FINAL REPORT OF BERING SEA ACTIVITIES

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Trophic Relationships Among Ice-Inhabiting Phocid Seals and Functionally Related Marine Mammals in the Bering Sea

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I. Summary

A total of 62 spotted seal, 28 ribbon seal, 199 ringed seal, 218 bearded seal, 3 belukha, and 53 walrus stomachs containing food and collected in the Bering Sea were analyzed between October 1975 and August 1980. Most of the specimens were obtained from Eskimo subsistence hunters at five coastal villages: Nome, Gambell, Savoonga, Diomede, and Wales. Samples were collected at several times of year in order to assess seasonal changes in feeding patterns. The most complete sample coverage was near the coast in spring and summer when hunting activity is greatest. Poorest sample coverage was in winter and in the vast offshore areas of southern and central Bering Sea that are not accessible to coastal based hunters.

The diet of spotted seals consists mostly of pelagic and semi-demersal fishes. In southeastern Bering Sea in spring capelin are the major prey, in the southcentral and central regions the major prey are pollock and also eelpout, and in northern Bering Sea arctic cod, saffron cod, and capelin are most commonly eaten. During late summer and autumn, when spotted seals are present in coastal areas, they feed on saffron cod, herring, capelin, smelt, and sand lance. Foods during winter months are poorly known, but it is likely that arctic cod are important at that time. Belukha whales eat many of the same species of fishes as do spotted seals, in addition to cephalopods and crustaceans, especially shrimps. It is probable that the distribution of belukhas and spotted seals is at least partially determined by the distribution and abundance of the aggregating fishes upon which they feed.

Ribbon seals have not been sampled during times of year when they feed intensively. During spring, when feeding occurs at very low levels, they prey on pollock, eelpout, Greenland halibut, and capelin in southern and central Bering Sea, and on arctic cod and occasionally saffron cod, sculpins, octopus, and pollock in northern Bering Sea.

Bearded seals and walruses are primarily benthic feeders. Bearded seals forage mostly on epifaunal invertebrates such as crabs, shrimps, and, during summer, clams, whereas walruses eat mainly infaunal clams. Bearded seals and walruses compete for the cockle Serripes, and there are indications that their combined predation is in excess of the sustainable yield of that species.

The feeding of ringed seals in the Bering Sea shows pronounced seasonal variation. Saffron cod are most important in the diet during autumn and spring along the mainland coast. Arctic cod are the primary species eaten during winter months. Shrimps are eaten in small amounts in all seasons and at all areas, but are of greatest importance during spring and summer in northern Bering Sea and Norton Sound. Mysids are eaten in largest quantities in southeastern Bering Sea and near St. Lawrence Island. Gammarid amphipods and sculpins are eaten most commonly near St. Lawrence and Little Diomede Islands. Age-related dietary differences are pronounced. Crustaceans make up most of the diet of recently weaned pups and of yearlings, whereas adults eat mostly fish.

Two other species of pinnipeds, the northern fur seal and the Steller sea lion, are also abundant in the Bering Sea and compete for food with phocid seals. In total more than 2 million pinnipeds are being supported primarily by the pelagic and semidemersal fish resource of Bering Sea. The same species of fishes (pollock, capelin, arctic and saffron cods, herring, and smelt) are consumed in large numbers by some species of whales, porpoises, and seabirds. In addition, humans compete directly with pinnipeds for food. Commercial fisheries currently remove in excess of 1 million metric tons of fish per year from Bering Sea.

If the trophic subsystems such as the pelagic and benthic food webs described for Bering Sea marine mammals are in equilibrium, changes in population size of either consumer or prey species as a result of commercial fisheries or petroleum exploration and development can be expected to have direct effects on other consumer populations. The mechanisms and magnitude of the response of pinniped populations to such changes are presently impossible to predict.

II. Introduction

In 1975 the Alaskan Outer Continental Shelf Environmental Assessment Program (OCSEAP) was initiated to conduct environmental research prior to oil and gas exploration and development in Alaskan waters. Six proposed lease areas have been identified, four of which are in the Bering Sea. Those areas and proposed sale dates are: Norton Basin, September 1982; St. George Basin, December 1982; North Aleutian Shelf, October 1983; and Navarin Basin, December 1984. In preparation for those sales this research unit has been investigating trophic relationships of ice-associated marine mammals, primarily phocid seals, of western and northern Alaska. This final report presents information collected in the Bering Sea during a 4-year field program and makes it available to other scientists and resource managers for consideration during tract selection, EIS preparation, and policy formulation.

The waters off the coast of Alaska support a tremendous abundance and diversity of marine mammals. Some species occur only during ice-free months while others are more or less dependent on sea ice as a habitat in which to whelp, breed, molt, and feed. The relationship between northern marine mammals and sea ice has been well summarized by Burns (1970) and Fay (1974). Seven ice-associated species are seasonal or year-round residents of the Bering Sea. They are: ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), spotted seals (*Phoca largha*), ribbon seals (*Phoca fasciata*), walruses (*Odobenus rosmarus*), belukha whales (*Delphinapterus leucas*), and bowhead whales (*Balaena mysticetus*). The four species of seals were the main focus of this project. Preliminary data were collected on an opportunistic basis for walruses and belukhas. Bowhead whales were outside the scope of this project and will not be included in this final report.

Sea ice begins to form in the northern Bering Sea in early November, particularly in Norton Sound and along the coast. As winter progresses the ice advances southward, reaching south of St. Lawrence Island by January and usually south of St. Matthew Island by February. Maximum extent of the ice which usually occurs in March may reach as far as the continental shelf break south of the Pribilof Islands. In April the ice begins to melt and recede north and by May the southern and central Bering Sea is ice free. Ice remnants persist in northern Bering Sea into June and sometimes early July. Open water persists from July through October.

Several zones or ice types are found in seasonal sea ice. The front region occurs at the leading edge of the ice and consists of a band of relatively thin, dispersed moving floes. The size of the floes and the width of the band are largely determined by prevailing wind and weather conditions. The exact geographical position of the ice front varies widely depending on meteorological conditions in a particular year. North of the front lies the pack ice which consists of thicker, more closely packed and larger floes. Pack ice coverage may be close to 100 percent. Along the coast land-fast ice is present. It is most extensive in sheltered areas of convoluted coastline and in the lee of coastal promontories. Fast ice forms a large, continuous sheet of ice and is the most stable of the ice zones. Between the fast ice and pack ice one finds a transition region where the two zones interact. Considerable ice movement and ridged and deformed floes are characteristic of this zone, as well as leads and other openings.

Ribbon seals are associated with the winter-early spring ice front and late spring ice remnants in the Bering Sea during which time they give birth, support young, mate, and molt. When the last of the sea ice disappears the ribbon seals become pelagic; their distribution during the open water season, when they probably feed intensively, is largely unknown (Burns 1970). Population size in the Bering Sea is estimated at 90,000 to 100,000 (Burns, in press). Of the four Bering Sea lease areas, ribbon seals probably are most common in Navarin and St. George Basins. They sometimes occur in Norton Basin during late spring in association with receding ice remnants.

The entire Bering Sea population of 200,000-250,000 spotted or larga seals is found in the ice front region of the Bering Sea during February to May when they bear and nurse their young and breed. As the ice begins to disappear in May and early June, largas are concentrated in the remaining ice remnants where they spend much of their time molting and basking on the ice. In months when ice is absent in the Bering Sea they are found feeding near shore and hauled out on the coast, frequently near estuaries. Spotted seals occur in all four of the Bering Sea lease areas but are least common on the North Aleutian Shelf.

Bearded seals are widely, though not uniformly, distributed throughout the drifting pack ice of the Bering Sea during winter. Highest densities occur in the northern part of the ice-covered Bering Sea shelf. Like spotted and ribbon seals, they bear and nurse their young in April on the drifting ice. Bearded seals migrate north from mid-April through June following the receding ice through Bering Strait to the Chukchi Sea where they spend the summer near the fragmented margin of the multi-year ice. Some bearded seal pups occur in the open sea during summer. The fall migration back to the Bering Sea occurs in late fall through winter. Population size is estimated at 300,000 (Burns and Frost 1979). Few bearded seals occur in the North Aleutian shelf and in Navarin Basin, as the two areas are infrequently covered by ice. St. George Basin is on the southern boundary of bearded seal range, with its importance being directly related to annual ice conditions. Norton Basin is important bearded seal habitat from November through June. Large numbers migrate through the area in spring and fall, and they are abundant residents whenever ice is present.

Ringed seals are the most widely distributed and abundant pinniped in Alaskan waters, probably numbering in excess of one million seals. They are high trophic level consumers, constitute the basic diet of polar bears, and are utilized in large numbers by coastal Eskimos. They occur seasonally in the Bering Sea, appearing with the formation of seasonal sea ice in November. In late March and early April ringed seal pups are born in lairs excavated in snow-covered ice. Stable landfast ice is the preferred area for pupping and the greatest density of ringed seals occurs there, although some pups are born on drifting ice. Subadult animals are often found congregated along transient lead systems. Subsequent to pupping and breeding ringed seals undergo a period of molting during which they spend a large amount of time hauled out on the ice. As the ice melts in the Bering Sea in May and June, ringed seals move into the Chukchi and Beaufort Seas where they spend the summer dispersed throughout ice-covered areas. With the onset of winter and the increase in ice cover the area occupied by ringed seals expands accordingly and again includes the Bering Sea. Of the four lease areas, Norton Basin is by far the most important to ringed seals.

The Pacific walrus population ranges seasonally throughout the waters covering the Bering and Chukchi Sea platform. Since they are benthic feeders they do not regularly occur in deep waters off the continental shelf. During winter and spring walruses are found throughout areas of moving pack ice in the Bering Sea and Bristol Bay. Most calves are born on the ice in May. Much of the population moves north through Bering Strait as seasonal ice disappears. Several thousand walruses summer on coastal haulouts in Bristol Bay and the northern Bering Sea. Recent estimates indicate a population in excess of 209,000 (Krogman et al. 1978). Walruses are present in all four proposed lease areas. They occupy Navarin and St. George Basins in winter-spring and North Aleutian Shelf and Norton Basin in spring through autumn.

The distribution and abundance of belukha whales in the Bering Sea are not well known. The whales winter primarily in areas of moving ice in the Bering Sea. They move north in spring through leads in the ice to the Chukchi and Beaufort Seas where they spend the summer. Some of them remain in Bering Sea where they may bear their young in coastal lagoons and estuarine systems. Belukhas move away from the coast and south in autumn as the ice forms. The size of the present population is estimated at about 9,000 (U.S. Dept. Commerce 1979). These whales are seasonally present in St. George, Navarin (winter), and Norton Basins (year-round), and are largely absent from the North Aleutian Shelf.

