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ECOSYSTEM DYNAMICS BIRDS AND MARINE MAMMALS

Part I

Preliminary Estimates of Pinniped - Finfish Relationships in the Bering Sea

by

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ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF

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An important task of scientists associated with the Alaskan Outer Continental Shelf Environmental Assessment Program is to conduct research and analyze all known data to determine the structure and behavior of the Bering Sea ecosystem. This research is essential if we are to understand the impact on the environment of man's activities on the outer continental shelf. We now know very little about the dynamic behavior of this ecosystem, but we do have some information which helps to shed some light on the subject. Most of our information exists as individual population assessments, oceanographic analyses, and the results of food chain studies which have been undertaken by several research agencies. All of these independent studies should be integrated into a single unified concept describing interrelationships among marine organisms in the ecosystem.

For years, marine mammals have been hunted and populations reduced or eliminated to control assumed predation on commercial stocks of fish and shellfish. Yet actual mechanisms of the cause and effect relationship between pinnipeds and fish abundance remain largely unknown. Some information is available on direct relationships such as feeding, but the nature and extent of indirect relationships remain obscure. Many of the marine mammal species that occur in Alaskan waters are seasonal entrants whose range includes thousands of miles of coastal and pelagic waters of other nations. The commercial fishery off Alaska is both U.S. and foreign. Consequently, the status of marine mammals there is of concern and potential value to other nations. The Marine Mammal Protection Act of 1972 established a moratorium on the taking of marine mammals by all U.S. citizens except for certain Alaskan natives who may harvest certain species for subsistent, and for others who may take animals for display and scientific collection. The northern fur seal, a species regulated by international treaty with Canada, Japan, and the USSR, is harvested on land by the United States. All activities which will affect either marine mammals or their environment must be consistent with provisions of the Marine Mammal Protection Act, particularly with the requirements to maintain a healthy ecosystem. Major changes in mammal or fishery stocks will affect the several components of the ecosystem, but the magnitude. extent, and even direction of the effects of a particular management action are difficult to predict in a complex ecosystem. In addition, impacts caused by environmental changes must be considered.

In order to improve our understanding of how fisheries and mammals interact in the. Bering Sea, the Northwest Fisheries Center of the National Marine Fisherie Service has been examining some of the relationships between marine mammals and fisheries. Some of this research is being conducted as part of a study on the northern fur seal to fulfill obligations under the Interim Convention on the Conservation of North Pacific Fur Seals. In addition, research is being conducte on aspects of the ecosystem under the Alaskan Outer Continental Shelf Environmental Assessment Program. A detailed analysis of all eastern Bering Sea and eastern North Pacific pelagic data collected during research carried out on northern fur seals since 1958 on distribution, reproductive rates, and feeding ha been started. Information on other marine mammals, fisheries stocks, and oceanographic data are also being combined with an analysis of fur seal data to determine the dynamics of the Bering Sea ecosystem.

Studies reported on in this paper represent the results of research proposed within Research Unit 77 of the OCSEAP to integrate and synthesize these data into a conceptual submodel of the ecosystem describing trophodynamic relationships in the eastern Bering Sea including interactions among northern fur seals, other marine mammals, marine birds., and several species of fish. The amount of food consumed by fur seals and other pinnipeds has been estimated and compared with the amount of fish caught by commercial fisheries in the same waters.

The Bering Sea Ecosystem

In terms of fishery exploitation and the distribution of marine mammals it is convenient to consider the Bering Sea as divided into two subunits: the eastern Bering Sea shelf and the Aleutian area (Figure 1). Pinniped stocks in the Bering Sea are large, including northern fur seals for which extensive research and population data are available, and provide a basis for estimating biological parameters for other pinnipeds where direct observations are not available. The area is one of high overall productivity and of heavy commercial utilization with a good historic fisheries data base. Although not adequate to the degree one would like, data exist for estimating productivity at the upper trophic levels, and by inference at least, throughout the food web.

The food web is enormously complex in the ocean and the eastern Bering Sea is no exception. Although much of the primary productivity of phytoplankton takes place in the water column, blooms of algae in and beneath the sea ice in late winter, and eelgrass and epibenthic phytoplankton growing on mud flats in summer all contribute to the total primary production of the area (McRoy et al., 1972). Progress has been made in understanding the amount of primary production in the water column which can be used as a basis to estimate overall productivity, however, the interrelationships between pelagic, in-ice, and epibenthic production remain to be properly identified. Sanger (1974) has reviewed the available data (Table 1), and obtained a value of 415 mg $C/m^2/day$ as an estimate of primary production in the Bering Sea. Estimated production in the Aleutian area is lower, averaging near 100 mg C/m*/day.

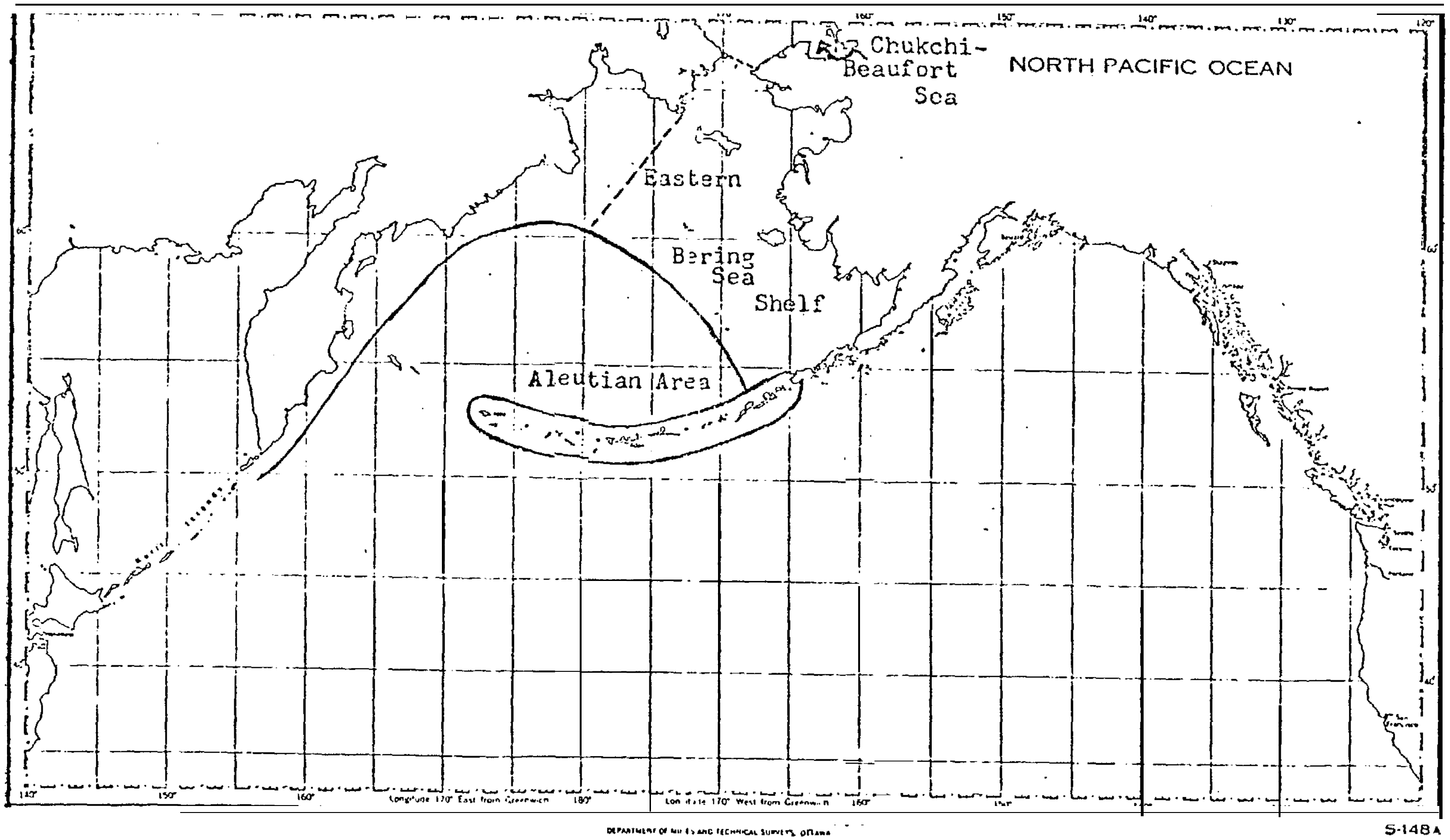


Figure 1. -- Oceanic areas adjacent to Alaska, based on the schematic Domains of Dodimead et al (1963).

