INTERACTIONS BETWEEN FUR SEAL POPULATIONS AND FISHERIES IN THE BERING SEA

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ABSTRACT

In this paper we consider fur seal-fisheries interaction in the Bering Sea by asking whether the slower than originally predicted recovery of the fur seal stock from female fur seal harvest during 1956-68 might be a result of a reduction in carrying capacity because of the large fishery harvest of walleye pollock and Pacific herring—fish which are important fur seal prey.

The changes we found occurring in the fur seal population did not support the hypothesis that fur seal carrying capacity was reduced by the fisheries. In fact the population parameters changed little, or changed in a direction opposite to that proposed by the hypothesis.

Study of the fur seal diet data indicated that walleye pollock comprised a larger part of the fur seal diet in the 1970's, after the establishment of the fishery, than earlier, although average pollock size appeared to drop significantly. This trend may have been induced by an increased harvest of older fish. Since walleye pollock are cannibalistic, the removal of the older fish by the fishery could result in lower mortality among the younger pollock stocks, the outcome being an increase in the pollock resource available to both the fishery and the fur seal.

In this paper we assess and clarify possible relationships between fur seals and fisheries in the Bering Sea. The event most prominent in focusing concern on fur seal-fisheries interactions was the failure of the Pribilof Islands' fur seal herd to recover as predicted from large female harvests during 1956-68. While the present herd appears to have stabilized, it has stabilized at a population 30% below the maximum sustained productivity estimates made in 1955 (York and Hartley 1981). A number of possible explanations for this have been presented, including reduced fur seal carrying capacity.

In this paper we 1) briefly summarize and highlight the available fur seal and fish data, including studies of cases of other known marine mammal-fish interactions, 2) consider the evidence about fur seal population dynamics and seal-fish interactions, and 3) suggest analyses of existing data and further field sampling needed to clarify the effect of the Bering Sea fishery on fur seal populations.

AVAILABLE DATA

The relevant data may be divided into fur seal data, Bering Sea fish stock and fishery data, and anecdotal marine mammal-fish interaction data. The fur seal data consist of 1) annual fur seal collections at sea during 1958-74 in the eastern North Pacific Ocean and the eastern Bering Sea conducted jointly by the United States and Canada under terms of the Fur Seal Interim Convention (Kajimura et al. 1979,[2] 1980[3]); 2) harvests from 1950 to 1978 on the Pribilof Islands of subadult males (Lander 1981) and counts of harem and nonharem bulls from 1905 to 1978 on other island rookeries; 3) estimates of pup production on the Pribilof Islands from 1912 to 1924 and from 1951 to 1979 (Johnson 1975; Lander 1981), and counts of dead pups from 1950 to 1979 (Lander 1981); and 4) studies of fur seal rookery behavior (Bartholomew and Hoel 1953; Gentry[4]), food habits (Spalding 1964; May 1937; Wilke and

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[2]Kajimura, H., R. H. Lander, M. A. Perez, A. E. York, and M. A. Bigg. 1979. Preliminary analysis of pelagic fur seal data collected by the United States and Canada during 1958-74. Report submitted to the 22d Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission, 247 p. Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

[3]Kajimura, H., R. H. Lander, M. A. Perez, A. E. York, and M. A. Bigg. 1980. Further analysis of pelagic fur seal data collected by the United States and Canada during 1958-74. Part 1. Submitted to the 23d Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission, 94 p. Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

[4]R. Gentry, Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115, pers. commun. May 1980.

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Kenyon 1957; Fiscus 1979; Kajimura et al. footnotes 2, 3), and fertility (Abegglen and Roppel 1959).

Bering Sea groundfish and pelagic fisheries data, which give estimates of relative abundance, life history parameters, and migratory patterns of important fish stocks, are contained in a number of Northwest and Alaska Fisheries Center (NWAFC) reports (Pereyra et al. 1976[5]; Favorite et al. 1979[6]; Pruter 1973; Bakkala et al. 1979[7]). These data cover the period of development of the large foreign groundfish fishery in the eastern Bering Sea (1954-78) and include catch, catch per unit effort (CPUE), mortality, seasonal migration patterns, and diets for a number of commercially important fish, including walleye pollock and Pacific herring, important food sources for the fur seal in the eastern Bering Sea.

Fur Seal Data Synopsis

Seal Data Collected at Sea

Fur seal migration patterns were deduced from fur seals sampled at sea from 1958 to 1974. Adult males remain year-round in the Bering Sea and Gulf of Alaska, while females migrate south in winter, with smaller (younger) females tending to migrate the farthest south. Many subadult males also migrate south, but not nearly so far as the females. Females begin returning to the rookeries of the Pribilof Islands in June, and the rookeries are almost completely established by the end of July (Kajimura et al. footnotes 2, 3).

Pelagic data were also used to construct a fur seal life table (Lander 1981) which, along with a pup production estimate, gave an overall fur seal biomass estimate for the Pribilof Islands stock of 29,000 t or 1.25 million animals. Seasonal patterns of growth were also computed from the pelagic survey data (Lander 1981). Stomach content data were pooled over years by region and by month, and were presented as the frequency of occurrence (proportion of stomachs containing a particular food item), the volume and the percent of total food volume comprised by each prey type, and the number of specimens of each prey type and their percent of the total diet. Diet composition of fur seal stomachs by percent volume (which we consider to be the most reliable measure of prey abundance in predator stomachs) in the eastern Bering Sea is given in Table 1 (modified from Kajimura et al. footnote 3) pooled by month over all years of data collection.