Ringed, bearded, and spotted seals, walruses, and belukhas are of cultural and economic importance to the residents of the Bering Sea coast. Seal hunting regularly occurs at, among others, the villages of Hooper Bay, Mekoryuk, Nome, Wales, Gambell, Savoonga, and Diomede. Walruses are important to residents of Nome, Wales, Gambell, Savoonga, and Diomede and belukha whales are sometimes taken by villages of inner Norton Sound. Marine mammals are not only important to humans as food but they compete directly with humans for food. Pelagic and semidemersal fishes such as pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), herring (*Clupea harengus*), arctic cod (*Boreogadus saida*), and saffron cod (*Eleginus gracilis*) comprise a major portion of the diet of spotted, ribbon, and ringed seals, and belukhas, while clams and brachyuran crabs are major foods of walruses and bearded seals. Commercial or subsistence fisheries exist or are developing for most of those species. Extant models which deal with consumption of finfish by pinnipeds indicate that more fish are consumed by pinnipeds than are caught by commercial fisheries in the Bering Sea (McAlister and Perez 1976). Since consumption of marine organisms by marine mammals and removal by human fisheries have grossly similar effects, i.e. a reduction in the standing stock of prey or target species, it is desirable and necessary to implement multi-species management in the formulation of fishery management plans and management policies for marine mammals. In addition, because marine mammals, and fisheries, are of such import to people, it is imperative that the potential effects of oil and gas exploration and development in the Bering Sea on marine mammals be anticipated and minimized to whatever degree possible. Such an evaluation requires an understanding of the biology of the species involved, as well as how they affect and are affected by their environment. The study of trophic relationships of the marine mammals included in this report will contribute to such an understanding.

In the discussions that follow it will be necessary to give the names of many species of marine animals. The authors realize that there are advantages to the use of either common or scientific names. In this report we will use common names whenever such are available and appropriate. For purposes of clarity and ease of reference, the accepted scientific names of most species for which we will use common names are given in Table 1. For species mentioned seldom in this report, both common and scientific names are given at the first mention of that species.

Table 1. Common and scientific names of species commonly mentioned in this report.

Common Name	Scientific Name
Pollock	*Theragra chalcogramma*
Arctic cod	*Boreogadus saida*
Saffron cod	*Eleginus gracilis*
Herring	*Clupea harengus*
Rainbow smelt	*Osmerus esperlanus*
Sand lance	*Ammodytes hexapterus*
Capelin	*Mallotus villosus*
Greenling	*Hexagrammos* sp.
Eelpout	*Lycodes* sp.
Stickleback	*Pungitius pungitius*
Prickleback	*Lumpenus* sp.
Sculpin	Family Cottidae
Flatfish	Family Pleuronectidae
Poacher	Family Agonidae
Tanner crab	*Chionoecetes opilio*
Spider crab	*Hyas* spp.

III. Current State of Knowledge

We know of only seven accounts of the food habits of ice-inhabiting phocid seals published prior to this OCSEAP study which began in 1975. The food habits of those seals in the Bering Sea had not been given systematic attention despite the fact that several species are known to feed extensively on commercially important fishes or invertebrates (Lowry et al. 1979a). A summary of the results of earlier studies follows as well as short summaries of studies on food habits of belukha whales and walruses in the Bering Sea. Published accounts of the food habits of those species in other parts of the world have been reviewed in 1978 and 1979 annual reports for this research unit (Lowry et al. 1978a; Lowry et al. 1979b).

Ringed seal

Kenyon (1962) reported on the stomach contents of 14 ringed seals taken at Little Diomede Island, 11 May-14 June 1958. Shrimp of the genus *Pandalus* accounted for 96 percent of the food items encountered with mysids, amphipods, and fishes present in small amounts.

Results of our OCSEAP studies of the food habits of ringed seals in Bering Sea waters have been compiled and presented in several publications (Lowry et al. 1977; Lowry et al. 1978b; Lowry et al. 1979a; Lowry et al. 1980a; Frost and Lowry, in press a; Lowry and Frost, in press).

Bearded seal

Kosygin (1966, 1971) reported on the foods of the bearded seal in the Bering Sea in spring and early summer (March to June) 1963 to 1965. Stomachs from 565 animals were examined, 152 of which contained food. The tanner crab was the species most commonly eaten, making up from 53 to 76 percent of the food. Shrimp (particularly *Argis* (=*Nectocrangon*) *lar*) were the second most important food. Snails were also important. Octopus, priapulids, and fishes (particularly pricklebacks and flatfishes) were eaten quite regularly. Kosygin noted considerable constancy in the diet from year to year which he explained by the fact that the animals tend to be found in the same areas each year. Some annular changes were noted (e.g. polychaetes were commonly eaten in 1963 but not in 1964 or 1965) which Kosygin thought were mostly due to heavy ice fields excluding animals from certain feeding areas. No age- or sex-related feeding differences were noted with the exception that it appeared that young bearded seals foraged mostly in the morning while mature animals ate more in the afternoon. The average amount of food in the stomachs decreased from April to June.

Kenyon (1962) reported on the stomach contents of 17 specimens taken at Little Diomede Island, 11 May-6 June 1958. Shrimps (*Pandalus* sp. and *Sclerocrangon* sp.), crabs (*Hyas coarctatus alutaceus* and *Pagurus* sp.), and clams (*Serripes groenlandicus*) comprised the bulk of the contents. Other benthic invertebrates (sponges, annelids, and snails) and several species of fish were present in small amounts.

In his summary of the biology of the bearded seal, Burns (1967) reported on his examination of stomachs from seals collected at Nome, Gambell, and Wainwright. In May he found that crabs (*Hyas coarctatus alutaceus* and *Pagurus* sp.) accounted for 57 percent of the contents with shrimp, fishes (saffron cod, arctic cod, and sculpins), and sponges comprising most of the remainder. In July and August clams (*Serripes groenlandicus*, *Spisula* sp., and *Clinocardium* sp.) were the most abundant food item, with shrimp, crabs, and isopods also quite commonly found.

Frost et al. (1977), Burns and Frost (1979), Lowry et al. (1979a), Lowry et al. (1979c), Lowry et al. (1980b), and Lowry and Frost (in press) report the results of our OCSEAP studies of bearded seals.

Spotted seal

Many studies have been done on the food of Phoca vitulina; however, most of these have been done on the land-breeding subspecies (P. v. richardsi). A single report has been found dealing with the feeding habits of the ice-breeding form (P. v. largha) in the Bering Sea.

Gol'tsev (1971) examined 319 stomachs from seals collected primarily in the northwest Bering Sea during the 1966-1968 hunting seasons (April-June). From his collections he concluded that spotted seals feed in the morning and in the evening and digest their food quite rapidly. The food of newly weaned young (5 weeks old) was entirely amphipods (Nototropis sp. and Anonyx nugax) and some algae. At 7 to 8 weeks old they begin to feed on shrimps (Spirontocaris macarovi, Eualus fabricii, and E. gaimardii) and sand lance. When 12 weeks old, larger fish (flatfish and saffron cod) begin to be eaten. Juveniles (age 1 to 4 years) fed mostly on fish (arctic cod, sand lance, saffron cod) and shrimps (Pandalus sp.). Adults appear to feed more on benthic forms with octopus, crabs, flatfishes, sculpins, and other bottom fishes prevalent.

Recent data on foods of spotted seals collected in the Bering Sea by Soviet and American investigators have been summarized and presented in Frost et al. (1977), Lowry et al. (1979a), Bukhtiyarov et al. (in press), and Lowry and Frost (in press).

Ribbon seal

Shustov (1965) examined 1,207 stomachs from seals taken at the ice front of the Bering Sea from March through July. Only 32 of these stomachs contained recognizable food. Shrimps (Pandalopsis sp., Argis lar, Pandalus borealis, Eualus gaimardii, and others), amphipods (Parathemisto sp.), mysids, and cephalopods were frequently found. Many types of fishes, especially arctic cod, saffron cod, and herring, were encountered but were not very common. In interesting contrast to the findings in the Sea of Okhotsk (Arseniev 1941; Wilke 1954; Fedoseev and Bukhtiyarov 1972), no pollock were found in the Bering Sea sample. This can perhaps be explained by the fact that the seals examined by Shustov were taken in the northern Bering Sea, somewhat north of the main concentrations of pollock.

Burns (in press) reports on the food remains found in the stomachs of six specimens collected in the Bering Sea. Four animals were taken in April and May; one contained fish (Pholis sp.), two contained shrimps (Pandalus and Sclerocrangon sp.), and one contained only milk. The stomachs of two specimens collected in February contained large volumes of pollock and arctic cod.

Frost et al. (1977), Lowry et al. (1979a), Frost and Lowry (1980), and Lowry and Frost (in press) report results of our OCSEAP studies.

Belukha whale

The only published information on foods of belukhas in Alaska comes from the work of Brooks in Bristol Bay (Brooks 1954a, 1955 and reported in Klinkhart 1966). Five species of salmon (Oncorhynchus spp.), smelt, flatfishes, sculpins, blennies, lamprey (Lampetra japonica), shrimps, and mussels were found in the stomachs examined. Smelt were the main food in early May. In late May downstream migrating fingerling salmon were the most important food. From the first of July through the end of August upstream migrating adult salmon were the main prey. Preliminary data on food habits of belukhas collected on an opportunistic basis during our OCSEAP studies is presented in Frost and Lowry (in press b) and Seaman and Lowry (in prep.).

Walrus

Although there are quite a number of published reports dealing with the foods of walruses in different parts of the world, few pertain to the Bering Sea.

Brooks (1954b) examined stomachs of walruses collected during May and June in the Bering Strait region. He found molluscs to be the predominant food, with echinoderms, polychaete worms, and priapulids also eaten. The clam genera Mya and Clinocardium were most frequently eaten by bulls whereas Astarte and Macoma and the polychaete Nephtys were most common in cows. Brooks also noted that local hunters sometimes killed walruses that had eaten ringed and bearded seals and whale carrion.

Tikhomirov (1964), during an investigation of the distribution and biology of Bering Sea pinnipeds, examined the stomachs of 50 walruses collected about 160 km east of the Pribilof Islands in March. They had eaten shrimp, crabs (including several king crabs, Paralithodes sp.), and some mollusks, although the latter were not a main food item.

Fay et al. (1977) examined the stomachs of 107 walruses collected in northern Bering Sea near Gambell, Savoonga, Diomede, Nome, and King Island in spring (April to June). Identifiable prey items included representatives of 10 phyla and at least 45 genera, among which were polychaetes, sipunculids, echiurids, priapulids, crustaceans, mollusks, holothuroids, ascidians, and a bearded seal. The clams Mya, Hiatella, Spisula, and Serripes comprised more than 80 percent of the total wet weight of identifiable items, with Mya most abundant at all areas except Nome where Serripes was dominant. Other common food items were Echiurus, Priapulus, Tellina/Macoma, Neptunea/Beringius, Polinices, and Thyonidium. Females tended to select smaller items than males, regardless of age. Fay et al. reported on the stomach contents of only two walruses collected in winter in northern Bering Sea, both near St. Lawrence Island. One had eaten mostly Spisula with a few other clam and gastropod feet, while the other contained the tunicate Pelonaia, clam feet, and small quantities of amphipods and shrimps. From southeastern Bering Sea Fay et al. reported unpublished data of Stoker and Muktoyuk (2 stomachs) and Yu. Bukhtiyarov (21 stomachs). In both instances bivalves (mostly Clinocardium) and gastropods were the main foods. Recently molted brachyuran crabs had also been eaten. In summary the authors suggested that walruses in the Bering Sea removed at least 25 percent of the bivalve standing stock per year, a rate close to the estimated net annual production of bivalves, and that it was highly probable that the walrus population was at or near the carrying capacity of its winter range in terms of food supply.