'able 1. --Recent estimates of primary production in the water column for oceanic Waters contiguous to Alaska (Carbon- 14 method). [1]

.egion	Daily Rate (mg C/M'/ clay)	Dates	Source
ering Sca			
Bering Strait	4, 100	June 1969	McRoy et al (1972)
Eastern Bering Sea	21	February 1970	McRoy et al (1972)
leutian Area			
Unimak Fass Area	243	June 1968 & 1970	McRoy et al (1972)
	85	February 1967	McAlister et al (1970)
Amchitka Island Area	38-45	February 1968	McAlister et al (1968)
Adak island Coast	686	June-July 1967	Larrance (1971)
	581	August 1967	Larrance (1971)
	404	September 1966	Larrance (1971)
Adak Bay	350-460	March 1966	Larrance (1971)
	840-2, 400	late spring-summer	Larrance (1971)
entral Subarctic Domain			
Subarctic waters south to Adak Island	1.33	February	Larrance (1971) (Fig. 5, p. 604)
	325	March	Larrance (1971)
	280	May	Larrance (1971)
	327	June	Larrance (1971)
	250	July	Larrance (1971)
	207	August	Larrance (1971)
	240	September	Larrance (1971)

[1] Adapted from Sanger, 1974.

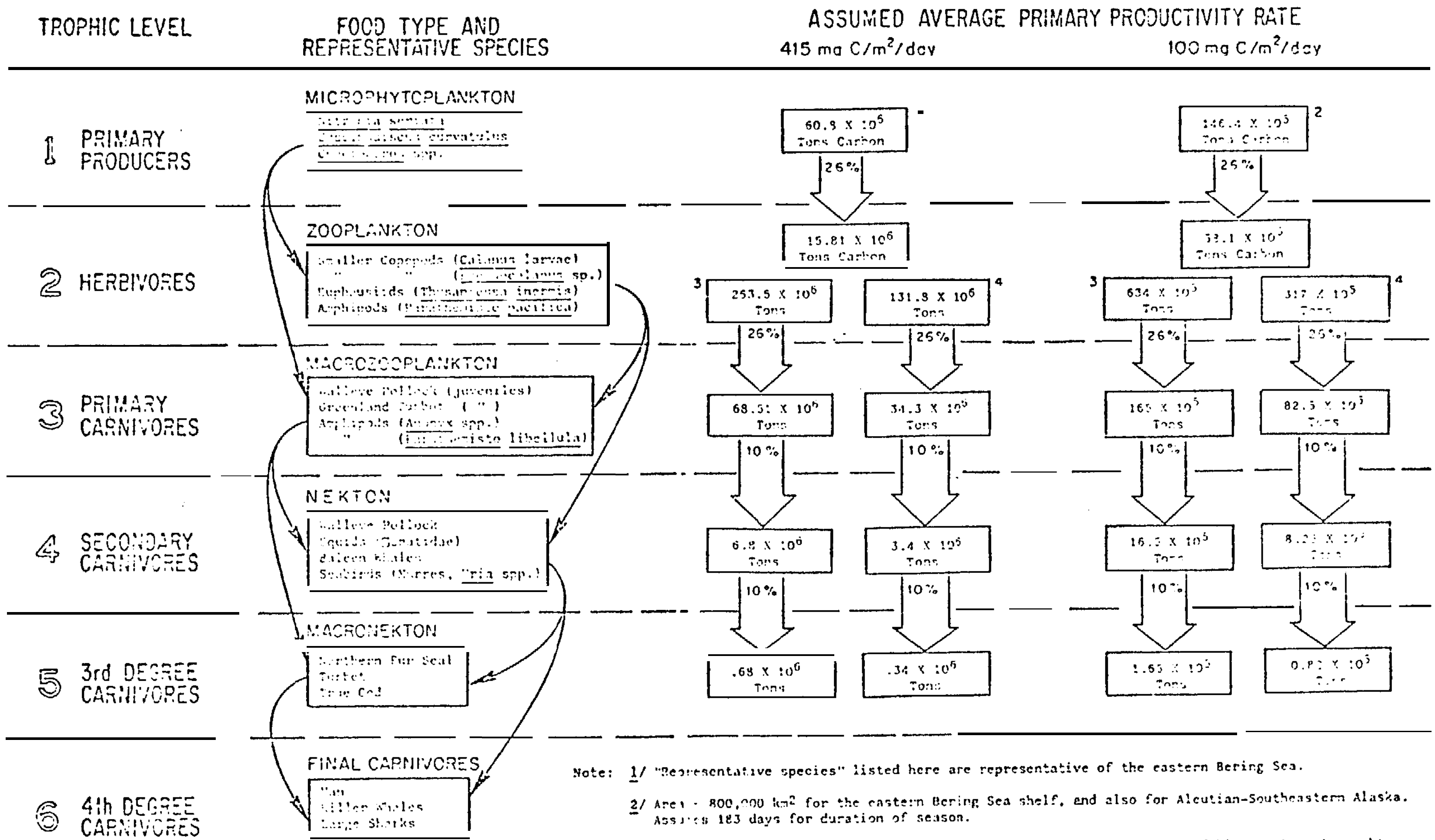
Figure 2 shows a schematic food chain for the eastern Bering Sea shelf area in summer (defined as June through November). Examples of representative species are given to show the kinds of organisms which would be expected to occur at the various trophic levels in the fur seal food chain. Karohji (1972), Hiroshi Kajimura (pers. comm.) .), and Donald S. Day (pers. comm.) provided suggestions for some of the representative animals used in Figure 2. Calculations of productivity at each trophic level are shown for average daily production rates of 415 mg C/m^2/day and of 100 mg C/m^2/day. The overall productivity rate needs to be revised upwards to account for ice edge/under ice, epibenthic, intertidal and eelgrass productivity.

Because primary productivity is measured and expressed in terms of organic carbon production, estimates of organic carbon at the herbivore level were converted to biomass to relate production to stocks of organisms at higher trophi levels. Sanger (1974) has reviewed the literature and discussed possible energy transfer coefficients between trophic levels and conversion factors of organic carbon to biomass for zooplankton. Figure 2 shows calculations for values of 6% and 12% as the carbon content of zooplankton biomass to represent the possible overall range of values. The values of energy transfer coefficients (percent of the production at trophic level n produced at trophic level n+1) used to calculate productivity at the next higher level are also shown in Figure 2; however, it should be stressed that many uncertainties exist concerning conversio factors between trophic levels in the fur seal food web, and that the calculation shown in Figure 2 should be considered as rough estimates only.

Food Consumption by Pinnipeds

In order to calculate the amount of food consumed by pinnipeds, it is necessary to know the size of the population, the biomass of each pinniped specie in the ecosystem, and consumption per pound of biomass. Table 2 lists the currer

Figure 2. Schematic, simplified summer (June- food chain, applicable to the eastern Bering Sea.