TABLE 1.—Major species in fur seal diets in the eastern Bering Sea (percent volume), June-September. (Kajimura et al. footnote 3).

Species	June	July	August	September
Herring	—	0.2	13.2	0.2
Capelin	69.9	16.4	17.0	15.2
Pollock	4.1	50.9	26.1	38.3
Deepsea smelt	—	4.0	3.5	8.6
Atka mackerel	19.4	1.5	1.7	1.8
Squid	4.9	22.0	29.4	17.5

Fur seals are pelagic feeders and are highly opportunistic (Kajimura 1981[8]), feeding on a wide variety of species. Of their major prey only pollock and herring are target species for a fishery. Data on fur seal diets outside the eastern Bering Sea corroborate the pattern of fur seals feeding primarily on schooling fish. South of British Columbia, hake replaces pollock in seal stomachs and herring and sand lance are increasingly important, while capelin decreases in importance. Anchovy is the most important fur seal food off California. Since fur seals and fisheries both tend to exploit schooling species, a possible competitive relationship may exist between fur seals and fisheries. Most fur seal feeding in the Bering Sea is done by lactating females during the summer pupping period, so the importance of food during this period cannot be overemphasized. Since this is the period of rapid pup growth and is also the period of maximum growth for nonpregnant females and subadult males (Fig. 1), food limitation during this period could have drastic consequences to pup survival, especially after they leave the rookeries.

[5]Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Proc. Rep., 619 p. Northwest and Alaska Fisheries Center Seattle Laboratory, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[6]Favorite, F., W. J. Ingraham, Jr., K. D. Waldron, E. A. Best, V. G. Wespestad, L. H. Barton, G. B. Smith, R. G. Bakkala, R. R. Straty, and T. Laevastu. 1979. Fisheries oceanography — eastern Bering Sea Shelf. Proc. Rep. 79-20, 481 p. Northwest and Alaska Fisheries Center Seattle Laboratory, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[7]Bakkala, R., L. Low, and V. Wespestad. 1979. Condition of groundfish resources in the Bering Sea and Aleutian area. NMFS Northwest and Alaska Fisheries Center report submitted to the International North Pacific Fisheries Commission, 106 p.

[8]Kajimura, H. 1981. The opportunistic feeding of northern fur seals off California. Unpubl. manuscr., 46 p. Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

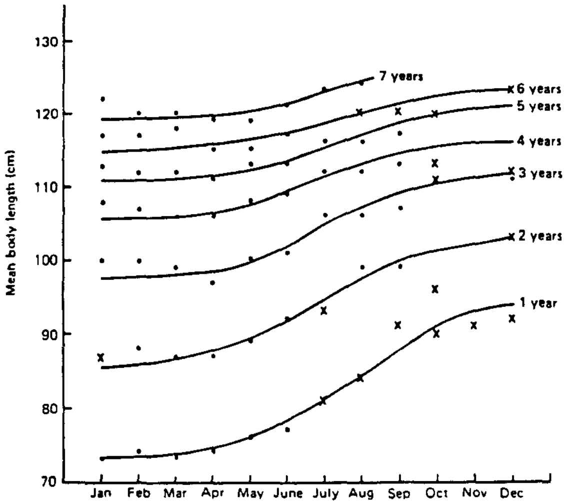

FIGURE 1.—Seasonal pattern of growth in mean length (cm) of nonpregnant female fur seals of age 1-7. Curves are drawn by inspection with the restriction of no downward curvature. An x designates <10 seals. From Lander (1981).

Sampling on the Fur Seal Rookeries

The herds on the Pribilof Islands (St. Paul and St. George Islands and Sea Lion Rock) are estimated to comprise 80% of the total world fur seal population. Every year from 1912 to 1924 and since 1950 some census of pup births has been made. Dead pup counts have also been made. Harvests of subadult males on the island hauling grounds have yielded information on weights, lengths, and age composition of these animals as well as limited food data from stomach samples. An estimate has also been made annually of numbers of harem bulls.

From 1956 to 1968 almost 300,000 females were harvested from St. Paul and St. George Islands, presumably to increase the sustained productivity of the herds. The herd subsequently failed to achieve a higher sustained productivity as was postulated from higher pregnancy and survival rates predicted from population projections (Abegglen et al. 1956[9]).

From 1912 to 1924, pup populations were estimated from direct counts. Fur seal populations increased steadily over this period at an 8% annual rate, as they recovered from heavy losses due to pelagic sealing in the late 19th and early 20th centuries. Direct counts were discontinued from 1924 to 1948, but an 8% annual population increase was assumed. However, estimates of pups in 1948 showed that the 8% increase had not continued. In 1947, tagging studies were set up to estimate pups and were continued until 1961. In 1960 an estimation procedure involving pup shearing and direct counts was initiated to replace the tagging method. Estimates of the number of pups born were computed by adding live pup estimates to dead pup counts.

The 1951-61 tagging studies are presently thought to have greatly overestimated actual pup abundance because of procedural difficulties and lost tags (Chapman 1973). The pup shearing procedure, although shown to be unbiased by comparing pup estimates with direct counts on small rookeries (Chapman and Johnson 1968), may be biased for large rookeries in such a way as to underestimate actual pup numbers (Fowler[10]).

Age-specific survival and weight at age were estimated from the weighing and aging of the preadult males harvested annually on the rookeries. Male harvest was discontinued on St. George Island in 1972 to study the effect of the male population density on seal population dynamics. Recent pup survival on St. George Island appeared lower than on St. Paul Island (Lander 1981), and this has been linked to the increased abundance of idle males on the rookeries (Fowler footnote 10).