The dietary overlap and potential competition between walruses and bearded seals has been discussed in Lowry et al. (1979c), Lowry et al. (1980b), and Lowry and Frost (in press).

IV. Study Area

The study area encompasses seasonally ice-covered regions of the Bering Sea which lie east of the US-USSR Convention Line. Collections were centered around prospective OCS lease areas including Bristol Bay Basin, St. George Basin, Navarin Basin, and Norton Basin. Most work was shipbased in the first three of these areas whereas in Norton Basin most collections were made at coastal hunting villages. Specimens were obtained from the villages of Gambell, Savoonga, Nome, Diomede, and Wales with smaller samples from Hooper Bay, Mekoryuk, and Stebbins. Collection locations and OCS lease areas are shown in Figure 1.

V. Sources, methods, and rationale of data collection

Literature

Compilation of existing literature and unpublished data on the food habits and trophic interactions of ice-inhabiting seals is essentially complete. Available information on the distribution, abundance, and natural history of potentially important prey species has also been compiled. Pertinent literature was obtained through an OASIS literature search for information about food habits of seals, discussion and consultation with personnel from the University of Alaska Marine Museum/Sorting Center, use of various translation services (Israel Program for Scientific Translations and Fisheries Research Board of Canada) for access to Russian literature, search of Alaska Department of Fish and Game reprint files, library and other literature collections, use of University of Alaska library facilities, and inter-library loan services.

Field collection of specimen material

OCSEAP-sponsored collection efforts began in 1975 and intensified in 1976-1979. Collectors were sent to coastal hunting villages during predictably good hunting periods. Specimen material, including jaws and claws for age determination, reproductive tracts, and stomachs, was purchased directly from hunters. Sampling was done by the principal investigators and other ADF&G employees. A schedule of field activities and summary of specimens obtained is presented in Table 2.

Shipboard collections of seals were made by project personnel in areas inaccessible to coastal hunters. Collection in the Bering Sea ice front, where the ice was often impenetrable by small boats, was aided by a Bell 206 helicopter. Other shipboard collection efforts were conducted from small boats. Animals were shot either on the ice or in the water, taken to the ship, and processed as described below. Two early spring collections were made in Norton Sound from helicopters.

Whenever possible, seals from which specimen material was taken were weighed, sex was determined, and a series of standard measurements was made for use in this and other ongoing studies of ice-inhabiting

Table 2. Schedule of field activities in the Bering Sea and summary of specimens obtained. Only stomachs containing food are included.

Location/ Platform	Dates	Ribbon Seals	Spotted Seals	Ringed Seals	Bearded Seals	Walrus	Belukha Whales
Mekoryuk	22 Apr-12 June 1975		8	6	12		
Savoonga	7 May-13 June 1975		5	1	6		
Gambell	7 May-13 June 1975			1	2		
Nome	May 1975			4	1		
Diomede	28 May-10 June 1975			12	6		
Nome	22-25 Jan 1976			1			
SURVEYOR	14 Mar-1 May 1976	5	7				
Savoonga	1 May-30 June 1976			4	2		
Gambell	1 May-30 June 1976			1	4		
Diomede	1 May-30 June 1976			1	4		
Nome	11-21 June 1976			4	5		
MILLER-FREEMAN	27 Sept.-13 Oct. 1976				1		
Nome	18-24 Nov 1976		1	5			
Stebbins	19-21 Nov 1976			2			
Nome	25-29 Jan 1977			4			
Nome	8-20 Mar 1977			21	4		
SURVEYOR	15 Mar-3 May 1977	4					
DISCOVERER	18 May-13 June 1977		3				
Savoonga	20 May-24 June 1977			1	1		
Gambell	20 May-24 June 1977		2	30	15		
Diomede	20 May-24 June 1977			7	4		
Wales	28 May-2 July 1977		2	10	6		
Elim	12 June 1977						3
Nome	28 May-4 July 1977			13	8		
Hooper Bay	Jan-Nov 1978		2	3	1		
Gambell	1-24 Mar 1978			12	4		
Nome	Jan-Apr 1978			8	3		
Gambell	28 Apr-29 May 1978		3	1	33		
SURVEYOR	1 May-15 June 1978	18	11	5	10		
Savoonga	27 May-11 June 1978		2	3	14		
Wales	31 May-17 June 1978		6	20	12		
Diomede	19 May-15 June 1978			3	2		
SURVEYOR	9 Apr-4 May 1979	1	1		4		
Savoonga	May-June 1979		5	4	21	15	
Diomede	May-June 1979				8	21	
Gambell	May-June 1979		4	2	19	15	
Nome	May-June 1979			1	6		
Wales	May-June 1979					2	
Hooper Bay	Jan-June 1979			9			
TOTAL		28	62	199	218	53	3

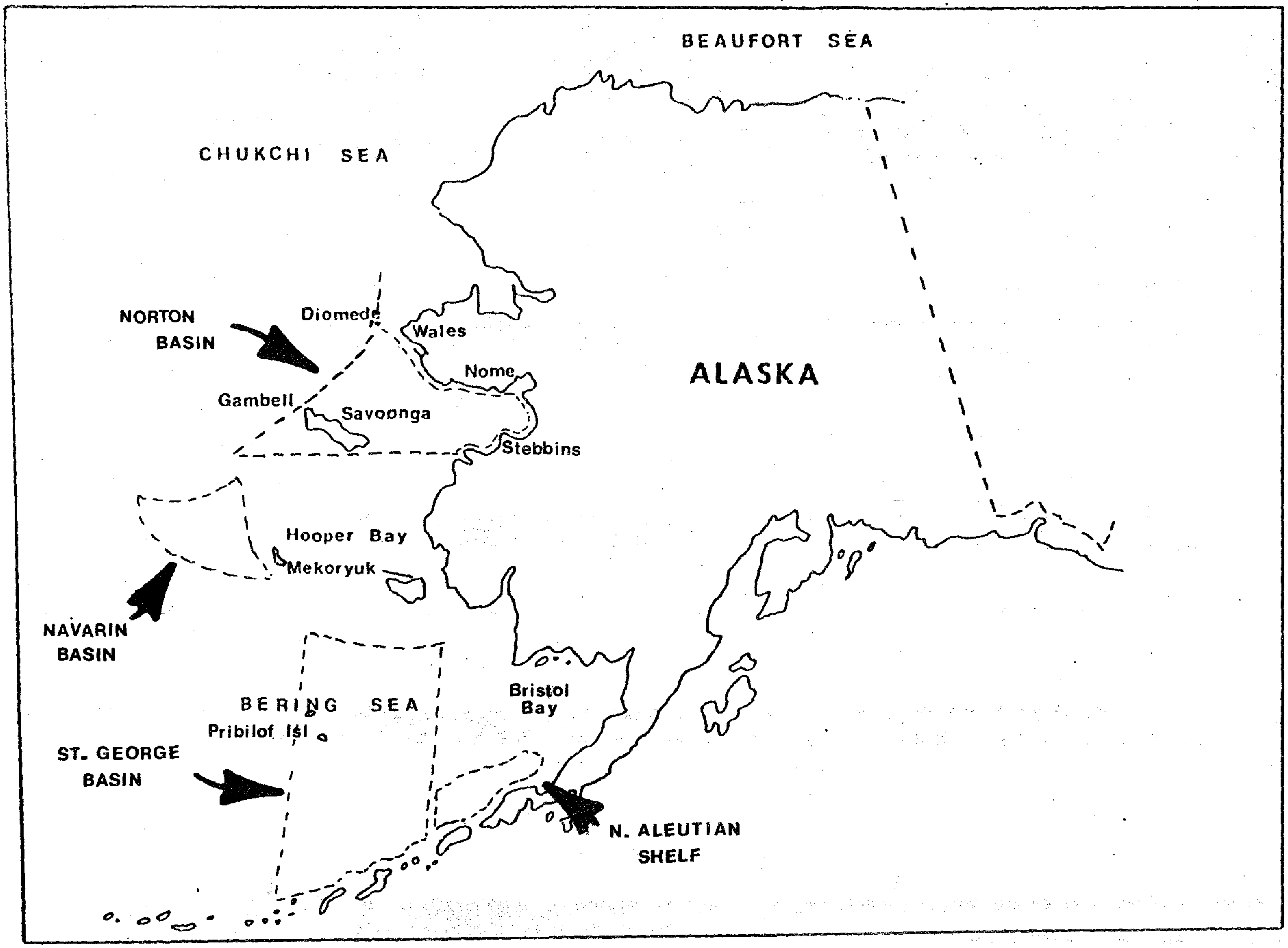

Figure 1. Locations where the major collections of specimen material and data were obtained during this investigation.

seals. Tissue and blood samples were collected in some cases and made available to other investigators for heavy metal, hydrocarbon, PCB, and pathogen analysis. (See methods section in RU #230, Annual Report, for detailed description of standard measurements and collection of additional specimen material.)

Only stomachs containing food were collected. Stomachs were tied at the cardiac and pyloric sphincters and severed from the remainder of the alimentary canal near these ties. They were then either injected with 10 percent formalin, labeled, and placed intact in plastic bags containing 10 percent formalin, or placed in bags and frozen. All stomachs were shipped to the ADF&G lab in Fairbanks. For some of the animals collected by project personnel, the contents of the small intestine were also retained and examined for food remains. In cases where the stomach was empty this often provided some information on recent diet. Upon arrival in the lab, stomachs containing large numbers of otoliths, which degrade rapidly in formalin, underwent a preliminary sort in which the otoliths were removed and stored in 95 percent ethanol.

When possible, bottom sampling for fishes and invertebrates with a 19-foot Marinovich otter trawl (1-3/8-inch stretch mesh body, 1/4-inch mesh cod end liner) was done in conjunction with the collection of seals. Trawls were of 10-20 minutes duration at a ship speed of 2-4 knots. Contents of each trawl were identified, enumerated, and representative specimens of organisms retained. Fishes were measured and weighed, and the otoliths removed and measured to determine the correlation of otolith size to fish size (see Frost and Lowry 1980; Frost and Lowry 1981). Stomach contents of some fishes were examined. Examples of selected invertebrate species were measured and weighed to provide an index of length/weight ratios that could be applied to partially digested food items found in seal stomachs.

Laboratory procedures and identification

The preserved contents of stomachs were washed onto a 1.0-mm mesh screen. Contents were sorted and identified to the lowest taxonomic level permitted by their condition, using appropriate taxonomic keys and reference specimens. In the majority of cases identifications entailed the sorting and recognition of small bits and pieces of organisms. Crustaceans were frequently identified by claws, carapaces, or abdomens. Fishes were identified on the basis of otoliths and bone fragments. The volume and number of each type of prey item were determined by water displacement and counts of individuals or otoliths. Size ranges of various prey items were determined when possible.

Virtually all identifications were made by project personnel. Necessary taxonomic keys and references, both published and unpublished, were accumulated. Much use was made of the University of Alaska Marine Museum/Sorting Center reference collection and of the expertise of Sorting Center personnel. A reference and voucher collection of invertebrates and fishes was established at ADF&G. In addition, an otolith collection was compiled. Considerable interchange of specimen material and ideas occurred among personnel of this project, Dr. James Morrow, OCSEAP RU #285, and John Fitch, California Department of Fish and Game (retired).