Note: 1/ "Representative species" listed here are representative of the eastern Bering Sea.

2/ Area - 800,000 km² for the eastern Bering Sea shelf, and also for Aleutian-Southeastern Alaska. Assumes 183 days for duration of season.

3/ Assumes a factor of 6% for conversion of the organic carbon content of biomass to wet weight.

4/ Assumes a factor of 12% for conversion of the organic carbon content of biomass to wet weight

Table 2. Population and biomass estimates for pinnipeds in Alaska

Species	Total. Alaska Population Size ($x10^3$)	Population Size in the: [1] Aleutians Summer	Aleutians Winter	Eastern Bering Sea shelf Summer	Eastern Bering Sea shelf Winter	Average Animal Weight
Northern Fur Seal	1, 300 [2]	37, 000	97, 300	55,000 [4] [3]	96, 650	50.3
Northern Sea Lion	225	41, 000	62, 000 [5]	100, 000	50, 000	400 [6]
Harbor Seal *Richardi*	270	85, 000	85, 000	65,000	65,000	140 [6]
Harbor Seal *largha*	250			125, 000	250, 000	140 [6]
Ringed Seal	250	-		125, 000	250, 000	65 [6]
Ribbon Seal	100			50, 000	100, 000	80 [6]
Bearded Seal	300			150, 000	300, 000	240 [7]

1/ Population size for pinnipeds, except northern fur seal, based on status of stock reports in ITG, 1975, - ADFG, 1775,

2/ Northern fur seal numbers rounded to nearest 100, 000 animals.

3/ Estimated summer distribution of northern fur seals based on pelagic observations by MMD, 1967-1973 and total population of 1, 300, 00(1 animals.

4/ Based on the following average weights: Pup=1 0Kg; males age 3 and older = 225 Kg; all others (females age 1 and older; males age 1 and 2)=48 Kg.

5/ ADFG, 1973 (b).

6/ Average weight based on ADFG (1973a), Nishiwaki (1972), and NMFS (1973).

7/ Adult bearded seals weigh up to 340Kg in winter,

.ta on standing stocks of pinnipeds and their average weight. Data for fur :als were obtained from pelagic observations by the Marine Mammal Division, 'FC, NMFS. Data on other pinnipeds are from reports by the Alaska Department Fish and Game, except that the summer/winter distributions are estimates based on observed seasonal migration patterns and given population sizes.

Many fishes and pinnipeds feed on either pelagic and benthic forms, or both. ey also feed in migratory patterns, which makes it difficult to ascertain their tual impact on a given species in a particular area. A simple multiplication of timated population numbers and average size gives only a very rough approximation biomass. The accuracy of these estimates has been improved by taking into count the variable summer/winter distribution. Additional future improvements 11 consider size of different age classes and amount of time spent at sea, though estimates for fur seals in this paper do include the amount of time spent sea.

Estimates of food consumption were made by multiplying biomass by number of ys (based on a 6 month season) by a daily consumption rate as percent of total dy weight. The data collected by the Marine Mammal Division are extensive ough to provide reasonable data for fur seals.

Estimates of food consumption for northern fur seals are shown in Table 3. nual consumption derived for these seals assume a daily consumption rate of 5% of the body weight. Most consumption rates have been calculated for animals ld in captivity; they have ranged from 6% to 8% for fur seals (Scheffer, 1950) d harp seals (Geraci, 1972; Sergeant, 1973). Where direct data were not ailable for other pinnipeds rates determined for fur seals were used as a first proximation. Therefore, a daily consumption rate of 7.5% of the body weight s also used for these other species. However, future data will lead to improved timates of rates for the species.

Table 3. -- Estimates of total annual or seasonal food consumption by northern fur seals from the Pribilof Islands.

Estimated herd size(thousands)	Area	Season	Food consumption (thousands of metric tons)
1,530	North Pacific	Annual	689 1/
1,300	S.E. Alaska, Bering Sea	Annual	318-340 2/
37	Aleutians	June-Nov.	25.5
97	Aleutians	Dec.-May	67.0
550	Eastern Bering Sea	June-Nov.	379.7
97	Eastern Bering Sea	Dec. -May	67.0
66 3/	Gulf of Alaska	Annual	91.1
849 4/	South of Alaska	Dec.-May	448.6
1,300	North Pacific	Annual	1078.9

1/ Scheffer (1950)

2/ Ancel Johnson (pers. comm.)

3/ Average of summer and winter months

4/ Assumes age and weight composition of 25% yearlings at 10 kg, and 75% "other" at 48 kg.

Estimates of the total annual or seasonal food consumption by northern ur seals in the North Pacific Ocean and waters off Alaska are given in Table 3. he average amount of food consumed annually by fur seals in the North Pacific cean is estimated to be nearly 1.1 million metric tons, based on a present opulation estimate of 1.3 million animals. This value is much larger than that f 689 thousand metric tons estimated by Scheffer (1950) when the population was arger. A.M. Johnson (pers. comm.) recently estimated that fur seals in the astern Bering Sea annually consume 318-340 thousand metric tons. Using a onsumption rate of 7.5% of the body weight, an average annual value of 442 housand metric tons has been obtained for the eastern Bering Sea (Table 3). anger (1974), using a consumption rate of 6.1% of the body weight, obtained an stimate of 357 thousand metric tons which is similar to the value obtained by .M. Johnson.

The Marine Mammal Division, NMFS, has also collected extensive data on the mount and type of food found during examination of fur seal stomach contents. he proportionate weight by food type, based on data from pelagic research uring the summers of 1968 and 1973 (NMFS, 1970; 1974), is shown in Tables 4 and 5. infish comprise nearly 90% of fur seal diets in the eastern Bering Sea (Table 4) nd 70% of fur seal diets in the Aleutian area (Tabel 5). In both areas, walleye ollock represents over half of the finfish portion of the fur seal diet.

The length distribution of walleye pollock, unidentified fish also belonging o the family Gadidae (which were probably pollock too, as pollock were the only ther gadids identified) and Greenland turbot found during examination of fur eal stomachs collected for pelagic research in the eastern Bering Sea in 1973 s shown in Figure 3, together with prerecruit limits for these fish. The inimum recruit size for fish entering the commercial fishery is 20 cm for walleye ollock and 22 cm for turbot (Bakkala, pers. comm.). It should be emphasized hat fish eaten by fur seals are generally of prerecruit size, as evident in

Table 4.--Estimated amount of food consumed by northern fur seals in the eastern Bering Sea, by food type, based on relative food consumption observed during July-September 1973.

Food type	Percent of total 1/	Proportionate weight of food consumed (in thousands of metric tons) Summer	Winter	Annual
Walleye pollock	67	254.4	44.9	299.3
Unidentified gadid	15	56.9	10.0	66.9
Gonatid squid	11	41.8	7.4	49.2
Bathylagid smelt	4	15.2	2.7	17.9
Greenland turbot	2	7.6	1.3	8.9
AU others	1	3.8	0.7	4.5
Totals		379.7	67.0	446.7

1/ NMFS, 1974.

Table 5. --Estimated amount of food consumed by northern fur seals in the Aleutian area of Alaska, by food type, based on relative food composition observed between Kodiak Island and Unimak Pass, May-August, 1968

Food type	Percent of total 1/	Proportionate weight of food consumed (in thousands of metric tons)		
		Summer	Winter	Annual
Walleye pollock	37.8	9. 6	25.3	35.0
Gonatid squid	30.8	7.8	20.6	2S. 5
Atka mackerel	16."3	4.2	10.9	15.1
Capelin	7.4'	1.9	5.0	6.9
Salmonidae	5.1	1.3	3.4	4.7
All others	2.6	0.7	1.7	2.4
Totals		25.5	67.0	92.5

1/ NMFS, 1970.