Bering Sea Fish Data

Data on commercially important Bering Sea fish stocks by species have been compiled by the NWAFC. Catch data from Japanese, Russian, Korean, Polish, United States, and Canadian fishing operations have been included. The major species (in order of magnitude of catch) are walleye pollock, *Theragra chalcogramma*; yellowfin sole, *Limanda aspera*; Pacific herring, *Clupea harengus pallasi*; Pacific salmon, *Oncorhynchus* spp; Pacific cod, *Gadus macrocephalus*; sablefish, *Anoplopoma fimbria*; Pacific halibut, *Hippoglossus stenolepis*; other flatfish (rock sole, flathead sole, Alaska plaice, Greenland turbot,

[9]Abegglen, C. F., A. Y. Roppel, and F. Wilke. 1956. Alaska fur seal investigations, Pribilof Islands, Alaska. Manuscr. rep., 143 p. Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

[10]C. W. Fowler, Head, Fur seal investigations group, Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115, pers. commun. June 1980.

and arrowtooth flounder); and Pacific ocean perch, *Sebastes alutus*. Pacific herring and walleye pollock (hereafter referred to as herring and pollock) are the most important of these species in the diet of fur seals in the Bering Sea, and have been heavily fished (as have yellowfin sole, halibut, and Pacific ocean perch). The intensity of fishing on herring and pollock suggests the possibility of fur seal stock depletion due to decreased food abundance, although stock depletions can also have other causes.

Figure 2, adapted from Pereyra et al. (footnote 5) and Favorite et al. (footnote 6), gives the total catch for pollock and herring as well as an index of relative abundance (CPUE) based on research trawl surveys conducted by the International Pacific Halibut Commission, the National Marine Fisheries Service (NMFS), and the Japanese Fishery Agency.

Pollock stocks have been heavily fished since 1964, with peak yields coming in the early 1970's. A steady increase in CPUE between 1964 and 1968 may have been due in part to improvements in fishing gear and tactics, but must also have been due to higher levels of recruitment of young fish (Pruter 1973), possibly because of reduced cannibalism. Pruter (1973) pointed out that, since only a few age groups of pollock are utilized in

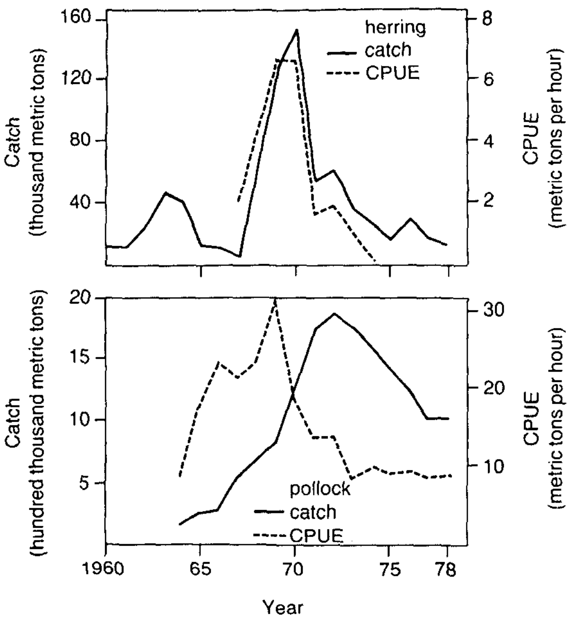

FIGURE 2.—Catch and relative abundance of walleye pollock and Pacific herring in the eastern Bering Sea. Adapted from Pereyra et al. (text footnote 5) and Favorite et al. (text footnote 6).

any given year, poor recruitment could have a disastrous effect on the fishery.

Herring harvest in the Bering Sea before 1968 was mostly west of long. 170°W. However, when stocks there declined, effort was shifted to the eastern Bering Sea, where the stocks were heavily exploited for 3 yr before abundance levels fell.

Relating stock abundances to fur seal food availability requires examining the overlap between Pribilof rookery feeding grounds and the area of the fishery. Since both fur seals and fishermen concentrated on areas of high fish density, we might expect competition for those fish species they both pursue.

Herring is a preferred food of fur seals, and evidence for heavy feeding on herring by fur seals in the Bering Sea was obtained from stomach samples taken in 1964 (Perez[11]). Since no large herring fishery exists in the eastern Bering Sea, we cannot be sure whether 1964 was a year of herring abundance or the high diet incidence of herring that year was just a local effect. Fur seals heavily exploit herring off Washington (Kajimura et al. footnote 3) where they are usually abundant. Heavy feeding on herring by fur seals has also been observed near Sitka, Alaska (Wilke and Kenyon 1957).

Schooling species such as herring, pollock, and squid provide a spatially heterogeneous, or patchy, feeding environment, making it difficult to interpret feeding patterns by average stomach content data. Pollock populations are patchy and mobile (Pereyra et al. footnote 5). The distribution of pollock between 1965 and 1970, generally warmer years, was more concentrated on the inner shelf than in the relatively colder years, 1971-75 (Pereyra et al. footnote 5). However, the region of the lower shelf between the Pribilof Islands and Unimak Island has consistently provided a large proportion of the Japanese catch of pollock throughout the history of the fishery in all months of the year (Pereyra et al. footnote 5). Thus, it may be that the fishery and the fur seal are most closely in competition for the pollock on the outer shelf. While fur seals are capable of taking relatively large prey, most pollock taken seem to be in the 6-20 cm range, while the fishery takes fish averaging 35 to 40 cm (Salveson and Alton 1976).