VI. Results

Spotted seals

We have examined the stomachs of spotted seals collected during research cruises in the Bering Sea ice front and ice remnants and of seals taken at coastal hunting sites. Seals associated with the Bering Sea ice front in March and April 1976 and 1977 had eaten capelin and pollock (Table 3). In outer Bristol Bay capelin were by far the major prey while one seal northwest of the Pribilof Islands had eaten only pollock. In April 1978 a seal taken in the ice front southwest of St. Lawrence Island contained remains of pollock, arctic cod, and sculpins. Seals associated with Bering Sea ice remnants in late May and early June had eaten fishes and octopus (Table 4). Capelin and herring were the only species eaten by seals near Nunivak Island in 1977. In 1978 seals taken at several locations west and east of St. Lawrence Island had eaten arctic and saffron cods in addition to capelin and herring. In addition to material in stomachs, otoliths recovered from intestines indicated that eelpout, sculpins, flatfish, and pricklebacks are occasionally eaten.

At coastal locations in May-June spotted seals we examined had eaten mostly fishes and shrimps (Table 5). Fishes eaten were mostly arctic and saffron cods, sand lance, and sculpins. Shrimps eaten were mostly *Crangon dalli* at Mekoryuk, *Pandalus goniurus* at Savoonga, and *Eualus gaimardii* at Gambell and Wales.

We have examined only 10 spotted seal stomachs with food from coastal areas in summer and autumn, 9 of which were collected prior to the commencement of OCSEAP. Fishes, primarily saffron cod, sand lance, smelt, and herring, comprised most of the stomach contents of those seals (Table 6).

Ribbon seals

Stomachs and intestines of 61 ribbon seals collected during research cruises in the ice front and ice remnants were examined. Very little fresh food was found in the stomachs; however, hard parts of prey, particularly fish otoliths, were found in digestive tracts of 28 seals. Weights of fishes of each species consumed were estimated from sizes of otoliths in seals or from average size of fishes of that species caught in trawls (Frost and Lowry 1980). The principal species of fish eaten varied with the area of collection (Table 7). Pollock and eelpout were major foods in the southcentral and central Bering Sea, while arctic and saffron cods were the main prey of ribbon seals in the northern Bering Sea. Invertebrates appeared to be only minor and perhaps incidental components of the diet. However, the dietary importance of invertebrates is difficult to evaluate since the seals we examined were not feeding at the time of collection.

Ringed seals

We have examined stomach contents of ringed seals taken during spring and early summer at seven locations on the Bering Sea coast

Table 3. Spotted Seal stomach contents data from Bering Sea ice front. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		outer Bristol Bay		NW of Pribilof Islands		outer Bristol Bay		SW of St. Lawrence Island			
Dates:		25-27 March 1976		22 March 1977		20 April 1977		28 April 1979			
Sample Size:		7		1		4		1			
Mean Volume (ml)		506.3		336.8		144.5		16.0			
Food Items	1	Fish Capelin	100 100	Fish Pollock	100 100	Fish Capelin Pollock	100 96 4	Fish Pollock Arctic Cod Sculpins	100 60 20 20		
	2										
	3										
	4										
	5										

Table 4. Spotted Seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area: Dates: Sample Size:		W of St. Matthew Island 26 May 1977 1	W of Nunivak Island 30 May 1977 2	around St. Lawrence Island May - June 1978 11		
Mean Volume (ml)		6.0	1134.0	270.5		
Food Items	1	Octopus 100	Fish 100 Capelin 51 Herring 49	Fish 96 Arctic Cod 43 Capelin 26 Saffron Cod 20 Herring 4 Octopus 3		
	2					
	3					
	4					
	5					

Table 5. Spotted Seal stomach contents data from Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:	Mekoryuk	Gambell	Savoonga	Wales	
Dates:	17-30 May 1975	May - June 1977-79	May 1975-79	June 1977-78	
Sample Size:	8	9	12	8	
Mean Volume (ml)	97.7	253.3	178.2	76.9	
Food Items 1	Fish* 87	Fish 96 Arctic Cod 34 Sand Lance 33 Sculpins 32	Fish 75 Arctic Cod 57 Sculpins 39	Fish 70 Saffron Cod 62 Smelt 12 Herring 10 Sand lance 6	
2	Shrimp 13	Shrimp 3	Shrimp 23	Shrimp 29	
3			Euphausiids 1		
4			Hyperiid Amphipods 1		
5					

* Accurate specific identification of fishes was [illegible] possible due to [illegible] with [illegible] by [illegible] mal [illegible] Se [illegible] l f [illegible] es were greenling (Hexagrammidae).

Table 6. Spotted Seal stomach contents data from Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Cape Woolley		Teller		Teller		Nome		
Dates:		14 Aug.-20 Sept. 1971 & 1972		12 Sept.-15 Oct. 1970 & 1972		8-21 November 1972		21 November 1976		
Sample Size:		2		5		2		1		
Mean Volume (ml)		50.1		1480.0		965.0		867.0		
Food Items	1	Fish Saffron Cod Sand lance	97 97 2	Fish Herring Smelt Capelin	100 70 20 10	Fish Smelt Saffron cod	100 76 24	Fish Sand lance Saffron cod	100 99 1	
	2	Gammarid amphipods	2							
	3									
	4									
	5									

Table 7. Food items in stomachs and intestines of ribbon seals collected in the Bering Sea during March-June, 1976-79

Food Item	Southcentral Bering March-April 1976, 1977 N = 9 Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences	Central Bering April-May 1978, 1979 N = 12 Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences	Northern Bering May-June 1978 N = 7 Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences
Invertebrates									
Clam	--	--	5	--	--	--	--	--	--
Snail	--	--	1	--	--	--	--	--	--
Octopus	--	--	3	--	--	--	--	--	2
Mysid	--	--	--	--	--	1	--	--	--
Shrimp	--	--	3	--	--	--	--	--	1
Tanner crab	--	--	--	--	--	--	--	--	1
Fishes									
Pollock	89.4	47.9	9	54.9	27.8	11	1.1	0.6	1
Arctic cod	--	--	--	3.7	6.8	2	86.0	95.0	7
Saffron cod	--	--	--	--	--	--	9.7	2.6	1
Eelpout	6.0	45.1	7	8.8	31.3	6	--	--	--
Capelin	2.7	2.3	5	8.5	3.3	5	--	--	--
Prickleback	0.4	0.4	3	11.2	7.6	4	--	--	--
Sculpin	0.1	0.2	1	--	--	--	3.2	1.8	2
Flatfish	0.7	1.8	2	12.9	18.5	9	--	--	--
Poacher	0.3	0.1	1	--	--	--	--	--	--
Snailfish	0.4	0.4	2	--	--	--	--	--	--

(Tables 8 and 9). At all locations fishes (mostly saffron and arctic cods and sculpins) and crustaceans made up most of the food. Shrimps (mostly Eualus gaimardii and Pandalus goniurus) were eaten at all localities. The dietary importance of other small crustaceans (amphipods, mysids, and euphausiids) varied considerably among the locations. The stomach contents of ringed seals collected in June in the ice remnant near St. Lawrence Island were similar to those of seals taken at nearby coastal villages (Table 10).

Data are available on the spring foods of ringed seals at Diomede for 7 years since 1958 (Table 11). Although shrimps, arctic cod, and gammarid amphipods were major prey in all years, the relative importance of those three kinds of prey varied from year to year. The highest volumes of stomach contents were generally found in years when arctic cod were the primary food.

Most of the ringed seal stomachs we examined from times other than spring and early summer were collected near Nome. Marked seasonality in foods was observed (Table 12). Saffron cod were the main food in November and May-June, arctic cod were the primary food in January-March, and shrimp were particularly important in the diet in March and April. Similar seasonality was seen in seals collected at Savoonga and Gambell (Table 13). Mysids and amphipods made up a greater portion of the diet in February and March than in May-June. More fishes, particularly arctic and saffron cods, were eaten in the latter period and quantities of food consumed were larger.

We combined all the data on stomach contents of ringed seals collected in the Bering Sea in April-June 1975-1979 and separated the results by age and sex categories (Table 14). Foods of male and female seals were similar. The proportion of fish in the diet increased dramatically with age from 1 percent in pups to 80 percent in seals 5 or more years old. The proportion of the food which was comprised of shrimps, hyperiid amphipods, and mysids showed a corresponding decrease with age.

Bearded seals

Stomachs of bearded seals collected in the eastern Bering Sea ice front and at coastal locations in the southeastern Bering contained mostly shrimps (Argis lar, Crangon spp.) and brachyuran crabs (Chionoecetes opilio and Hyas spp.) (Table 15). Particularly large quantities of Chionoecetes were found in three seals collected north of the Pribilof Islands in spring 1977.

In the northern Bering Sea in spring foods eaten by bearded seals at Diomede, Savoonga, and Gambell were very similar, with brachyuran crabs, sculpins, and shrimps the major foods (Table 16). Shrimp were a major component of the diet at both Nome and Wales. Brachyuran crabs at Wales and clams (Serripes groenlandicus) at Nome were other major foods. Bearded seals collected in the ice remnant near St. Lawrence Island in May-June 1978 had eaten mostly shrimp, clams (Serripes), and brachyuran crabs (Table 17).

Table 8. Ringed Seal stomach contents data from Southeastern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Mekoryuk	Hooper Bay			
Dates:		22 April-12 June 1975	March-May 1978-79			
Sample Size:		6	11			
Mean Volume (ml)		67.0	18.0			
Food Items	1	Fish 58 Saffron Cod 65 Sculpins 32	Mysid 87			
	2	Mysids 18	Fish 10 Saffron cod 87 Stickleback 6			
	3	Hyperiid Amphipods 13	Shrimp 2			
	4	Shrimp 4				
	5	Gammarid Amphipods 1				

Table 9. Ringed seal stomach contents data from northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

	Area:	Diomede		Savoonga		Gambell		Nome		Wales	
	Dates:	May-June 1975-78		May-June 1975-79		May-June 1979		May-June 1975-79		May-July 1977-78	
	Sample Size:	23		13		35		19		30	
	Mean Volume (ml)	63.5		110.4		85.5		312.4		122.5	
Food Items	1	Shrimp	38	Fishes Arctic cod Sculpin	62 95 3	Shrimp	41	Fish Saffron cod Sticklebacks	96 96 3	Fish Saffron cod	67 100
	2	Gammarid amphipods	34	Shrimp	20	Fish Arctic cod Saffron cod Sculpins Sand lance	35 40 33 17 2	Shrimp	3	Shrimp	27
	3	Fish Arctic cod Saffron cod Sculpins	18 81 11 5	Mysids	13	Mysids	13			Mysids	5
	4			Euphausiids	2	Hyperiid amphipods	6				
	5			Gammarid amphipods	1	Gammarid amphipods	4				

Table 10. Ringed seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		around St. Lawrence Island			
Dates:		June 1978			
Sample Size:		5			
Mean Volume (ml)		125.9			
Food Items	1	Shrimp 78			
	2	Fish 20 Arctic cod 72 Saffron cod 17 Herring 6 Sculpins 6			
	3	Gammarid amphipods 2			
	4				
	5				