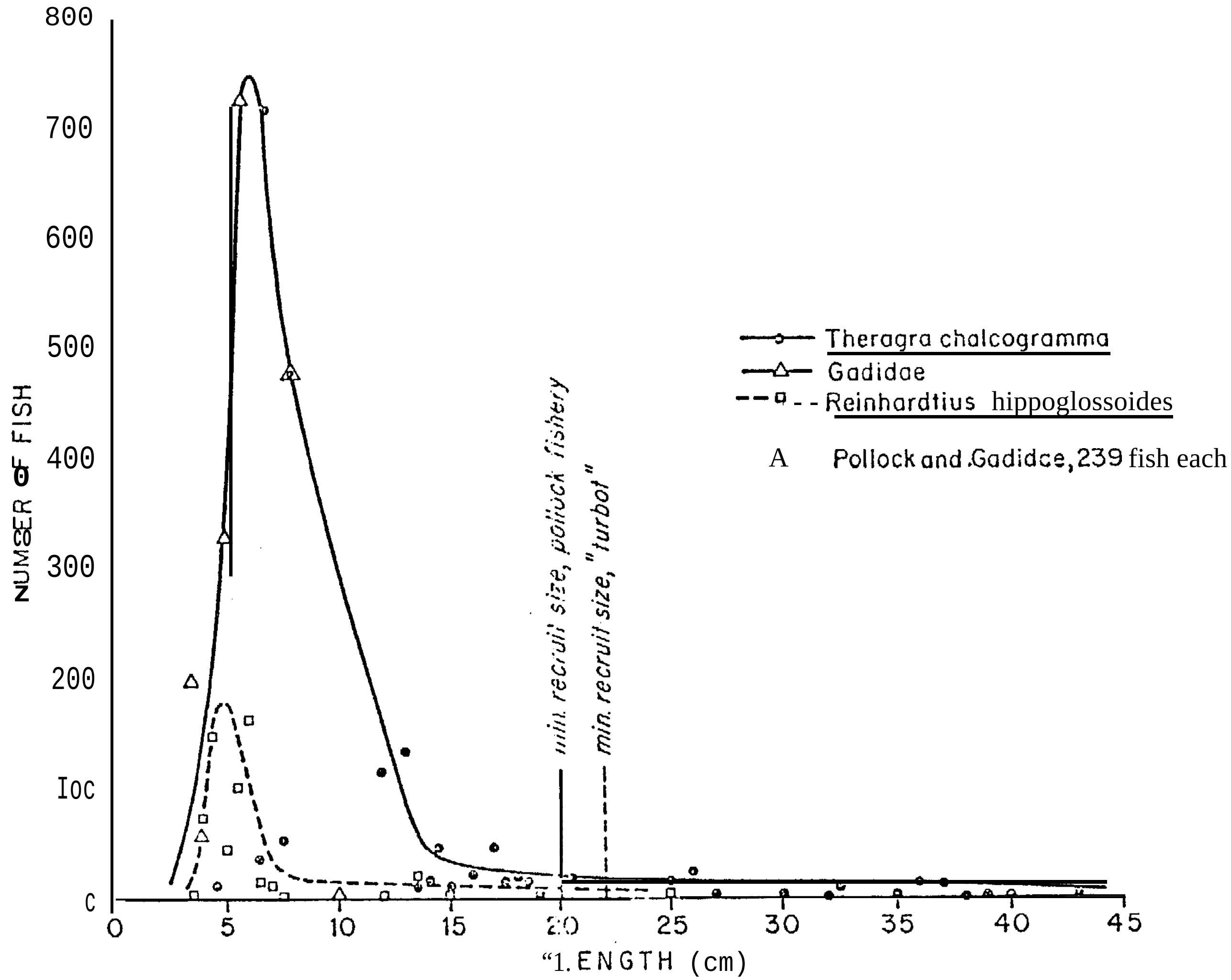


Figure 3. Approximate length distribution of pollock (Theragra chalcogramma), unidentified fish belonging to the family Gadidae, and Greenland turbot (Reinhardtius hippoglossoides) in fur seal stomachs from the eastern Bering Sea, July - September 1973. The minimum sizes the fish enter their respective fisheries are also noted ("turbot" here represents the minimum recruit size for the turbot fishery which includes arrowtooth flounder in addition to Greenland turbot; Bakkala, pers. comm.)

Figures 3 and 4. It should be noted that the data used to construct Figures 3 and 4 represent the total amount of fur seal stomachs in a season containing fish of measurable size. The contents of a large number of fur seal stomachs were in a state of digestion that did not Permit identification of the partly consumed fish. Also, the areas, in which fur seal stomachs were collected varied throughout the season in each of two years.

Similar methods have been used to estimate food consumption by other pinnipeds. We have made a best estimate for each species of that percentage of total consumption which is finfish. Where data have been lacking or inconclusive, we have used rates observed for fur seals as a first approximation; yet recognizing that the food consumed by other seals will often be species different from those selected by fur seals. Some species, for example, ringed seals, appear to avoid squid completely, while squid form a major component of fur seal diets. Tables 6 and 7 show consumption figures and data sources for northern fur seals, northern sea lions, harbor seals, ringed seals, ribbon seals, and bearded seals in the eastern Bering Sea. Total food consumption by pinnipeds in this area is estimated to be 4,223 thousand metric 'tons per year, of which fur seals account for approximately 447 thousand metric tons, or about 18% of the total finfish consumed. Northern sea lions account for over one-third of the total finfish consumption (Table 7).

Tables 8 and 9 show similar calculations for the Aleutian area of Alaska. Concumption in the Aleutian area is about one-third of eastern Bering Sea shelf values, with northern sea lions again being the largest single consumer of fish.

Figure 4. Length frequency distribution of walleye pollock, *Theragra chalcogramma*, in fur seal stomachs from the eastern Bering Sea, July-September 1974.