[11]M. A. Perez, Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115, pers. commun. May 1980.

Since there were no stomach content data for fur seals near the Pribilofs from 1968 to 1970, the years of the major herring fishery in the eastern Bering Sea, it was not possible to estimate how much interaction there was between fur seals and the herring fishery. Although herring is sometimes a food of fur seals, it may not be common in stomachs of the nursing female fur seals, because in summer the herring are not common in fur seal feeding areas but mostly remain in coastal waters (Wespestad 1978[12]).

Studies on Related Systems

Marine mammals are integrally tied to their environment. They can respond to reduction in competition by increases in abundance, which implies that many marine mammal populations are existing at or near their carrying capacities. Many marine mammals are opportunistic and voracious predators and can strongly affect trophic dynamics of lower trophic levels (Simenstad et al. 1978). Marine mammals are also frequently in food competition with each other. This is demonstrated 1) by the reduction in age of maturity of minke whales in the Antarctic Ocean after drastic reduction through harvest of sei and blue whales (Hofman[13]), 2) by the increase in ringed seal populations after depletion of bowhead whales in the Beaufort Sea (Lowry[14]), 3) in the fairly heavy predation of sea lions on fur seal pups (3.5 to 5.5% annually on St. George Island according to Gentry footnote 4), and 4) in the feeding overlap on hake by a large number of marine mammals (Fiscus 1979).

Work by Fowler (1981) showed that K-selected (low fecundity) animals demonstrate density dependence when near their carrying capacities, and from the above arguments it seems probable that most marine mammals exhibit density dependence in at least some of their population or growth parameters. Also, temporary reductions of a marine mammal population might provide an opportunity for a food competitor to reduce the carrying capacity of that marine mammal population. An important question in this case is whether the density-dependent effects experienced by a population at or near its carrying capacity are primarily a behavioral or a physiological phenomenon. The term "density-dependent" generally means that a population variable varies nonlinearly with changing population density. This does not, in itself, imply a direct cause or mechanism for this response. However, it may occur through increased mortality, reduced fecundity, reduced weight gains, or changes in animal condition. Each of these population parameters may be affected by a variety of density related factors.

In the case of the fur seal it has been hypothesized that reduction in fur seal populations due to female harvest gave the competing fishery an opportunity to increase harvest rates and thereby reduced the fur seal's carrying capacity. If this hypothesis is true, we should see a change in one or several of the population parameters discussed earlier.

EVIDENCE OF CHANGES IN FUR SEAL CARRYING CAPACITY

Fur Seal Population Trend

The fur seal population appears at present to be dropping. After the female harvests from 1956 to 1968, an increase in pregnancy rate and survival was expected. This expected response of the population did not materialize, and population numbers are reduced over model population projections.

Hypotheses to explain the reduction since 1956 (Fowler footnote 10) are:

1) The discrepancy is mainly due to overestimates of pup abundance during the tagging studies (1951-61) and underestimates in the subsequent pup shearing studies.

2) There has been a reduction in carrying capacity because of reduced available food in the Bering Sea, resulting from overfishing of major food sources for the fur seal—pollock and herring—in the feeding areas of the rookery seals.

3) The reduced pup abundance may be a transient effect of the female harvest. This is in spite of the observation that the direct effect of the animals removed has by now largely passed through the population (Lander 1981).

4) Increased abundance of nonharem adult males and an increase in ratio of these males to harem bulls on St. Paul Island may have reduced

[12]Wespestad, V. G. 1978. Exploitation, distribution and life history features of Pacific herring in the Bering Sea. Proc. Rep., 26 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[13]R. Hofman, Marine Mammal Commission, 1625 Eye Street NW., Wash., DC 20006, pers. commun. May 1980.

[14]L. Lowry, Alaska Department of Fish and Game, Fairbanks, AK 99701, pers. commun. May 1981.

land survival of pups. In pinniped populations on other islands—fur seals on the Commander Islands, Robben Island, and St. George Island, and elephant and grey seal populations on other islands—total adult populations are increasing and pup survival is going down. Thus, although pup production is increasing due to increased numbers of adult females, pup survival is reduced.

5) There may be reductions in survival and birth rates caused by pollutants and entrapment in fishing gear.

Among the most serious alternatives (from the standpoint of its implications for man) is that increased fishing intensity in the Bering Sea during the female harvest period has reduced the carrying capacity of the Bering Sea for fur seals. In our discussion of the Bering Sea fishery data we noted that the most probable link, if any, is in depletion by the fishery of pollock and herring in the feeding area of nursing females. Demonstration or corroboration of this hypothesis directly requires showing that pollock and herring stocks have been reduced in rookery fur seal feeding areas and that this has resulted in reductions of these foods in female fur seal diets, and reductions in lactating fur seal feeding rates and consequently in pup growth and survival. Present data available on fur seals, while substantial, is not sufficient to attempt so conclusive a test of this hypothesis. For example, fish surveys were not made in conjunction with pelagic fur seal surveys, so we do not know how selective fur seals are in their feeding or how dependent their feeding rates are on prey density and relative prey abundance. Also, we do not have direct estimates of the abundance of noncommercial species such as capelin and squid, which comprise large portions of the seal's diet and may be abundant in the absence of pollock and herring.