Table 11a Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Diomede	Diomede	Diomede	Diomede	Diomede
Dates:		17 May-14 June 1958	20 May-3 June 1970	23 May-11 June 1971	15 May-1 June 1974	28 May-1 June 1975
Sample Size:		14 Kenyon (1962)	12	14	15	12
Mean Volume (ml)		86.0	118.3	255.7	138.1	54.9
Food Items	1	Shrimp	Fish 99 Arctic cod 81	Fish 99 Arctic cod 100	Fish 88 Arctic cod 69 Saffron cod 23 Sculpins 8	Gammarid amphipods 58
	2	Gammarid amphipods		Shrimp 1	Gammarid amphipods 10	Shrimp 18
	3	Fish			Shrimp 2	Fish 14 Sculpin 54 Arctic cod 43
	4	Mysids				
	5					

Table 11b Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Diomede		Diomede						
Dates:		27 May-3 June 1977		21-28 May 1978						
Sample Size:		7		3						
Mean Volume (ml)		50.8		136.1						
Food Items	1	Shrimp	44	Shrimp	83					
	2	Fish Arctic cod Saffron cod	40 86 12	Gammarid amphipods	17					
	3	Gammarid amphipods	15							
	4									
	5									

Table 12 Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:	Nome and Stebbins	Nome	Nome	Nome	Nome
Dates:	November 1976	January-February 1976-78	March 1977-78	April 1978	May-June 1975-79
Sample Size:	7	8	26	3	17
Mean Volume (ml)	246.3	64.1	228.2	182.1	312.4
Food Items 1	Fish 96 Saffron cod 78 Boreal smelt 13 Arctic cod 4 Sand lance 3	Fish 100 Arctic cod 85 Saffron cod 15	Fish 63 Arctic cod 83 Saffron cod 12 Sculpins 3 Sticklebacks 1	Shrimp 99	Fish 96 Saffron cod 96 Sticklebacks 3
2	Shrimp 3		Shrimp 36	Fish 1 Sculpins 50 Sticklebacks 38 Saffron cod 12	Shrimp 3
3					
4					
5					

Table 13. Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Savoonga		Savoonga				Gambell		Gambell	
Dates:		February-March 1976		May-June 1975-79				March 1978		May-June 1977-79	
Sample Size:		4		13				9 ≥2 Years Old		7 ≥2 Years Old	
Mean Volume (ml)		71.8		110.4				58.0		267.3	
Food Items	1	Mysids	79	Fishes Arctic cod Sculpin	62 95 3			Gammarid amphipods	54	Fish Saffron cod Sculpins Arctic cod	55 54 29 17
	2	Hyperiid amphipods	11	Shrimp	20			Fish Sculpins Saffron cod Sand lance	32 81 12 6	Shrimp	37
	3	Shrimp	8	Mysids	13			Shrimp	12	Mysids	6
	4	Gammarid amphipods	2	Euphausiids	2			Mysids	1		
	5			Gammarid amphipods	1						

Table 14. Major food items of ringed seals collected in the Bering Sea, April-June 1975-1979. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish, and percent of total number for species of fishes.

	Sexes Combined				Seals ≧5 yrs old	
Food Item	Pups N=46	Yrlgs N=24	2-4yrs old N=17	≧5yrs N=32	Males N=14	Females N=18
Shrimp	59	46	28	14	20	10
Hyperiid Amphipod	8	2	*	*	*	*
Gammarid Amphipod	4	4	6	4	7	2
Mysid	23	24	6	*	*	*
Euphausiid	2	-	-	-	-	-
Total Fish	1	23	60	80	70	85
Saffron Cod	33	92	99	97	97	97
Arctic Cod	43	*	*	2	2	3
Sand lance	5	2	-	*	-	*
Sculpin	5	-	*	*	1	*
Mean Volume of Contents (ml)	39.4	65.8	155.0	288.3	221.9	340.0

Table 15. Bearded seal stomach contents data from Southeastern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		100 nm north of Pribilof Islands		outer Kuskokwim Bay		Mekoryuk		Hooper Bay		
Dates:		22 March - 23 April 1977		29 March 1977		6-30 May 1975		29 April 1978		
Sample Size:		3		1		12		1		
Mean Volume (ml)		1011.5		342.0		137.9		3.0		
Food Items	1	Brachyuran Crabs	92	Shrimp	64	Shrimp	39	Shrimp	100	
	2	Polychaetes	4	Brachyuran Crabs	22	Fish Sculpins Pollock Saffron Cod	19 85 7 5			
	3	Snails	2	Anomuran Crabs	5	Brachyuran Crabs	18			
	4	Fish Eelpout Flatfish Pollock	2 84 10 5			Isopods	10			
	5					Gammarid Amphipods	1			

Table 16. Bearded seal stomach contents data from northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

		Diomede		Savoonga		Gambell		Nome		Wales	
Area:		Diomede		Savoonga		Gambell		Nome		Wales	
Dates:		May-June 1975-79		May-June 1975-79		April-June 1975-79		May-June 1975-79		June-July 1977-78	
Sample Size:		24		42		58		21		18	
Mean Volume (ml)		555.6		429.9		452.4		436.1		307.0	
Food Items	1	Brachyuran Crab	35	Brachyuran Crab	34	Brachyuran Crab	43	Clam	56	Shrimp	46
	2	Fish Sculpins Arctic cod Eelpout	29 87 10 2	Fish Sculpins Poachers	29 95 1	Fish Sculpins Arctic cod Pricklebacks Poachers	16 94 3 1 1	Shrimp	32	Brachyuran Crab	45
	3	Shrimp	17	Shrimp	22	Shrimp	15	Brachyuran Crab	3	Fish Saffron cod Sculpins Arctic cod Flatfishes	4 79 17 2 1
	4	Sponge	4	Clam	5	Clam	11	Anemone	2	Clam	2
	5	Clam	3	Gammarid Amphipods	2	Sponge	3	Fish Sculpins Saffron cod Flatfishes	2 63 27 3		

Table 17. Bearded seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		around St. Lawrence Island				
Dates:		May-June 1978				
Sample Size:		10				
Mean Volume (ml)		595.3				
Food Items	1	Shrimp 41				
	2	Clam 22				
	3	Brachyuran Crab 13				
	4	Snails 5				
	5	Fish 3 Sculpins 56 Arctic cod 27 Saffron cod 17				

Samples of bearded seal stomach contents have been collected during spring at Nome and Diomede for several years since 1958. The most obvious difference among those samples was a marked decrease in the amount of clams consumed, particularly at Diomede (Table 18). Prior to 1975 at Diomede clams were a major component of the diet. After 1975 only small amounts of clams were found in bearded seals taken there. At Nome clams were a large component of the diet from 1970-1977. Very few clams were found in seals collected at Nome in 1979.

We have collected very few specimens from bearded seals which were taken at times of the year other than during spring and summer. Therefore, we have combined our data from all locations in the Bering Sea and separated the results into two time periods (Table 19). In May-September, clams, shrimps, crabs, and fishes are all major foods. In October-April stomach contents consisted mostly of shrimp and crabs. Clams (mostly *Serripes*) occurred in 30 of 46 seals in the former period but only 1 of 11 from the latter period.

Data from all seals collected in spring and summer in the Bering Sea were separated by age and sex categories (Table 20). Males consumed more clams and slightly less fish than did females. The diet of bearded seal pups was composed of a larger proportion of shrimp and a smaller proportion of clams than was found in seals 3 or more years old. In addition, the fishes eaten by pups included a large proportion of saffron cod while older seals ate almost entirely sculpins.

Walrus

We obtained and examined stomach contents from 53 walruses taken in the northern Bering Sea in May-June 1979. One walrus stomach from each location sampled (Savoonga, Gambell, Wales, and Diomede) contained primarily meat, blubber, and organs from seals. All other walruses examined had eaten mostly clams (Table 21). The quantities of the various clam species consumed varied among the localities. Overall, most of the clams eaten were *Mya* sp. which were the primary prey species at all localities except Wales where *Tellina* (or *Macoma* which cannot be distinguished from *Tellina* in stomach contents) made up most of the contents. Species other than clams were of minor importance in the diet except at Gambell where polychaetes (*Abarenicola* sp.) occurred in large quantities in two walrus stomachs.

Belukha whales

The only belukha whale stomachs we examined from the Bering Sea were from three animals taken at Elim on 12 June 1977. The stomach contents of the three animals were similar and consisted of a combined total of 887 ml of partially digested fish and 381 ml of pebbles, mostly 2 cm or less in diameter. Fishes eaten by the three whales included at least 3,900 saffron cod, 55 sculpins, and 5 herring. Saffron cod eaten averaged 16.5 cm long (range 6.5-29.1 cm) and 40.0 gms in weight (range 1.6-168.4 gms). Sculpins eaten averaged 35.6 cm (range 22.9-51.0 cm) and 524.6 gms (range 119.6-1,362.2 gms).

Table 18. Percent of total stomach contents volume which consisted of clams in bearded seals collected at Nome, Diomede, and Wainwright between 1958 and 1979. Frequency of occurrence (no. of stomachs containing clams/total no. of stomachs in sample) is given in parentheses. Only stomachs from seals collected between May and August are included.

Year	Nome	Diomede
1958	-	one of two primary foods[1] (9/17)
1967	-	59% (5/6)
1970	40% (1/2)	-
1975	48% (1/1)	9% (5/6)
1976	87% (4/5)	2% (2/4)
1977	44% (5/8)	0% (0/4)
1978	-	0% (0/2)
1979	* (1/6)	2% (3/8)

[1] Kenyon 1962
* Indicates values less than 1%

Table 19. Major foods of bearded seals collected in the Bering Sea sorted by time period. Results are presented as in Table 17. Percent frequency of occurrence (no. stomachs containing item/ total no. stomachs in sample X 100) is also given. Only specimens from seals 3 or more years old are included.

	1 May - 30 September N=46		1 October - 30 April N=11	
	Percent Volume/No.	Percent Frequency of Occurrence	Percent Volume/No.	Percent Frequency of Occurrence
Clam	28	63	*	9
Snail	2	48	1	27
Shrimp	20	94	53	73
Brachyuran crab	23	80	37	91
Total Fish	16	78	5	82
Saffron cod	3	4	4	36
Arctic cod	9	17	5	27
Sculpins	82	46	76	54
Flatfish	-	-	3	46
Mean Volume of Contents (ml)	662	-	743	-

* Indicates values less than 1%

Table 20. Major food items of bearded seals collected in the Bering Sea in spring and summer 1975-1978. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish and percent of total number for species of fishes.

	Sexes Combined			Seals ≧3yrs old	
	Pups N=52	1&2yrs old N=31	≧3yrs old N=50	Males N=25	Females N=17
Clam	2	3	25	36	18
Snail	*	*	2	*	6
Shrimp	45	26	27	20	20
Brachyuran crab	28	38	27	23	22
Total Fish	13	26	10	14	19
Saffron cod	41	5	4	-	4
Arctic cod	5	2	6	7	13
Sculpins	47	89	77	82	80
Mean volume (ml)	213	578	670	668	712

* Indicates values less than 1%

Table 21. Food items identified from stomachs of walruses taken in the northern Bering Sea in May and June 1979.