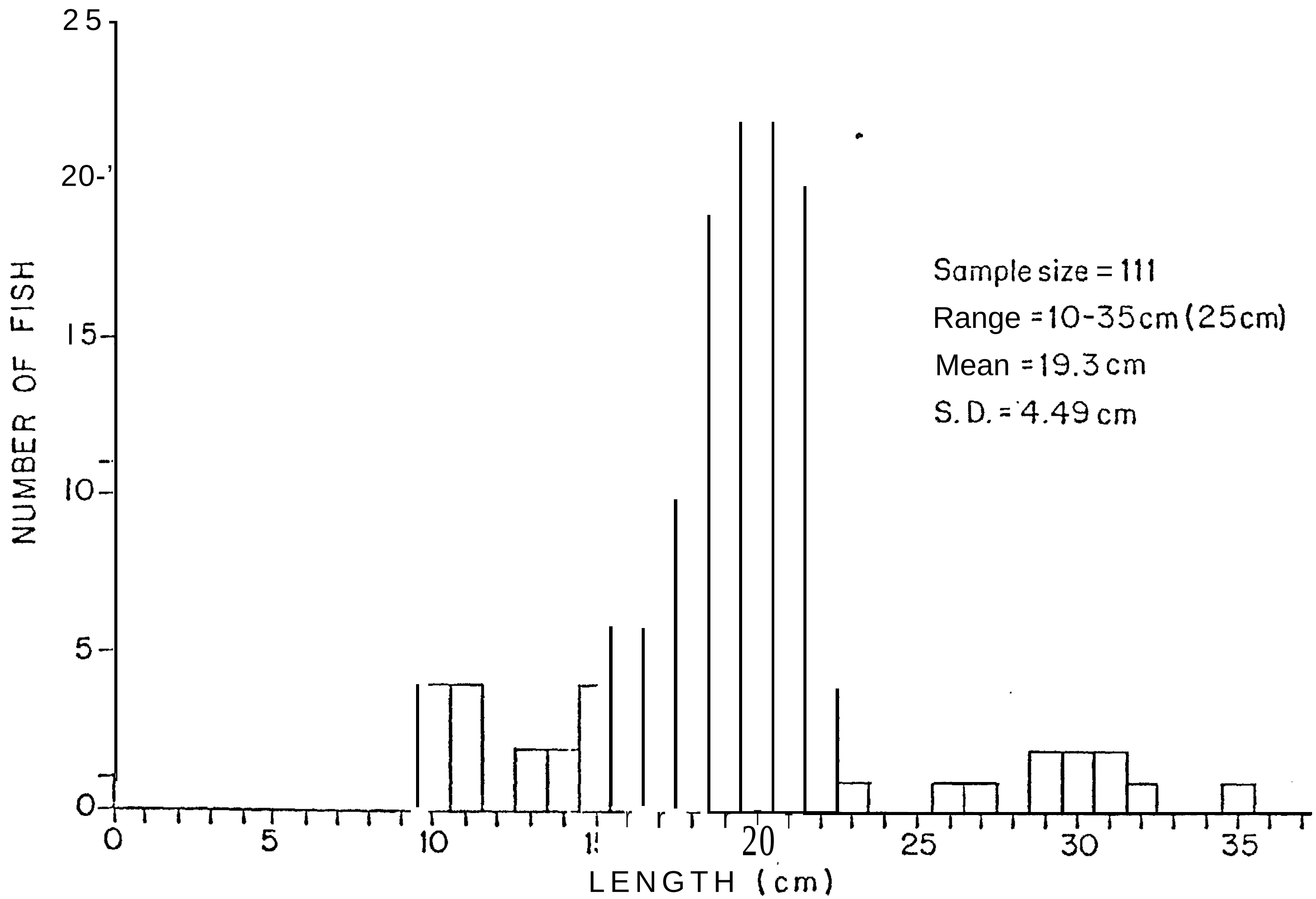


Table 6. -- Food consumption by pinnipeds in the eastern Bering Sea shelf (thousands of metric tons) .

Species	Summer	Winter	Annual	Percent of total
Northern fur seal[1/] (*Callorhinus ursinus*)	380	67	447	11
Northern sea lion[2/] (*Eumetopias jubatus*)	549	275	824	19
Harbor seal[2/] (*Phoca* sp.)	365	605	970	23
Ringed seal[2/] (*Pusa hispida*)	112	223	335	8
Ribbon seal[2/] (*Histriophoca fasciata*)	55	110	165	4
Bearded seal[2/] (*Erignathus barbatus*)	494	988	1,482	35
Subtotals	1,955	2,268		
Total	4,223			

1/ Consumption (rounded) from Table 3.

2/ Consumption based on biomass from Table 2. Average rate of consumption 7.5% of body weight per day and a season of 183 days: (biomass in metric tons) x 183 days x ($\frac{0.075}{\text{day}}$) = seasonal food consumption.

Table 7. -- Annual food consumption of finfish by pinnipeds in the eastern Bering Sea (thousands of metric tons).

Species	Food 1/ (thousands of metric tons)	Percent finfish (w = winter s = summer)	Finfish consumption (thousands of metric tons)
Northern fur seal 2/ (*Callorhinus ursinus*)	447	84	375
Northern sea lion 3,4/ (*Euxrretopias jubatus*)	824	90	742
Harbor seal 3,6/ (*Phoca* sp.)	970	50	485
Ringed seal 5/ (*Puss hispida*)	112s/223w	90w/40s	246
Ribbon seal 7/ (*Histriophoca fasciata*)	55s/110w	90w/40s	121
Bearded seal 5/ (*Erignathus barbatus*)	1,482	10	148
Subtotals	4,223		2,117

1/ From Table 6.

2/ NMFS, 1974.

3/ Spalding, 1964.

4/ Fiscus and Baines, 1966.

5/ Johnson et al., 1966.

6/ Fiscus, pers. comm.

7/ Present estimate.

Table 8. -- Food consumption by pinnipeds in the Aleutian area (thousands of metric tons) .

Species	Summer	Winter	Annual	Percent of total
Northern fur seal[1/] (*Callorhinus ursinus*)	26	67	93	10
Northern sea lion[2/] (*Eumetopias jubatus*)	225	340	565	57
Harbor seal [2/] (*Phoca* sp.)	163	163	326	33
Total			984	

1/ Consumption (rounded from Table 3).

2/ Consumption based on biomass from Table 2. Average rate of consumption 7.5% of body weight per day and a season of 183 days: (biomass in metric tons) x 183 days x $\left(\frac{0.075}{\text{day}}\right)$ = seasonal food consumption.

Table 9. --Food consumption of finfish by pinnipeds in the Aleutian area (thousands of metric tons).

Species	Food 1/ (thousands of metric tons)	Percent finfish	Finfish consumption (thousands of metric tons)
Northern Fur Seal 2/ (*Callorhinus ursinus*)	93	69	64
Northern Sea Lion 3,4/ (*Eumetopias jubatus*)	565	90	509
Harbor Seal 3,5/ (*Phoca sp.*)	326	50	163
Sub-totals	984		736

1/ From Table 8.
2/ NMFS, 1970.
3/ Spalding, 1964.
4/ Fiscus and Baines, 1966.
5/ Fiscus, pers. comm.

Comparisons with Fisheries Catch Statistics

The eastern Bering Sea is the source of a major commercial fishery harvested principally by Japan, the USSR, and South Korea. Japan resumed fishing operations in the Bering Sea in 1954 after an interruption during World War II. A harvest of yellowfin sole, herring, and pollock, primarily by Japanese and Russian fishing fleets, exceeded 2.3 million metric tons in 1972. These totals were expected to decrease to slightly over 1.7 million metric tons in 1975. The total sustainable fishery harvest of groundfish in the Bering Sea and Aleutians in 1975 has been estimated to be between 1.4 and 1.7 million metric tons, under present harvesting and environmental conditions (Table 10).

An analysis of catch and effort statistics and biological data indicate that the present high harvest levels of pollock in the eastern Bering Sea are exceeding sustainable levels (Alverson, 1975), as shown in Table 10. From an examination of all available information, U.S. fisheries scientists have indicated that the pollock fishery for the eastern Bering Sea shelf should be limited to a harvest of about 1.0 million metric tons.

Values derived for food consumption by pinnipeds have been compared with the commercial harvest and standing stocks in Table 11. Because the best available statistical data on the commercial fisheries combined both the Bering Sea and the Aleutian areas, we have included both areas in the values for pinnipeds for comparison purposes. It can be seen that consumption of finfish by pinnipeds is of the same magnitude as the commercial fishery, which is presently in a state of overfishing. Total consumption of finfish by pinnipeds in the eastern Bering Sea is estimated to be between 2 and 3 million metric tons, which is approximately equivalent to or slightly larger than the present commercial fishery. It should be noted, however, that pinnipeds eat different kinds of fish, and ice seals

Table 10. -- Expected fisheries catch in the eastern Bering Sea and Aleutians in 1975 (thousands of metric tons). 1/

Country	Pollock	Pacific Ocean perch	Yellowfin Sole and other	Herring	Totals
Japan	1,100	11	214	18	1,343
USSR	210	148	---	30	388
Other	3	---	---	--	3
Total	1,313	159	214	48	1,734
Estimated Sustainable Yield	1,000	350		40	1,390

1/ Letter Oct. 17, 1975, Dr. D. L. Alverson to Hon. Mike Gravel, U.S. Senate.