We suggest, and others have suggested before (Fowler 1980; Eberhardt and Siniff 1977), that there is a need to examine the changes in a number of behavioral and physiological indices of fur seal populations which might have presaged or reflected reduced carrying capacity. Measures that we considered are 1) the age at which females attain sexual maturity, 2) the weight at age for harvested preadult males, 3) the number of pup deaths on land compared with total pup births, 4) the average time spent at sea by lactating females (or some composite index of the time at sea plus the time suckling pups), 5) the survival rate of pups to age 3 computed from harvest of 3-yr-old males and pup counts 3 yr earlier, and 6) changes in diet composition after the development of the pollock fishery. We also used estimates of fur seal abundance, fish stock, and daily food intake to see how great an impact the fur seals actually made on this stock and whether estimated fishery reductions in the stock were sufficient to impact the fur seals.

Fur Seal Population Indices

Age at Sexual Maturity

Kajimura et al. (footnote 3) used a method modified from Lett and Benjaminsen (1977) to compute an average age of maturity for year classes from 1954 to 1964 (from the 1958-74 pelagic cruises). These are graphed in Figure 3 (from Kajimura et al. footnote 3). The average age at maturity increased sharply for the 1956 year class, the first year the females were harvested. Age at maturity subsequently dropped and remained stable, though at a higher average age than before 1956. The graph in Figure 3, as well as the results of other studies done before 1956 on age at maturity, suggests that post-1956 age at maturity was greater than pre-1956 averages.

There are a number of alternative explanations for the apparent increase in age of maturity in addition to the carrying capacity of fur seals being reduced. First, the increase may also have been due to the female harvest on the Pribilofs, selecting a higher fraction of mature females at a given age than actually existed in the population. Since the Pribilofs are a rookery, the presence of mature females in higher proportion than in the

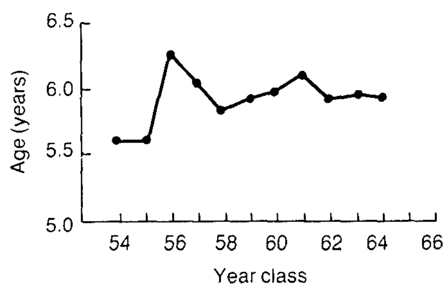

FIGURE 3.—Estimated average age at first reproduction of female northern fur seals based on females pregnant at least once for the 1954-64 year classes. From Kajimura et al. (text footnote 3).

entire population would leave the nonrookery population with a higher proportion of immatures which would then affect the samples taken at sea. Another difficulty with these data is that only 2 yr of pre-1956 age class data were available from the pelagic cruises, and the other pre-1956 data reported by Kajimura et al. (footnote 3) may not have used the same index of maturity as Kajimura et al. (footnote 3). Other possible sources of bias in the age at maturity estimate were the tendency of the pelagic fur seal samples to contain a higher number of older individuals than expected, and the underlying assumption that survival rates of pregnant and nonpregnant females are the same (Kajimura et al. footnote 3).

Growth With Age

Preliminary analysis by the National Marine Mammal Laboratory (NMML) (Fowler footnote 10) of the data from 3-yr-old males harvested on the Pribilof Islands showed a statistically significant increase in weight over time from 1964 to 1970 in contrast to growth rate reductions to be expected under a reduced fur seal carrying capacity.

Kajimura et al. (footnote 2) plotted the average length of pregnant females against age for the time periods 1958-62, 1963-68, and 1969-74. Their results (Fig. 4) indicate that growth rates were greater from 1963 to 1974 than from 1958 to 1962. These results raise the possibility that the fur seal might actually have experienced an increase in carrying capacity since 1963. However, Berdine[15] noted that if fur seal population density and carrying capacity both decline, growth rate could still show an increase. As mentioned earlier, changes in carrying capacity can result from a variety of causes, and until stronger links are established between fur seal populations and their controlling processes, arguments that carrying capacity changes are reflected by certain changes in population parameters will be incomplete.

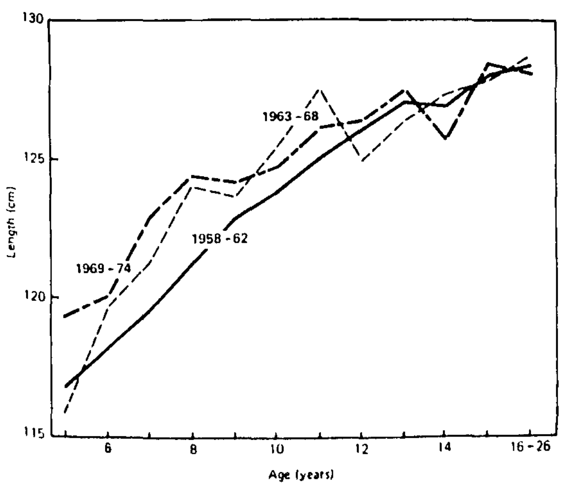

FIGURE 4.—Comparison of average lengths of pregnant fur seal females age 5 to 16-26 for combined months of January to April 1958-62, 1963-68, and 1969-74. Sample size ≥10 seals. From Kajimura et al. (text footnote 2).

Pup Deaths on the Rookery

Counts of dead pups on the rookeries of the Pribilof Islands are an indication of the survival rate of pups, when these are used in conjunction with total pup birth estimates. Gentry (footnote 4) estimated that dead pup counts include around 95% of the actual dead pups on the islands. From 1970 to 1979 pup death estimates on the Pribilof Islands varied between 4,500 and 54,000, averaging about 25,000—about 7% of the average pup population (Lander 1981). Earlier pup count data indicated extremely high pup mortality in 1954, 1956, 1960, and 1961; the last three years were also the years when mature females were harvested—this may account for the high pup mortalities.