Food Item	Savoonga N=14 % of Total Weight	Savoonga N=14 Number of Occurrences	Gambell N=14 % of Total Weight	Gambell N=14 Number of Occurrences	Wales N=1 % of Total Weight	Wales N=1 Number of Occurrences	Diomede N=20 % of Total Weight	Diomede N=20 Number of Occurrences
Clam Total	79.9	13	56.0	13	96.4	1	92.9	20
Hiatella sp.	-	-	2.2	1	-	-	3.9	1
Mya sp.	54.0	12	34.7	11	-	-	78.2	20
Serripes sp.	16.3	8	7.1	10	-	-	*	2
Spisula sp.	2.0	7	8.1	10	3.3	1	4.9	17
Tellina/Yoldia sp.	3.0	3	1.5	4	92.6	1	5.0	2
Other	4.6	3	2.3	6	*	1	-	-
Snail	1.2	13	4.1	11	*	1	*	4
Sea Cucumber	1.3	6	*	5	-	-	2.1	13
Priapulid	1.4	7	*	5	-	-	*	3
Echiuroid	4.3	2	2.5	3	-	-	*	2
Polychaete	*	4	17.6	2	-	-	*	2
Crustaceans	*	4	1.2	10	-	-	-	-
Rocks/Pebbles	10.8	9	16.6	12	3.6	1	2.8	19
Mean Weight of Contents (kg)	1.52		2.17		1.17		3.09	

* Indicates values less than 1%

VII. Discussion

A. Foods of Marine Mammals

Our investigations of the foods utilized by marine mammals in the Bering Sea were based on stomachs collected during 1975-1979. In 1977 we were able to obtain stomachs from three belukha whales. In 1979 we systematically collected stomach contents of walrus taken in the northern Bering Sea.

All belukha and walrus stomachs and most of the seal stomachs we examined were obtained from animals killed by Eskimo subsistence hunters. Therefore, the majority of our samples came from the spring and early summer from locations in the northern Bering Sea. In order to extend our geographical coverage, we made collections of seals (primarily ribbon and spotted) from ice-strengthened NOAA vessels in the Bering Sea ice front and ice remnants during spring. Also, in order to obtain information on seasonal aspects of feeding, we collected ringed seals in Norton Sound from NOAA helicopters in March and April. Although our efforts have greatly increased our understanding of foods of Bering Sea marine mammals, substantial data gaps still exist. These data gaps relate primarily to summer and autumn foods of seals and belukhas in the coastal zone and winter foods of seals and walruses in the Bering Sea ice. Needs for further study are discussed in more detail in section IX.

For purposes of discussion we have divided the Bering Sea into four major areas (Figure 2).

Spotted seal

The entire Bering Sea population of 200,000-250,000 spotted seals is associated with the ice front zone during the months of February, March, and April. During May and June adults and pups are found concentrated in remnants of seasonal ice while subadults appear to have moved to coastal waters. During summer and autumn spotted seals haul out in coastal areas from northern Bristol Bay to the western Beaufort Sea.

The results of recent Soviet studies and of our OCSEAP research on foods of spotted seals in the Bering Sea have been summarized by Bukhtiyarov et al. (in press). Thirty-one spotted seals with food remains in stomachs or intestines collected in the American sector of the Bering Sea were examined. All of those animals were collected in the ice front and ice remnants during spring months. Fishes were the major food in all areas. In the southeastern Bering Sea capelin were by far the major food, followed by herring and pollock. In the southcentral and central Bering Sea pollock were the major food and eelpout were also commonly eaten. In the northern Bering Sea, arctic cod, saffron cod, and capelin were all major foods. Pollock, herring, sand lance, and sculpins were minor food items in this area. Spotted seals collected in Soviet waters in the western Bering Sea in spring were found to have eaten similar species of fishes (Gol'tsev 1971; Bukhtiyarov et al., in press). In Soviet waters, crustaceans (amphipods, shrimps, and

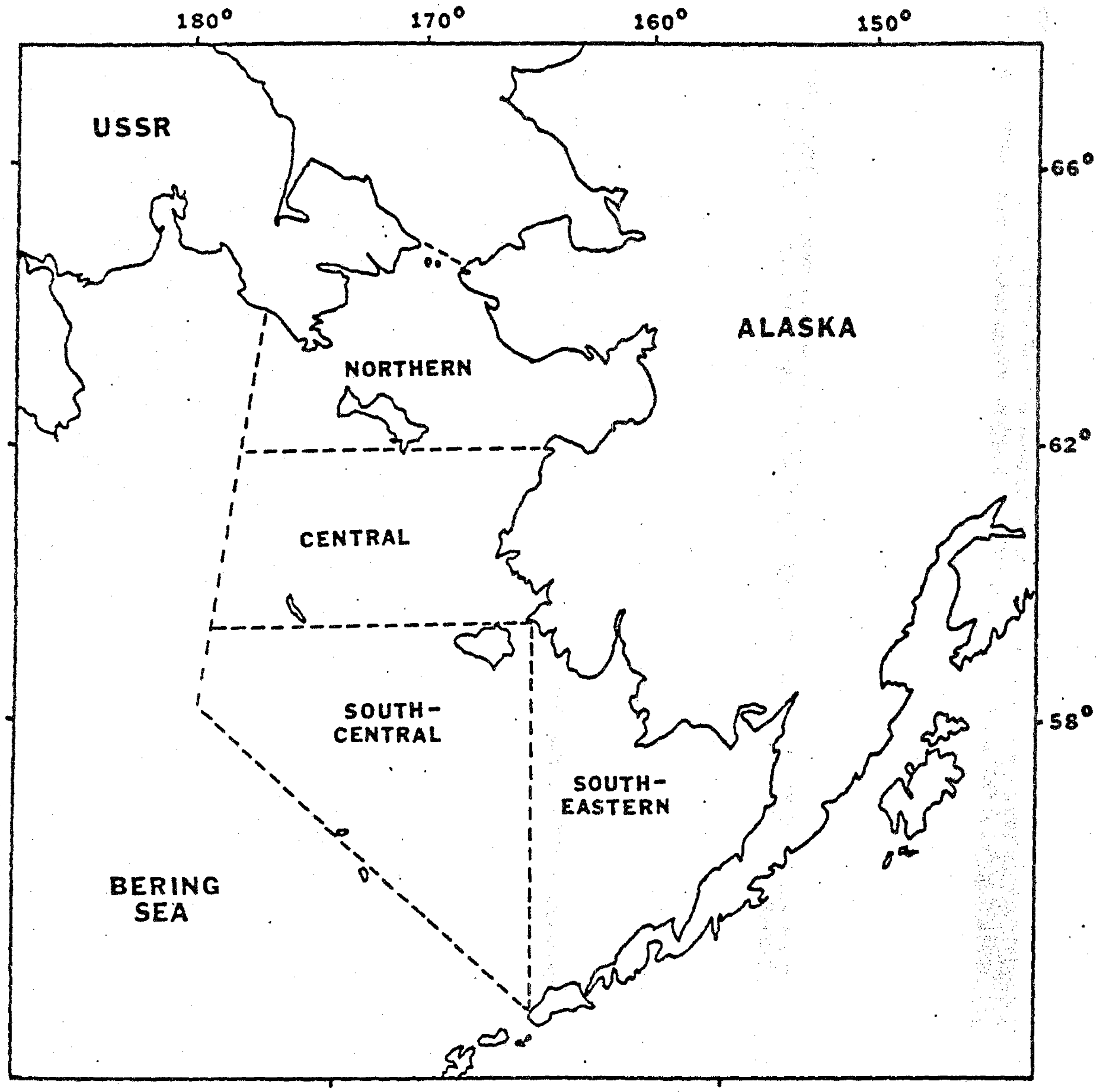

FIGURE 2. MAP OF THE BERING SEA SHOWING REGIONS DISCUSSED IN THE TEXT.

euphausiids) and octopus were eaten more commonly than in the eastern Bering Sea. Crustaceans appeared to be most important to young seals while octopus were most frequently eaten by adults (Bukhtiyarov et al., in press).

Other than during spring, there are few data available on foods of spotted seals in the Bering Sea. Saffron cod, sand lance, herring, smelt, and capelin were the primary prey of 10 spotted seals collected along the southern Seward Peninsula in late summer and autumn. These species of fishes are probably the main foods of spotted seals in the eastern Bering throughout summer and autumn. Based on observations of ringed seal foods, it is likely that during winter months arctic cod is also a major food of spotted seals. In the Chukchi Sea in June-October herring are a major food of spotted seals (Lowry et al. 1980c). Saffron cod, sculpins, shrimps, and isopods were also found in stomachs of spotted seals collected in the Chukchi Sea.

Ribbon seal

The Bering Sea population of ribbon seals, numbering about 100,000 animals, is found in the Bering Sea ice front and ice remnants during spring. During these months the animals pup, breed, molt, and spend little time feeding. Although there is little direct evidence, ribbon seals are thought to spend the remainder of the year feeding pelagically in the vicinity of the Bering Sea shelf break (Burns, in press).

All major studies of foods of ribbon seals have been based on animals collected during the spring period of reduced feeding. Shustov (1965) examined the stomachs of 1,207 seals taken in the ice front of the Bering Sea (between St. Matthew and St. Lawrence Islands and the Gulf of Anadyr) in the months of March to July. Only 32 stomachs contained recognizable food, most of which was shrimps, amphipods, mysids, and cephalopods. Several species of fishes, particularly arctic cod, saffron cod, and herring, were eaten, but not frequently.

Results of recent OCSEAP studies on foods of ribbon seals in the Bering Sea are summarized in this report and Frost and Lowry (1980). Animals were collected in the months of March to June. Food remains were found in the stomachs of seven of 61 animals examined. By collecting otoliths from small intestines, data on the species of fish consumed were obtained for a total of 28 animals. Trace amounts of invertebrates (octopus beaks, fragments of shrimps, and small clams) were found in 11 of the 28 specimens examined. In the southcentral Bering, pollock were the most numerous prey, and capelin and eelpout were also eaten in substantial numbers. In the central Bering, pollock were again the numerically dominant prey followed by eelpout, Greenland halibut (Reinhardtius hippoglossoides), pricklebacks, and capelin. North and east of St. Lawrence Island arctic cod were the major food with saffron cod, sculpins, octopus, and pollock occasionally eaten. Based on the size of otoliths recovered and the relationship between fish weight and otolith length, eelpout eaten were about nine times as heavy as pollock. Therefore, eelpout may be a more important food in the southcentral and central Bering Sea than is indicated by the number consumed.

Burns (in press) reported the stomach contents of two ribbon seals collected in the Bering Sea in February. One of the seals had eaten exclusively pollock, the other had eaten arctic cod. Each of these specimens contained over a liter of food in the stomach. Unfortunately, these are the only data available on the foods of ribbon seals during the period of active feeding.

Ringed seal

Ringed seals are the most widely distributed and abundant of northern hemisphere pinnipeds. They occur seasonally in the Bering Sea, appearing with the formation of sea ice in November and leaving during ice disintegration in May and June. They are found primarily in coastal areas where shorefast ice provides a stable substrate for care and weaning of pups. Ringed seals of the Bering, Chukchi, and Beaufort Seas appear to constitute a single population estimated to number 1 to 1.5 million individuals.