Table 11. -- Consumption of fish in the eastern Bering Sea and Aleutian areas

	Thousands of metric tons
stimated finfish consumed by fur seals[1/]	439
stimated finfish consumed by other pinnipeds[1/]	2,414
stimated finfish consumed by sea birds[2/]	500
Estimated vertebrate predation	3,353
timated 1975 catch by commercial fishery[3/]	1,734
Estimated total catch plus vertebrate predation	5,087
timated stock of all finfish[4/]	17,000
rcent standing stock annually consumed by man and other vertebrates -- approx.	30%
rcent consumed by fur seals -- approx.	3%
rcent consumed by marine mammals and birds -- approx.	20%
rcent consumed by fisheries -- approx.	10%

Table 7, Table 9.

Using the value given by Sanger, (1972) that seabirds directly or indirectly consume 0.8% of the primary carnivore production in the subarctic Pacific regions, finfish consumption by seabirds in the Bering Sea and Aleutian areas may range from 60 to 600 thousand metric tons depending on which estimate of the average daily production rate and energy transfer coefficient given in Fig.2 is used to calculate seabird predation on finfish.

Table 10.

INPFC Documents 1680 and 1663 (Pruter, 1973). The estimate of the finfish stock includes only commercial species. Noncommercial species such as the ice-edge fish (arctic cod, saffron cod, sculpins, etc.) have been excluded. Therefore, percentage of the finfish stock consumed by several predator groups may be slightly high.

may not eat commercial species such as pollock as a fish of preference.

Consumption values in Table 11 were calculated under the following assumptions: (1) fur seals and man are direct competitors for the same species of fish, (2) a direct correlation may exist between the size of the fur seal herd and the amount of fish consumed as food and (3) the ecosystem is presently in equilibrium (which is probably not the case).

These values show that fur seals account for approximately 3% of all fish taken annually in the eastern Bering Sea, an amount equivalent to approximately 25% of the amount taken by the fisheries.

The effects which fur seals and other pinnipeds may presently have on the commercial fishery are still not yet clear. As stated above, fur seals as well as other marine organisms may impact on the potential catch as competitors with man, but they may also affect the potential growth of the fish populations. As mentioned earlier, the data from 1973 and 1974 in Figures 3 and 4 show that fur seals generally consume juveniles of walleye pollock and Greenland turbot. However, pollock conusmed by fur seals in 1974, as shown in Figure 4, were in a size range approximately equal to that of fish being recruited into the commercial fishery. Therefore, fur seals may not only compete with man directly in consuming fish of catchable size, but may also affect the potential population growth of the fish themselves because of their predation of juvenille fish. There interactions between fur seals and their fish prey need to be determined.

It should be emphasized, however, that pinnipeds also eat noncommercial speci of fish, and there is no direct equivalence between the commercial fish catch and pinniped assumption of finfish. Johnson et al, (1966), for example, has shown that ringed seals and bearded seals (when the latter species eat fish at all; it primarily feeds upon benthic invertebrates) eat mostly sculpins, saffron cod and Arctic cod. It is also important to consider geographic differences between the istribution of pinnipeds and fish and their different feeding niches. For xample, Phocids may have a lesser interaction with commercial fish species, s compared to that by Otariids.

reclusions

Although this report is preliminary and the first step in a detailed recess of analyzing all known data on the feeding relationships of pinnipeds, t does appear to provide a good estimate of the range of finfish consumption y fur seals and other pinnipeds. Pinnipeds do consume a quantity of food resisting of both noncommercial and commercial fish stocks, especially pollock, ıich is nearly as great as that of the commercial fishery; although, the impact E fur seals is apparently not as great as that of other pinnipeds such as the orthern sea lion. Also, the fact that finfish consumed by fur seals are enerally of prerecruit size means that the potential size that the adult fish opulation can reach is affected. What effects present exploitations have on ıe fishery is not yet clear, but with overfishing by man at present and predation -of juvenile fish populations by pinnipeds, fish, and other marine organisms, : may be difficult to achieve a maximum sustained yield in the fishery.

It must be emphasized that finfish are not the only food of pinnipeds. quid actually form a higher percentage of fur seal diets than nfish by occurrence. Because organisms change their diet from one ecies to another in their food web as a given species becomes increasingly fficult to find, it might be true that fur seals will consume a greater amount squid as the standing stocks of fish decrease. How other species might react to ecific food species reduction is uncertain. The impact of pinnipeds on the shery is a "complex interaction, and further analyses of data on the ecosystem d trophodynamic relationships of pinnipeds and finfish are required before the stem can be understood.

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FINAL REPORT

RU-77

ECOSYSTEM DYNAMICS BIRDS AND MARINE MAMMALS

Part II

Aspects of the feeding ecology of Bering Sea Avifauna*

by

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ENVIRONMENTAL ASSESSMENT' OF THE ALASKAN CONTINENTAL SHELF

Sponsored by

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i

ABSTRACT

The aucnors spent about 65 person-days preparing a report on the birds ıf the eastern Bering Sea under a subcontract to OCSEAP RU-77 (Ecosystem ynamics-Birds and Mammals). The pertinent literature was reviewed on ten pecies of marine birds which are important in that area either because of heir large biomass, or as representatives of the diversity of the pelagic ird community. Dramatic seasonal changes occur in the abundance of birds n the eastern Bering Sea. Peak abundance occurs in early spring with the nflux of Sooty and Short-tailed Shearwaters from their breeding grounds in he southern hemisphere, and with the staging of Alaskan breeding species rior to nesting.

During the Alaskan birds' breeding season, the distribution of all pecies except the shearwaters is strongly oriented toward colonies. Little s known about the diets of the birds, but the abundant shearwaters and urres appear to consume large quantities of euphausiids, and schooling elagic and demersal fishes. Prey items range in size from copepods of mm or less (eaten by Least Auklets) to fish of at least 25 cm (eaten by urres). Glaucous-winged Gulls, Black-legged Kittiwakes, and Northern ulmars probably benefit greatly from offal produced by Walleye Pollock isheries. The fisheries have possibly created an imbalance in the ecosystem hich has benefitted planktivorous birds.

Recommendations to further refine ecosystem data on marine birds n elude: 1. More intensive studies on population sizes and the diets of the hearwaters; 2. Better estimates of colony population sizes, and the elationships between numbers of birds on the colonies and numbers at sea; . Many more food samples collected systematically throughout the year; . Included in the model of the ecosystem should be meroplankton (including chthyoplankton); copepods; euphausiids; small pelagic fishes; epibenthic acroplankton; and fisheries offal.

PREFACE

Research Unit 77 of the BLM/NOAA Outer Continental Shelf Energy Assessment Program, entitled "Ecosystem Dynamics - Birds and Mammals" was originally designed to provide a conceptual ecosystem model for marine bird and mammal populations in the eastern Bering Sea. The principal investigators and their parent agency, the National Marine Fisheries Service (NMFS), had no expertise on marine birds. They subcontracted to the U.S. Fish and Wildlife Service, Office of Biological Services - Coastal Ecosystems, Anchorage, AK, to provide a basic literature review of marine birds in the eastern Bering Sea. The literature review was to emphasize marine bird feeding studies and other ornithological information.

