, animals have been observed entangled in pieces of gill net at sea, yet the net entangled animals hauling out on the Pribilof Islands are entangled almost entirely in trawl net material. Females are known to travel over much longer distances than the males in their annual migrations. Not only are they thus potentially exposed to more debris, but their chances of returning to the islands are reduced. Not only were large fragments (over 5 lb [2.3 kg]) more numerous in Merrell's study, they also constituted over 90 percent of the weight of net material found on the beaches of Amchitka Island. Large fragments of net probably exhibit a higher probability of attracting seals and a higher probability of entanglement. Entanglements observed at sea involve large fragments of net and include at least one case of more than one seal caught in the same fragment of

Table 2. Estimates of mortality rates within the Pribilof Island fur seal population created by entanglement in debris as related to various estimates of the survival (and mortality) rates of entangled animals.

Time (months) for mortality of 0.75	m[a]	Monthly survival of animals in small net fragments	Annual rate of entanglement: In small net fragments (percent)	Annual rate of entanglement: In large net fragments (percent)	Total mortality due to entanglement (percent)
2	8.32	0.50	3.33	13.31	17.75
4	4.16	0.71	1.67	6.65	8.87
6	2.77	0.79	1.11	4.44	5.92
8	2.08	0.84	0.83	3.33	4.44
10	1.66	0.87	0.67	2.66	3.55
12	1.39	0.89	0.56	2.21	2.96

[a]A yearly instantaenous total mortality rate of animals entangled in small fragments of net (annual survival is e^{-m}).

trawl gear (Fiscus and Kozloff 1972, Jones 1982, Bouchet, personal communication). Large fragments tend to concentrate more fish of interest to seals, serve as potential "haulout platforms," and have more openings in which a seal can insert its head during play or in chasing prey (Fiscus and Kozloff 1972). Some gear is lost through being caught on the bottom. Nothing is known about whether or how often seals dive to feed near such debris and become entangled.

It is possible that a reduction in pregnancy rates has contributed to the decline observed in the population of northern fur seals. This is an alternative explanation to be compared to the extrinsic sources of mortality as emphasized in this paper. The result (a decline) would be the same in each case. However, based on physiological considerations, a depressed birth rate would be inconsistent with the increased growth rates, increased birth weights and other factors indicating that individual fur seals are showing many signs of good health. The empirical information concerning pregnancy rates shows little evidence of change (York 1979, Bigg 1979). There is a possibility that the age at maturation increased slightly in the year classes up to and including the 1956 year class (York 1982), but no trend is clear. It is possible to argue that age at maturation has declined since 1956 as shown by Fowler (1982) using correlations developed by York (1979) and Lander (1979b). Based on these sparse bits of information, it is doubtful that pregnancy rates have declined since 1956, but the possibility should not be ruled out.

It should be pointed out that the information presented in this paper should not be used to argue that the carrying capacity of the fur seal ecosystem has not been reduced. It can only be used to argue that a reduction in the carrying capacity for fur seals is not supported as a cause of the decline in the numbers in the population. Except for arguments by Swartzman and Harr (1980), it remains possible that the carrying capacity is lower than it was in the 1950s. The information presented in this paper simply leads us to the conclusion that the population is below the current carrying capacity of the ecosystem. Owing to the complexity of this issue and the lack of relevant information, the present carrying capacity is difficult to evaluate.

Summary and Conclusions

Starting about 1956 and proceeding to 1968, the fur seal population on the Pribilof Islands underwent a decline which, to a large but limited extent, is explained by the effect of the harvest of females that occurred during that period (York and Hartley 1980). The population did not recover from that reduction nor did it exhibit a tendency to produce harvestable males in greater abundance. The lack of recovery of the fur seal population following the female harvest and the current decline in the fur seal population are of particular concern. This problem developed concurrently with the growth of commercial fisheries in the Bering Sea and North Pacific Ocean. It is thus tempting to blame these problems on changes in the Bering Sea and the North Pacific ecosystems created by commercial fisheries. The most common cause-and-effect mechanism invoked in explaining this decline has been a hypothetical reduction of food resource levels available to the fur seals.

The available evidence concerning trends within the fur seal populations of the Pribilof Islands, however, does not support this hypothesis. During the same period, changes that occurred within the population tend to support the conclusion that conditions for fur seals improved. It is thus difficult to support the conclusion that changes within the fur seal's biotic ecosystem deteriorated in such a way as to create the lack of response following the female harvest and the current decline. Moreover this possibility cannot be supported on the basis of information concerning the feeding ecology of fur seals. They are opportunistic in their feeding strategy, making it likely that a reduction in prey of one type would cause a change in the composition of the diet rather than a significant reduction in consumption.

In view of the evidence concerning the positive changes that have occurred within the population, it became necessary to examine the argument that the population has undergone a decline created by extrinsic mortality. The evidence indicated that mortality at sea increased since 1956. The positive changes can then be interpreted as density dependent responses typical of other species of large mammals (Fowler et al. 1980). If such is the case, we are faced with the problem of defining the nature of mortality that would create the reduction. In view of the information concerning the abundance and character of net debris in the areas occupied by fur seals, combined with information concerning the nature of net fragments on entangled fur seals, it may be that the lack of recovery and the current decline of fur seal population is, in large part, due to entanglement in debris.

The precise degree to which the direct effects of fisheries influence fur seal population dynamics has yet to be reliably estimated. We know some mortality is caused by the incidental taking of fur seals directly in fishing operations, and that much of the entanglement observed in the population involves materials other than fragments of nets. Mortality caused directly as a result of fisheries operations may be responsible for a large part of the observed declines. Considering the current rate of decline of the population, in combination with the information in Table 2, 5 percent or more of the fur seal population may die each year due to the direct effects of fisheries. At current levels for the Pribilof Islands, this would be over 50,000 seals per year.

At the very least, the information presented above serves as a strong argument for the need to undertake further research concerning the importance of entanglement and incidental taking. It should also underscore the need to curtail the discarding of debris into the ocean.

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