Although there have been numerous studies of foods of ringed seals in various parts of their range, until recently there was only one published report on foods of ringed seals in the Bering Sea. That study (Kenyon 1962) reported the stomach contents of 14 seals collected at Diomede in spring 1958. Recent OCSEAP studies have considerably expanded our understanding of foods of ringed seals in the Bering Sea. Most of the specimens have been collected at the northern Bering Sea villages of Nome, Gambell, Savoonga, Diomede, and Wales. At all locations, over 80 percent of the stomach contents in our samples of ringed seals was made up of three or four of the following prey: arctic cod, saffron cod, sculpins, shrimps, mysids, and gammarid amphipods. The major prey utilized vary both seasonally and geographically. Saffron cod are most important in the diet during autumn and spring months along the mainland coast. Arctic cod are the primary species eaten during winter months in northern Bering Sea. Shrimps are eaten in small amounts at all areas and in all seasons but are of greatest importance during spring and summer in northern Bering Sea and Norton Sound. Mysids are eaten in largest quantities in the southeastern Bering and near St. Lawrence Island. Gammarid amphipods and sculpins are eaten most commonly near St. Lawrence and Little Diomede Islands.

Sufficiently large samples have been collected to allow testing for age- and sex-related dietary differences. Foods of male and female ringed seals collected in the Bering Sea were similar. However, major differences were found in the relative importance of the various prey types to different age classes of seals collected during spring. Crustaceans (primarily shrimps, mysids, and amphipods) made up 98 percent of the food of recently weaned pups, 77 percent of the food of yearlings, 40 percent of the food of 2- to 4-year-old seals, and 20 percent of the food of seals 5 or more years old. The importance of fish in the diet showed a corresponding increase with age.

Year-to-year variations in the primary prey at a single locality and season have also been documented at Diomede. Shrimps and arctic cod were each the primary food in 3 years, and gammarid amphipods were the primary food in 1 year. These differences showed no systematic pattern and are therefore probably related to annual differences in relative abundance of the various prey species. Foods of ringed seals in the Bering Sea are generally similar to those reported in the Chukchi Sea (Lowry et al. 1980c). Arctic cod and small crustaceans appear to be of greater importance in the diet in the Chukchi while saffron cod and shrimps are eaten in larger quantities in the Bering. In comparison with the Beaufort Sea (Lowry et al. 1979d), foods of ringed seals in the Bering Sea are more variable and include a wider array of prey species. Aspects of variability in the diet of ringed seals throughout Alaskan waters are dealt with in detail in Lowry et al. (1980a).

Bearded seal

Bearded seals are circumpolar in distribution and common throughout areas of moving ice in the Bering Sea. Like ringed seals they occur only seasonally in the Bering Sea, being generally absent during ice-free months. Bearded seals in the Bering and Chukchi Seas are considered a single population numbering about 300,000 animals.

Results of Soviet investigations on foods of bearded seals in the Bering Sea have been reported by Kosygin (1966, 1971). Kenyon (1962) reported on the stomach contents of 17 bearded seals taken at Diomede in spring 1958. Burns (1967) reported the results of his examinations of 23 bearded seal stomachs collected in the northern Bering and Chukchi Seas. Results of recent OCSEAP studies based primarily on specimens collected at coastal villages have been summarized in Burns and Frost 1979 and Lowry et al. 1980b. Most specimens reported on in both Soviet and American studies were collected during spring.

Throughout the Bering Sea, crabs (*Chionoecetes opilio* and *Hyas* spp.), shrimps (*Argis* spp., *Crangon* spp., Eualus spp., and *Pandalus* spp.), and clams (mostly *Serripes groenlandicus*) make up the bulk of the bearded seal diet, while fishes are generally of little importance. The fishes most commonly eaten are sculpins and saffron cod. Kosygin (1971) reported snails, octopus, and flatfishes as important foods and did not find *Serripes* in his samples.

Geographical variations in the relative importance of the major prey species are evident (Lowry et al. 1980b). Shrimps comprise a relatively constant proportion of the food, ranging from 16 to 33 percent. The species of shrimps eaten change in relation to patterns of shrimp distribution. Similarly, *Chionoecetes* is the major species of crab eaten in offshore waters of the southeastern and southcentral Bering while *Hyas* is more commonly eaten nearshore and in the northern Bering. The proportion of clams in the diet is highly variable, ranging from 4 to 69 percent depending on locality. Consumption of clams and crabs appears to be inversely related. In areas where large amounts of clams are consumed, crabs are not eaten in quantity. Sculpins were found in particularly large quantities in bearded seals taken at Diomede. Similar foods have been reported from bearded seals collected in the Chukchi and Beaufort Seas (Lowry et al. 1979d, 1980c).

Differences in foods of male and female bearded seals are slight and probably not significant. Age-related changes in foods are marked.

The importance of clams in the diet increases with age while the relative amount of shrimps consumed decreases. In recently weaned pups saffron cod are eaten almost as frequently as sculpins, while over 75 percent of the fishes eaten by older seals are sculpins.

Seasonal changes in major food items are also marked. Clams are eaten in significant amounts only during spring and summer months. The relative proportion of shrimps and crabs in the diet is greatest during fall and winter.

Data on foods of bearded seals taken during spring at Diomede during the period 1958-1979 suggest long-term changes in food availability. Clams were the primary food found in 1958 and 1967. Since 1975 clams have been a minor component of the food, accounting for less than 10 percent of the stomach contents. It has been suggested (Lowry et al. 1980b) that this is due to a reduction in clam populations caused by increased numbers of walruses foraging in the area. Similar changes may presently be occurring near Nome. However, further data are required from that area.

Walrus

The Pacific walrus population ranges seasonally throughout the waters covering the Bering-Chukchi platform. Since they are benthic feeders they do not regularly occur in deep waters off the continental shelf. During winter and spring months walruses are found throughout areas of moving ice in the Bering Sea and Bristol Bay. Much of the population moves north through Bering Strait as seasonal ice disappears. Several thousand walruses summer on coastal haulouts in Bristol Bay and the northern Bering Sea. Recent estimates indicate a population in excess of 200,000 (Krogman et al. 1978).

The only significant published accounts of foods of walruses in the Bering Sea are those of Fay et al. (1977 and in press). The following summary is taken directly from those reports.

The contents of the stomachs of 21 walruses collected in March and April 1976 in the southeastern Bering Sea were examined. The major foods were clams (mostly Serripes groenlandicus and some Mya truncata), tanner crabs, and snails (Neptunea sp. and Buccinum sp.).

Fay et al. (in press) reported on the stomach contents of 107 walruses taken near five locations in the northern Bering Sea (Gambell, Savoonga, Nome, King Island, and Diomede) during April to June 1974-1976. Five genera of clams (Mya, Serripes, Hiatella, Spisula, and Clinocardium) made up from 85 to 99 percent of the identifiable food at all areas. Other prey items such as crustaceans, worms, tunicates, and echinoderms were of only minor importance in the diet. Mya was the primary prey at all locations except south of Nome where Serripes made up 98 percent of the identifiable stomach contents.

Although the same array of species is eaten by both male and female walruses, in the northern Bering Sea females tend to eat smaller clams than do males. Females tended to eat the smaller species such as

Hiatella and small individuals of the large species such as Mya and Serripes. Males fed primarily on large individuals of large species, particularly Mya.

Age-related differences in diet have not been rigorously examined. Fay et al. (in press) suggest that young animals may feed on smaller items than do adults.

Our results agree very closely with those reported by Fay et al.

Belukha whales

Belukha whales are widespread in arctic and subarctic waters. Many belukhas spend the summer months in the coastal zone, frequenting shallow bays and estuaries. Their distribution is amphiboreal; Atlantic and Pacific populations apparently do not mix (Tomilin 1957). The Bering Sea stock winters in the central Bering Sea and moves in spring to the Yukon-Kuskokwim Delta, Norton Sound, Kotzebue Sound, and north through the Chukchi Sea to the Beaufort Sea. There is a resident population in Bristol Bay (Tomilin 1957; Harrison and Hall 1978) estimated at 1,000-1,500 individuals (Lensink 1961). The rest of the Bering Sea belukha population is estimated to number at least 8,000 whales.

Belukhas eat primarily pelagic and semidemersal fishes. In addition, they eat cephalopods and crustaceans, especially shrimps. Among the fishes eaten are herring, salmon, saffron cod, arctic cod, capelin, flatfishes, Pacific cod (Gadus macrocephalus), and whitefish (Coregonus spp.) (Vladykov 1946; Tomilin 1957; Kleinenberg et al. 1964; Sergeant 1973).

There is little published information on foods of belukhas in Alaska. Brooks (1954a, 1955) found five species of salmon, smelt, flatfishes, sculpins, blennies, lamprey, shrimps, and mussels in the stomachs he examined from Bristol Bay belukhas. Smelt were the main food in early May. In late May downstream migrating fingerling salmon were the most important food. From the first of July through the end of August upstream migrating adult salmon were the main prey. Saffron cod and sculpins were the major prey eaten by the three whales we examined from Norton Sound. Lowry et al. (1980c) reported on the foods of belukhas in the Chukchi Sea. Whales from Kotzebue Sound had also eaten mainly saffron cod. In addition, sculpins, herring, octopus, smelt, and eelpout were eaten at one or both locations.

It is probable that belukha distribution is partially determined by the distribution and abundance of aggregating fishs such as herring, salmon, and arctic cod. Kleinenberg et al. (1964) and Klumov (1937) have suggested that the distribution and movements of belukhas in northern waters are correlated primarily with those of arctic cod. In the Bering Sea saffron cod and herring may play a similar role in determination of belukha distribution and movements.

A detailed treatment of the foods of belukhas in Alaskan waters is currently being prepared (Seaman and Lowry, in prep.).

B. Biology of Major Prey Species

Walleye pollock

Walleye pollock are found throughout the north Pacific and in greatest abundance along the continental shelf break of the Bering Sea. They comprise over 40 percent of the total apparent biomass of fishes and invertebrates in southeastern Bering Sea (Pereyra et al. 1976). Abundance decreases rapidly north of St. Matthew Island, and they are caught only rarely north of Bering Strait (Pereyra et al. 1976). They are not common in Norton Basin. The species supports a commercial fishery of almost 1 million metric tons per year, one of the largest in the world. Pollock form a major portion of the diet of all pinnipeds of the southern Bering Sea, except bearded seals and walruses, and are eaten by at least 4 species of cetaceans, 13 species of seabirds, and 10 species of fishes in that area. The distribution, abundance, and biology of pollock in the Bering Sea have been summarized in considerable detail by Pereyra et al. (1976), Berg (1977), Bakkala and Smith (1978), and Svetovidov (1948) and for that reason we will present only a general discussion of pertinent life history events taken from those reports.

Pollock undergo seasonal migrations from deeper parts of the shelf and the upper slope in winter (160-300m) to, at least in warm water years, shallow shelf waters in summer. Large winter concentrations occur between the Pribilof and Unimak Islands and southwest of St. Matthew Island where almost 80 percent of the total pollock biomass is located. A spawning concentration forms northwest of Unimak Island in spring in the shallower waters of the outer shelf (90-140 m), and spawning begins in March, peaks in May, and ends in the middle of July (Berg 1977).