Correspondence between G. A. Sanger, and F. Favorite and T. Laevastu of the NMFS summarizing pertinent published and unpublished data on shearwaters and murres provided the initial marine bird data input to the model. This was followed by a 13-page preliminary report (Sanger 1976) which provided additional data on murres and shearwaters in the Bering Sea. The data emphasized feeding habits, pelagic populations, and breeding chronology. This final report provides similar data on eight more species, integrates essential information from the preliminary report, and attempts to present a general background picture of marine birds in the eastern Bering Sea and factors pertinent to their feeding ecology.

There is a glaring dearth of published information on marine birds in the eastern Bering Sea. A few years hence, when the present wealth of data beginning to accumulate from OCSEAP studies is analyzed, a much clearer picture of the ecology of marine birds in the eastern Bering Sea will be available. Meanwhile, we believe this report is reasonably complete in reviewing and integrating information pertinent to the role of marine birds in the ecosystem of the eastern Bering Sea.

INTRODUCTION

At least 130 species of "marine oriented" birds occur in the eastern Bering Sea or in its adjacent estuarine and intertidal habitats (Sanger and King in press). Since the initial ecosystem modeling attempts for the eastern Bering Sea (Laevastu and Favorite 1976) include only pelagic faunal communities, this report considers only pelagic species of birds. For an initial attempt at modeling a marine bird community, however, areas away from land are a good place to start; there are fewer variables affecting bird distribution and abundance here than in areas closer to shore (Sanger 1972a).

This report summarizes information and biological concepts important to a basic understanding of the role of birds in the ecosystem of the eastern Bering Sea. It is not an exhaustive review of the literature, but rather sets a basic ornithological and environmental background, It focuses on specific ecological factors on some ten species of marine birds which should be useful for portraying much of the marine bird community of the eastern Bering Sea in an ecosystem model. It is assumed the reader has little or no background in ornithology.

The specific objectives of the report are:

1. To give a general ornithological background for the eastern Bering Sea.

2. To give enough general environmental background of particular importance to birds so that they may be better understood as integral components of the ecosystem.

3. To give "best available" estimates of the seasonal distribution and abundance of a few key species of marine birds.

4. To provide lists of the prey species of ten species of marine birds.

5. Provide recommendations for further field and laboratory studies which would further our ecological understanding of marine birds in the eastern Bering Sea and enable further refinement of ecosystem models.

6. To provide recommendations for expanding the present list of components of an ecosystem model which will more accurately reflect the birds' feeding ecology.

GENERAL BIOLOGICAL BACKGROUND

The Distribution and Abundance of Prey and Predators

Any model of the eastern Bering Sea ecosystem must include data on the abundance of both prey and predator species during the breeding and non-breeding seasons, because seasonally different regulating factors may be operating on each of them (Fretwell 1972). Moreover, summer population sizes of consumers may be determined by winter food availability (Pulliam 1975). For seabirds, density-dependant winter mortality may occur in some species, and this usually affects young birds greatest since they are inferior competitors for food with adults (Ashmole 1971). In the eastern Bering Sea, only Shuntov (1972) has published information on winter populations of marine birds. The absolute abundance of prey is an important factor to consider in food web analyses; the prey may be locally abundant, but not high enough in overall abundance to be consistently located by consumers.

Similarly, distribution data on both prey and predators needs to be considered in ecosystem modeling. Many authors have noted close associations between predators and their prey (e.g.; Ashmole 1971, Royama 1970). In high latitudes with short, well defined seasons of biological productivity such as the eastern Bering Sea, similar influences no doubt act on prey availability (e.g.; Bedard 1969a). As noted below, this factor probably has influenced the locations of breeding colonies in the eastern Bering Sea.

Prey-Predator Relationships

Royama (1970) regards "percentage predation" (i.e., percent composition of all food comprised by a prey species) as an important variable to consider in studying food webs. This factor apparently varies in a curvilinear fashion with prey abundance. The very real possibility of preferential prey selectivity by a predator (Helling 1968, Ivlev 1961) needs to be known, but there apparently is little or no such data in the eastern Bering Sea.

Feeding rates depend on many factors other than availability of prey to the consumer. Royama (1970) believes that "What is important from a predator's viewpoint is not density of prey, but rather the actual amount of prey that a predator can collect for a given time in a given hunting situation." Feeding rates may also depend on absolute densities as stated above, or on behavioral interactions among the predators in feeding associations. In inter- and intra-specific situations, competition from other predators may affect feeding rates, so an ecosystem model must consider all consumers. Feeding rates can sometimes decrease when consumer density increases; this effect is apparently a mechanism for maintaining ecosystem stability (DeAngelis et al 1975). DeAngelis et al (1975) suggest that feeding rates should be examined as a function of relative densities of prey and consumers.

The maximum consumption rate upon a prey species by a predator must be differentiated from natural fluctuations in prey population (i.e., those caused by other predator species, physical environmental affects, etc.). Finally, an analyses of prey partitioning among all of its' predator species needs to be examined (Schoener 1974). However, for beginning attempts at modeling the relationships between marine birds and their prey, it would seem expedient to assume simple Lotka-Volterra relationships (predators and their prey are in equilibrium and their populations fluctuate roughly in inverse proportions) (Lotka 1925, Volterra 1926) until shown otherwise by hard data.

What is a Trophic Level?

Webster's Seventh New Collegiate Dictionary defines the word trophic as: "Of or relating to nutrition", and the word nutrition as: "The act or process of nourishing or being nourished." "Trophic" thus expands to "Of or relating to the act or process of nourishing or being nourished." In the context of a simple food chain, each link in the chain represents a level of nutrition, and thus represents a trophic level. In an ecosystem involving food webs, however, the existence of trophic levels is more a concept than a reality. In an exceedingly complex environment such as the eastern Bering Sea shelf, organisms exist in an infinite number of sizes ranging from the smallest detrital particles and phytoplankton up to the largest baleen whales. In a sense, there is also an infinite number of trophic levels. Also, as most planktonic and nektonic animals grow, they ascend to higher and higher trophic levels until fully grown. However, knowledge of the actual food web pathways and dynamics is imprecise. Thus, the assumption of distinct trophic levels is a useful tool to begin to portray an ecosystem in a model (Schaefer and Alverson 1968; Sanger 1972b).

Work by Parsons and LeBrasseur (1970) and LeBrasseur and Kennedy "(1972) in coastal British Columbia and at Ocean Station Papa in the North Pacific Ocean has shown that food chains in coastal areas tend to be shorter than in oceanic areas. This is due to much of the oceanic primary production occurring from nannoplankton (phytoplankton less than 20 microns in size) which is not abundant in coastal areas. Thus, microzooplankton such as radiolarians are the herbivores in the oceanic areas, while the dominant phytoplankton along the coast are relatively large diatoms, which are preyed upon directly by the euphausiid, Euphausia pacificus. Offshore, E. pacificus prey upon the radiolarians, so the same species is thus two trophic levels apart in the two areas. In reality, what is termed a trophic level actually contains a range of sizes of organisms; their average sizes differ, but there can be considerable overlap in sizes from one level to the next.

Gallopin (1972) states that, to define a trophic level, the proportion of common prey species to total prey species of all predators must be examined as well as the magnitude of flow of biomass and energy. This flow depends in part on the relative abundance of prey and predators. The relative allocation of biomass flow from all species to each predator should also be known. Consumers are at the same trophic level if the proportions of the flow from the same prey are the same for the consumers being compared (Gallopin 1972). He thus suggests obtaining an index of similarity weighted by the proportion of biomass or energy flow to define trophic levels. However, Gallopin's (1972) scheme would seem more realistic if size classes of prey would be included.