Several facts about the dead pup counts are: 1) Large pup losses appeared more frequently before 1956 than after, although this bears further corroboration; 2) the year-to-year variability in pup mortality was large; and 3) pup mortality on St. Paul Island did not appear to be correlated with that on St. George Island, while temporal patterns of pup mortality from one rookery to the next on either island were more closely correlated with each other. The last fact seems to argue against food limitation as the controlling factor for pup survival through the rookery period and suggests, instead, some more local effects on the populations.

Average Time at Sea for Mother Seals

Bartholomew and Hoel (1953) recorded time at sea and nursing for 12 nursing fur seals in 1952

[15]J. Berdine, Judson Hall, Room 621, 53 Washington Square South, New York, NY 10012, pers. commun. August 1980.

on St. Paul Island. Gentry (footnote 4) made similar observations on nursing fur seals in the late 1970's and found no significant change in time at sea from those of Bartholomew's study.

Pup Survival to Age 2

Lander (1981) calculated early survival rates to age 2 for male fur seals from the 1950-70 year classes. York and Hartley (1981) analyzed these estimates, using Mann-Whitney and Student's *t* tests, and found pre-1956 rates to be significantly lower than post-1956 rates (0.32 vs. 0.40 average). This does not appear to support the hypothesis of reduced carrying capacity.

Time Trends in Fur Seal Diets

Fur seal stomach contents taken in 1960, 1962-64, 1968, and 1973-74 cruises were used to investigate trends in fur seal diets to see whether these might have changed after development of the pollock fishery. These data were summarized by month.

Figure 5 indicates that the age composition in catch in the pollock fishery shifted from a mode of 4 yr in 1964 to 3 yr in 1974 with the 2-yr-old catch also being strongly represented. H. Kajimura, who was present on the cruises, suggested that the size of pollock in fur seal stomach samples decreased from 1964 to 1974. Examination of average volume per pollock specimen in fur seal stomachs (Unpubl. data[16]; Table 2) corroborates this observation, with average specimen size decreasing significantly between 1968 and 1973-74. We also note that the percentage volume of the total stomach content comprised of pollock was consistently high in 1973-74 (>48%), while earlier, especially before 1968, pollock comprised a variable and usually low percentage of the diet (<20% in 8 of the 11 mo sampled).

These data indicate that there may have been an interaction between fur seal diets and the pollock fishery. As fishing pressure on pollock increased, fishing out of older age classes reduced the average size of the fish and increased the average growth rate of the pollock. Furthermore, young pollock survival may have been increased through reduced cannibalism. These increased

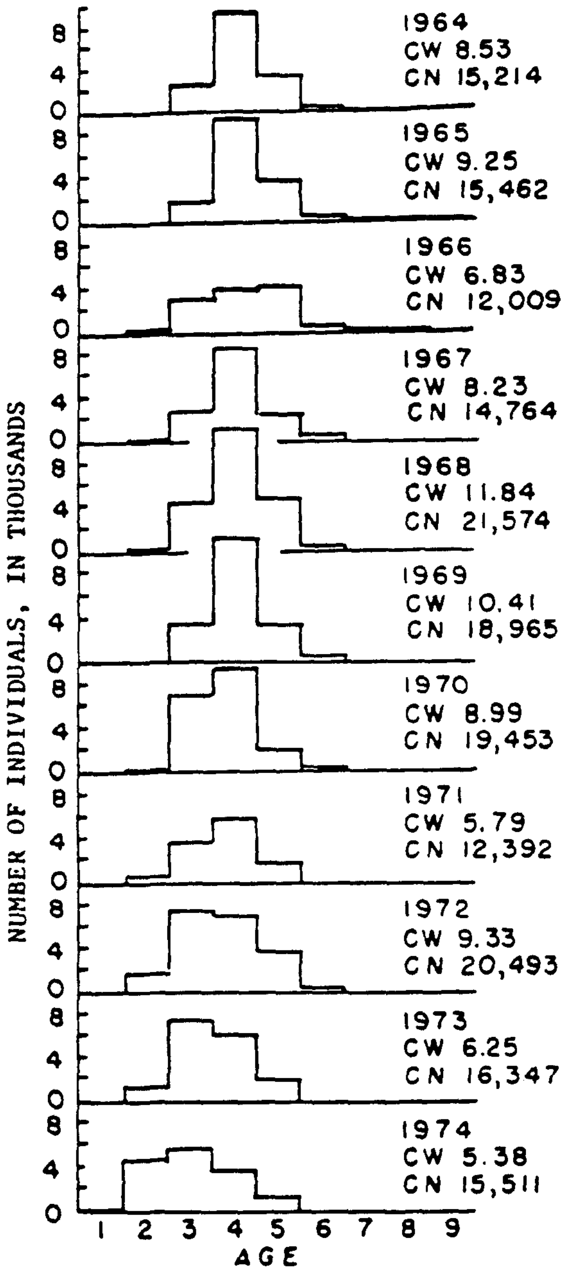

FIGURE 5.—Age composition in catch per unit effort (CPUE) of walleye pollock from the Japanese trawl fishery in the eastern Bering Sea. Japanese trawl fishery includes the mothership fishery and the North Pacific trawl fishery, but not land-based-dragnet fishery. From Salveson and Alton (text footnote 12). CW = CPUE in weight in metric tons; CN = CPUE in number.

stocks of smaller fish were reflected by the increase in abundance of pollock in fur seal diets after 1968 and by a marked decrease in the average size of fish taken by the fur seals. This in-

[16]Data obtained from Dr. M. Tillman, Director, Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

TABLE 2.—Fur seal diet of walleye pollock from pelagic samples in the eastern Bering Sea. (Unpubl. data (text footnote 16).)