ORNITHOLOGICAL BACKGROUND

General Aspects

Although marine birds are usually seen flying above the sea or floating on the water, they are very much a part of the nekton community. Most species are able to swim under water agilely, propelling themselves with their wings, or feet, or both. Many species in the eastern Bering Sea regularly and normally feed on or near the bottom, at depths ranging down to 75 meters (Ainley and Sanger in press). Even the surface feeders usually feed with at least their bills or heads beneath the surface. Depending on species, they may feed at or just beneath the surface (most gulls), in the upper few meters (shearwaters), at mid-depths (puffins, some other alcids), or from mid-depths to the bottom (murres, cormorants, sea ducks).

Two natural factors overwhelmingly influence the distribution of marine birds in the eastern Bering Sea: the distribution of sea ice in winter, and the locations of breeding colonies in spring and summer. The affect of the ice edge on the distribution and ecology of marine birds will only be mentioned in passing here; it is the subject of an ongoing OCSEAP Research Unit (RU #330, "The distribution, abundance and feeding ecology of birds associated with the Bering and Beaufort Seas Pack Ice"), and information from that study will be useful in modeling aspects of the marine bird community in winter.

APPENDIX C
STATISTICAL BACKGROUND FOR CONFIDENCE INTERVALS AND TESTS

1.0 *CONFIDENCE INTERVALS FOR MEDIANS*

We used the approach of Breiman (1983) to obtain confidence intervals for medians. In Section 4.2.3 such intervals were computed for the median water depth for all possible bowhead sightings which might have been made during the nearshore fall (September-October) migration in 1982. There were n = 103 such sightings during random $N-S$ transect. survey flights. Let $x_{(1)} \leqq x_{(2)} \leqq \cdots \leqq x_{(n)}$ represent the observed water depths corresponding to these sightings, arranged in order from shallowest to deepest, Let $x_{0.5}$ denote the median we seek to estimate. Let $[0.5\ n\text{-}k]$ denote the smallest integer greater than or equal to $0.5\ n\text{-}k$.

Then Breiman shows that for large n, a 100 γ percent confidence interval for $x_{0.5}$ is given approximately by $[x_{([0.5\ n-k\ ])}, x_{([0.5\ n+k\ ])}]$ where $k = 0.5z\sqrt{n}$, and if Z is an $N(0, 1)$, or standard normal, random variable, then z is defined by $P(-z \leqq Z \leqq z) = \gamma$. For example, when $\gamma = 0.99$, $z = 2.58$. We obtained the 99 percent confidence 'interval for the overall axis of migration in 1982 using this approximation.

For small n, $6 \leqq n \leqq 65$, values *of k* such that a 95 percent or 99 percent confidence interval *is* $[x_{(k)}, x_{(n-k+1)}]$ *are* given in Table VII.3 of the *CRC Handbook* (Beyer, 1968). The interval for the region east of 146°W longitude reported in Section 4.2.3 was obtained using this table.

20 TESTS FOR DIFFERENCES IN DISTRIBUTIONS

Breiman (1983) discusses tests for differences between distributions in Chapter 9. Derivation of the two-sample Wilcoxon, or *Mann-Whitney,* test and the chi-square (χ^2) test for homogeneity are given by Breiman, and we will not repeat them here. The tests are available in standard statistical packages such as Minitab (Ryan et al., 1980).

The table for the χ^2 test on the overall distribution of water depths z discussed in Section 4.2.3 might be:

Year	$z < 20m$	$20 \leq z < 30$	$30 \leq z < 40$	$40 \leq z < 50$	$z \geq 50m$	Total
1982	16	21	31	17	18	**103**
Another year	-	·	•		·	·
Total	·	·				·

where the number to be filled in for the second year would be number of sightings in each of the indicated depth ranges.

The asymptotic theory on which the χ^2 test is based does not hold when the expected number of sightings in some categories is small, say <5. Thus, when the total number of sightings is small, a *smaller* number of depth categories must be used. For example, a *more* appropriate table for latitude east of 146°W longitude would be:

Year	$z < 35m$	$35m \leq z \leq 45m$	$z \geq 45m$	Total
1982	9	21	**11**	**41**
Another year	-			·
Total			-	-

if the second year had roughly the same number of sightings.

3.0 LEVELS AND POWERS OF TESTS, CHOICE OF LEVEL

We recommended in Section 4.2.3 that the Mann-Whitney test for a shift in median depth of bowhead sightings be done at the 1 percent level since it will need to be performed at least three to five ties if the tests of the 1979 and 1981 data versus 1982 are included. The analyses of that section indicate that we have reasonable power to detect changes of the magnitude of interest even if tests are done at the 1 percent level.

Recall that *power* is the probability of rejecting the null hypothesis of no change when it is false and therefore detecting the change. Recall that the *level* a of a test represents the probability that the null hypothesis will be rejected when it is in fact true due to random error. Thus, for a single test at the 1 percent level ($\alpha = 0.01$) the probability that the null hypothesis will be accepted when it is in fact true is $1-\alpha = 0.99$.

Now, suppose we perform five independent tests of the same true null hypothesis with a = 0.01 in each test. Tbe probability that we will accept the null hypothesis all five times is $0.99^5 = 0.951$. Hence, the probability that we will incorrectly conclude at least one time out of five that the null hypothesis is false and a shift has occurred is 1 -0.951 = 0.049. That is to say, our overall level is approximately 5 percent. The same calculation when the individual tests are done at the 5 percent level gives an overall level of $1-0.95^5 = 0.226$, or nearly 23 percent.

Tbe results are not very different if we allow for the possibility that the repeated tests are dependent. In this case, if the individual tests are at the 5 percent level, the probability of concluding at least one time out of five that a shift had occurred when, in fact, it bad not, might be as high as 25 percent. This result is derived from Bonferroni's Inequality (Montgomery and Peck, 1982).

4.0 POWER OF ANALYSIS-OF-VARIANCE TESTS

Standard charts of power of analysis-of-variance tests such as Table A-13 in Dixon and Massey (1969) can be used to determine detectable changes. We illustrate the technique with the linear blade growth data for kelp at DS-11 given by Dunton (1983) and discussed in Section 4,2.7 of this report.

From his Figure 2 we obtained the following values:

Year	Sample Size	Blade Growth, cm.	Standard Deviation
1976-'?7	$n_1 = 11$	24.8	10.0
1977-?8	$n_2 = 32$	22.2	8.0
1978-79	$n_3 = 42$	24.1	6.2

and from them a pooled estimate of residual variance $\hat{\sigma}^2$ = 55.6 and an overall mean μ = 23.7 which we assume was the true mean in all three years: $\mu_1 = \mu_2 = \mu_3 = \mu$. Now assume that the sample size n_4 in a fourth *year* of sampling is, say, $n_4 = 20$ and the mean $\mu_4 = \mu + \Delta$ so that the new overall mean is $\bar{\mu} = \mu + \Delta/4$. Then the parameter Φ in Table A-13 of Dixon and *Massey* (1969) is given by

$$\Phi^2 = \frac{1}{k\sigma^2}\sum_{i=1}^{k} n_i(\mu_i - \bar{\mu}) = \frac{1}{222.4}\left(11\frac{\Delta^2}{16} + 32\frac{\Delta^2}{16} + 42\frac{\Delta^2}{16} + 20\frac{9\Delta^2}{16}\right) = \frac{1}{222.4}\,\frac{265}{16}\Delta^2$$

since k = 4. Then Φ = 0.27Δ.

Using the chart with $\nu_1 = k - 1 = 3$ and $\nu_2 = \sum_{i=1}^{k} n_i - k = 101$ and assuming we wish to test at level α = 0.05, we obtain the following table of detectable differences vs. power.

Power = 1-β	Φ	Δ, cm
0,50	1.2	4.4
0.70	1.5	5.6
0.80	1.7	6.3
0.90	1.9	7.0
0,95	2.1	7.8