Date	Number of stomachs with food	Volume of pollock in diet		Number of pollock in diet	Percent of total numbers	Pollock volume/ specimen (cm^3)
		cm^3	Percent			
June 1960	4	385	12.3	19	5.2	20.26
July 1960	152	39,807	61	403	9.8	98.7
Aug. 1960	61	37,124	75	148	10	251
June 1962	53	295	2.4	2	0.16	147.5
July 1962	137	4,343	12.6	45	1.1	96.5
Aug. 1962	277	17,266	18.3	323	3.1	53.45
Sept. 1962	111	10,342	28	235	5.4	44.0
July 1963	256	11,188	14.16	62	0.56	180.45
Aug. 1963	536	9,758	5	163	0.59	59.9
Sept. 1963	17	700	11.06	1	0.11	700
July 1964	97	2,354	9.5	7	0.27	336
Aug. 1964	213	29,296	15.4	792	9.8	37
July 1968	78	31,901	76.9	384	14.3	83
Aug. 1968	53	11,206	37.4	30	1.21	373.5
July 1973	148	72,427	90.7	1,418	33.0	51.07
Aug. 1973	191	36,564	60.7	1,305	15.1	43.34
Sept. 1973	178	32,511	48.5	2,172	23.7	14.9
July 1974	52	13,658	87.4	244	58.6	36.0
Aug. 1974	110	15,198	63.2	390	20.2	38.9

crease in total stock biomass, mostly in the younger age classes, can account both for the increased fur seal diets on (mostly smaller) pollock and the continued high yield of the fishery after over 10 yr of heavy fishing pressure.

Table 2 indicates that both fur seals and the fishery may have exploited the same pollock resource, since both show a drop in size of "catch" over time. We suspect that the trend toward greatly increased abundance of pollock juveniles in the Bering Sea has also resulted in larger schools (patches) of juvenile pollock, which has made them an easier target for the fur seals and also the fishery, than previously. One possible, dangerous consequence of future increased fishing pressure on pollock, however, is that most of the catch will be of premature individuals. With continued heavy fishing pressure, this might result in inadequate recruitment to maintain the stock.

A possible alternative explanation for why pollock were so consistently taken by fur seals in 1973-74 is that these were relatively cold years with pollock aggregating more on the outer shelf than in warmer years (Pereyra et al. footnote 5). Another possible explanation is that the Pribilof area, where the bulk of the 1973 and 1974 stomach samples were taken (unlike the earlier samples which did not focus as heavily on this area), is a nursery area for young-of-the-year pollock, which may account for the reduced average size and increased abundance of pollock in fur seal stomachs during 1973 and 1974. Despite these possible alternatives, the most plausible hypothesis is that pollock has increased in importance in fur seal diets since the initiation of the pollock fishery.

Energetics Approach to Fur Seal Food Consumption

The total amount of food consumed by fur seals (and other marine mammals as well) in the eastern Bering Sea has been estimated by a number of individuals (Laevastu and Larkins 1981; McAlister and Perez 1976[17]; Anonymous 1979[18]). McAlister and Perez (footnote 17) estimated that fur seals eat 378,000 t of fish and squid every year. They used an estimated feeding rate of 7.5% body weight daily while Miller (1978)[19] suggested that 14% body weight daily may be more appropriate to support seals at 7°C, the average summer temperature in the Bering Sea. Miller based his arguments on metabolic studies in which he recorded oxygen consumption at different temperatures in the laboratory for a number of juvenile seals and also conducted feeding studies using food most commonly found in the diet of

[17]McAlister, W. B., and M. A. Perez. 1976. Preliminary estimates of pinniped-finfish relationships in the Bering Sea. Background paper for the 19th meeting of the North Pacific Fur Seal Commission, 29 p. Northwest and Alaska Fisheries Center National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

[18]Anonymous. 1979. Draft environmental impact statement of the Interim Convention on Conservation of North Pacific Fur Seals. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Seattle, Wash., 39 p.

[19]Miller, L. K. 1978. Energetics of the northern fur seal in relation to climate and food resources of the Bering Sea. U.S. Marine Mammal Commission Report MMC-75/08, 27 p.

fur seals in the Bering Sea. Using Miller's estimate for consumption would give an estimate of 705,000 t eaten annually by fur seals. Laevastu and Larkins (1981) gave an estimate of 513,000 t taken by fur seals annually in the eastern Bering Sea, with an additional 368,000 t taken in the Aleutian region. The latter estimates were based on runs of the PROBUB (prognostic bulk biomass) model. Estimates of fur seal populations of the Bering Sea and the Aleutian Islands and their mean consumption rates, given in Table 3 (Anonymous footnote 18), were used to compute a total fur seal consumption of 219,000 t.

These estimates can be compared with annual fish catches in the eastern Bering Sea and Aleutian Islands (North Pacific Fishery Management Council[20]). Between 1968 and 1976, annual fish catches varied between 750,000 and 2,100,000 t in the eastern Bering Sea and between 40,000 and 80,000 t near the Aleutian Islands. These figures indicate that fish harvests by marine mammals and by man in the Bering Sea are comparable and that the marine mammals' harvest exceeds man's in the Aleutian Islands' area. It is important to note, however, that fur seals prey on a larger number of species than man, and thus a part of their harvest is not in direct competition with man's. As a consequence of the fur seals' greater ability to switch prey when abundances of preferred prey species are low, total fur seal consumption is probably fairly steady from year to year, while man's is highly variable.

It has been estimated (Anonymous footnote 18: table 12) that 9.8% of fish standing stock in the eastern Bering Sea and the Aleutian Islands is consumed annually by marine mammals, 5% by man, and 1.8% by birds (1.9% by fur seals). Laevastu and Larkins (1981) estimated a total commercial fish standing stock of 24,880,000 t in the Bering Sea and Gulf of Alaska, which implies that 3.5% of all commercial fish stocks are taken by fur seals annually and 10.7% by all marine mammals. The fur seal figures are deceptive, since fur seal impact on fish stocks is relatively localized. Thus, fur seals near the Pribilof Islands are probably consuming considerably more fish than man is, though man may be harvesting some different species than fur seals. This energetics computation is inconclusive with respect to fur seal-fishery interaction, except to show that competition between the two is possible.

[20]Data available from North Pacific Fishery Management Council, 333 W. Fourth Ave., Suite 32, P.O. Box 3136DT, Anchorage, AK 96813.

DISCUSSION

Suggested Analyses of Existing Data

Population Indices

Following Eberhardt and Siniff's (1977) suggestion that a population's response to impact may be reflected by various indices, we suggest

TABLE 3.—Fur seal population estimates at sea (June-November) in the eastern Bering Sea and Aleutian area (Anonymous text footnote 18).

Age class	Population[1] total	June-Nov. eastern Bering Sea and Aleutian	Estimated percent of time at sea (June-Nov.)	Estimated population at sea (June-Nov.)	Mean[2] weight (kg)	Mean[3] daily consumption rate (%)
Pups	349,000	[4]321,000	10	32,100	10.00	14.00
M+F, age 1	174,000	67,000	[5]90	78,300	9.54	13.76
M+F, age 2	122,000	61,000	[5]75	45,750	16.69	12.32
F, age 3	55,000	23,000	[5]80	22,400	18.80	12.53
F, >age 4	582,000	46,000	[6]79	368,140	35.64	11.76
M, age 3-7	101,000	71,000	[7]10	7,100	32.60	7.60
M, >age 7	11,000	9,000	[7]10	900	105.25	7.01
Total	1,394,000	1,043,000 [8](754,100)		554,690	29.92	11.71

[1]Average 1969 to 1974.
[2]Based on National Marine Mammal Division, NMFS pelagic research data, 1958-74, $N = 13,772$, except average weight for pups (10 kg) based on observations in the Pribilof Islands during September; total mean weight based on an effective fishery population 754,000, on time spent on land and at sea for each class during June and September.
[3]Weighed by mean animal weight of estimated body weight for animals weighing <10 kg or <45 kg in waters colder than 15°C; 7% for >10 kg on land or >45 kg at sea.
[4]Based on the ratio of males to females (0.085) in the eastern Bering Sea during June-November from National Marine Mammal Division, NMFS pelagic research data, 1958-74 ($N = 4,451$).
[5]8% mortality, pups estimated to feed at sea only 18 d (10% of time) during September-November.
[6]These percentages represent proportions of the total population of the respective age class not on the rookeries during the breeding season.
[7]Based on percent of time out of 130 d not on rookery.
[8]Effective fishery population (June-November).

that the available data from which these indices are computed be also studied for trends. Indices that are most easily obtained for the fur seal are pup birth estimates, dead pup counts, male survival to age 3 (from male harvest data), and length at age for preadult males (from harvested males).

Fur Seal Diet Trend

We have suggested a relationship between fur seals and the fishery via greatly increased abundance of juvenile pollock (Table 2). The data used, however, were already combined in such a way that we were unable to separate the data by region where the data were collected and the degree of digestion of the prey. We suggest that the original data be used to conduct a complete statistical analysis with corrections made for the area in which the sample was taken and, if possible, the time of day the samples were taken (assuming that the correlations found between the proportion of the stomachs empty and time of day the samples were taken also applies to the percentage of food digested). Variance estimates can also be computed and used to make statistical tests for time trends both in the average size of pollock in fur seal stomachs and in the percentage of the total diet comprised of pollock.

Role of Patchiness in Seal Feeding

Although we suspect from survey data on pollock (Smith 1979) that pollock are quite patchily distributed in the eastern Bering Sea, the survey data need to be reexamined for an indication of the size of patches or degree of aggregation. An attempt should be made to represent this patchiness stochastically (in terms of probability). One important question to be considered with these data is whether or not there has been a trend in pollock school size from 1963 to 1974 in the eastern Bering Sea. Another approach to consider patchiness is to use the abundance of pollock in fur seal stomachs collected at different locations as an index to the spatial separation and size of pollock schools.

Suggested Future Data Collection

We suggest that a fish trawl survey targeting on pollock be conducted between the Pribilof Islands and Unimak Pass from June to September with study designed to focus on areas of high pollock density to determine the size distribution of pollock, the size of the schools, and, if possible, to observe fur seal feeding intensity around the schools. The pollock and fur seals might be tracked by using multibeam sonar techniques. Additional stomach samples of fur seal taken in conjunction with the trawl survey would give useful insight into fur seal food selectivity.

CONCLUSIONS

In summary, we see rookery fur seal behavior and multispecies, age-classed, patch-feeding models as directions for future study. Before proceeding in this direction we recommend further detailed analyses of the fur seal stomach content data, to explore more fully the interaction between the fur seal and the walleye pollock fishery (Table 2), and to elucidate other interactions with fisheries of which we may be unaware at this time.

The available fur seal and fishery data, while limited, appear to be the best mammal-fishery data in the world and as such deserve to be fully archived and fully utilized.

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