The eggs, which are pelagic, occur at depths of 13-300 m, mainly in the upper 100 m layer where they develop. Hatching takes 10-30 days depending on water temperature, with the most rapid development occurring in warmer (6-10°C) water (Pereyra et al. 1976). Newly hatched eggs float at the surface until the yolk sac is absorbed (10-22 days depending on water temperature). Larval pollock feed near the surface on diatoms, copepod eggs, and nauplii, and as they grow larger on copepods, euphausiids, and other zooplankton. They become demersal at a length of 35-50 mm, and reach 90-110 mm by the end of their first year of life. One and 2-year-old pollock (the size classes most important as food of marine mammals, birds, and fishes) appear to be widely distributed with no discernible seasonal patterns. They are generally found closer to the surface than older fish. Overall, age groups 1-3 make up over 90 percent of the estimated total number of pollock. Pollock grow rapidly during the first 4 years of life, maturing at age 3 or 4, after which time growth slows down. The oldest pollock caught in the Bering Sea in resource assessment test fishing was a 17-year-old female (Pereyra et al. 1976).

Predominant food items of pollock include semi-pelagic crustaceans such as euphausiids, copepods, and amphipods. Large pollock (over 50 cm) eat as much as 50 percent 0- to 1-year-old pollock.

Arctic cod

Arctic cod is the single most important forage fish in far northern waters (Klumov 1937; Tomilin 1957; Tuck 1960; Frost and Lowry 1981). It is one of the major prey species of marine mammals and seabirds in Norton Basin. In September-October 1976, Wolotira et al. (1979) found them to occur in 83-93 percent of the trawls in each sample area in Norton Sound and northern Bering Sea, being most common south of Golovnin Bay, south of Nome, and west of Nome at about 167°W. Arctic cod caught during that survey ranged in size from 4 to 26 cm, with an average of about 13 cm. Fish smaller than 8 cm (first year class) were found almost exclusively in deeper water northeast of St. Lawrence Island, whereas larger fish were more widely distributed. Arctic cod were virtually absent from inner Norton Sound during that survey. Winter distribution and abundance in the Bering Sea is unknown except by inference from the catches of coastal subsistence fishermen or the winter diets of marine mammals, which suggest they are locally very abundant at that time.

The distribution of adult arctic cod is closely related to low temperatures and/or the presence of sea ice, with much of the population believed to stay under or near the edge of compact ice for most of the year (Svetovidov 1948; Andriyashev 1954; Ponomarenko 1968). Andriyashev (1954) indicated that in autumn large schools may be found nearshore, especially in warm, relatively fresh water near river mouths. Recent OCSEAP research in the Beaufort Sea has also documented large concentrations of arctic cod in nearshore areas in late summer and autumn (Bendock 1979; Craig and Haldorson 1979). The precise time and location of spawning for arctic cod in Alaska is unknown. In the Beaufort Sea individuals caught nearshore during November were gravid, and by the next sampling period in February all individuals had spawned. This coincides closely with spawning periods in the Barents and Kara Seas and eastern Siberia (Moskalenko 1964; Rass 1968; Ponomarenko 1968). Spawning probably occurs in coastal areas.

Arctic cod have the largest and fewest eggs of all cods (Svetovidov 1948; Andriyashev 1954). The eggs develop in surface waters under the ice and probably hatch in May or June. Larvae live in surface waters until August or September when transition to the juvenile stage takes place and the fry descend to the bottom (Rass 1968; Baranenkova et al. 1966). Association with the ice is thought to begin after the first year. Individuals mature at 3 to 4 years and probably do not live much longer than 6 years (Gjosaeter 1973).

Arctic cod eat a variety of euphausiids, copepods, benthic amphipods, shrimps, mysids, hyperiid amphipods, and small fish (Klumov 1937; Craig and Haldorson 1979; Lowry and Frost in prep.).

Saffron cod

Saffron cod occur in the eastern Bering and Chukchi Seas and throughout the western Arctic Ocean (Andriyashev 1954). They are also present, but less abundant, in the Beaufort Sea. They are important prey of seals, belukhas, and seabirds, and are a major subsistence food item to local residents (Tomilin 1957; Lowry et al. 1978a, 1979b; Barton 1979; Frost and Lowry 1981).

Saffron cod are very abundant in Norton Basin. Barton (1979) found them to be the most frequently encountered species in gillnet catches and the second most frequent in beach seines in Norton Sound during summer. Wolotira et al. (1979) found saffron cod to be the most abundant fish species encountered, with large concentrations in outer Norton Sound and the eastern portion of the northern Bering Sea. Fish ranged from 5-35 cm and averaged 11.5 cm. Most large fish occurred in outer Norton Sound. Age groups 0-2 predominated by number, comprising over 96 percent of the total fish, with age group 0 alone comprising 67 percent. Most 0-2 age fish were found in outer Norton Sound and northeastern Bering Sea.

In southern Bering Sea saffron cod occur only on the inner shelf region, generally in the area between St. Matthew, Nunivak, and the Pribilof Islands. Pereyra et al. (1976) found catch per unit effort (CPUE) to be only 25 percent of what Wolotira et al. (1979) reported for the northern Bering Sea.

Saffron cod are thought to reside in the coastal zone, coming close to shore in the fall to spawn in river mouths, bays, and inlets, and moving into deeper water (30-50 m) in summer to feed (Svetovidov 1948, Andriyashev 1954). Spawning probably takes place between December and February (February in Norton Sound) at subzero temperatures (-1.0 to -1.8°C). The eggs are demersal and are spawned on clean, sandy or pebbly bottoms (Andriyashev 1954). Most larvae hatch in April. Normal embryonic development occurs at temperatures of -3.8° to 8°C and salinities of 28-30 ppt. Development is suspended below -3.8°C; however, eggs will resume growth even after freezing in ice once temperatures are greater than -3.8°. Larvae perish en masse in water warmer than 8°C (Mukhacheva 1959). Larvae stay near the surface after hatching and are often associated with the jellyfish Cyanea sp. (they live inside the protection of the mantle and tentacles). Growth is probably very slow until August when larvae are fully transformed into fry and descend to the bottom to assume a demersal life similar to the adults. Maximal growth occurs in the first 3 years of life, and almost all of each year's growth occurs in September-October. Sexual maturity occurs at 2-3 years and individuals probably live at least 12 years (Svetovidov 1948). Saffron cod eat a variety of benthic organisms including polychaetes, shrimps, crabs, mysids, and amphipods.

Herring

Herring are locally and seasonally abundant throughout the Bering Sea. They are important prey of a large number of marine birds, mammals, and other fishes, and support substantial commercial and subsistence fisheries in Alaska. They were fished in Norton Sound as early as 1909, on their wintering range northwest of the Pribilofs since the 1960's by the Japanese and Soviets, and in Bristol Bay near Togiak also since the 1960's (Macy et al. 1978). They are most abundant south of the Yukon delta, especially in the Togiak district of Bristol Bay. North of the Yukon River they are most abundant in southern and eastern Norton Sound.

The biology of herring has been well summarized by Macy et al. (1978) as well as Barton (1979), Andriyashev (1954), and Rumyantsev and Darda (1970). The following will be an abbreviated discussion of those reports. Herring exhibit strong schooling behavior and are highly migratory. They winter in deep water (>100 m) over the continental shelf, mainly northwest of the Pribilofs, and along the southern edge of the ice pack, with some found near Unimak Island. During winter they are found 5-10 m off the bottom, moving to mid- or surface waters at night to feed. In March and April they begin to move towards the coast and by April or early May are found southwest of Nunivak Island in water 10-70 m deep. Spawning occurs shortly after the ice breaks up--during May in Bristol Bay and progressively later farther north (early June in Norton Sound). During July and August they live in the warmed surface waters of the coastal zone from Unimak to Nunivak, and extending in a narrow strip to Norton Sound, usually within 20 miles from the shore in less than 30 m of water and temperatures of 4-6°C. In August-September they begin to leave the coast, and by October the first large offshore concentrations are again found northwest of the Pribilofs.

Most spawning occurs nearshore in shallow water (from <1 m to 12-15 m) usually on vegetation such as kelp or surf grass in sheltered bays, along steep, rocky shores, or on open, sandy beaches. South of the Yukon most spawning is intertidal, whereas in Norton Sound where tidal amplitude is low, spawning is subtidal.

The eggs are adhesive and are deposited on solid surfaces where they are fertilized by the males. Egg development requires 12-50 days (usually around 20-25) depending on water temperature and salinity, with normal development occurring at 0.5-9.2°C and 6.7-25.8 o/oo. The planktonic larvae hatch at 4-8 m, grow to 35-40 mm after 40-70 days, at which time they metamorphose to actively swimming, schooling juveniles. By 1 year the juveniles attain lengths of 90-100 mm. One- and 2-year-olds are found in schools off shore. They mature at 3-4 years, at which time they show up at nearshore spawning areas.

Mortality is extremely high in herring. Mortality may be as high as 80 percent in eggs, greater than 99 percent in larvae, and 30-40 percent by age 4. As few as 0.1 percent of the eggs produced may survive to spawn.

Herring are mostly zooplankton feeders. The larvae eat microscopic eggs, diatoms, and nauplii of small copepods. Fry 20-100 mm prey on copepods, barnacle and mollusk larvae, and a variety of other small plankton. The adults eat almost entirely crustaceans, including euphausiids, copepods, gammarid and hyperiid amphipods, and mysids, and some fish fry (pollock, smelt, capelin, and sand lance). Feeding is most intensive after spawning and during summer, and least so during spawning. Herring probably compete for food with capelin, sand lance, pink salmon, and pollock.

Capelin

Capelin are widely distributed over much of the arctic. They are present along the entire Alaskan coast but are most abundant in the southern Bering Sea, where they are found in large schools near the bottom (benthopelagic). In spring and summer they move toward the shore to spawn. Barton et al. (1977) found them to be the most geographically widespread forage fish in southeastern Bering Sea and second in abundance of fishes captured inshore. He found capelin to be present but not abundant in Norton Sound during the late 1970's. Abundance may vary considerably from year to year, as early explorers to Alaska remarked about their extreme abundance in Norton Sound.

Spawning takes place in May and June in Bristol Bay, and somewhat later farther north. Primary spawning habitat in Alaska includes relatively smooth sand and gravel beaches in 1-4 m of relatively high salinity water (Andriyashev 1954, Barton et al. 1977). The eggs are adhesive. Known spawning grounds in Bristol Bay include the area from just north of Cape Newenham south and around to Togiak Bay (Macy et al. 1978). The actual spawning occurs mostly at night just after high tide. Once released and fertilized, the eggs become buried in the sand by waves where they remain until they hatch (about 15 days at 10°C) and are washed out of the sand and carried out to sea where they spend most of their early life in deep water (Musienko 1970; Macy et al. 1978). Research cruises in the Bering Sea have located relatively large concentrations of larvae west of Cape Newenham, south and east of the Pribilofs, and northwest of Unimak Island. Most growth occurs in the first 2 years of life. Capelin become reproductively mature at the end of the second or third year at a size of about 11.0-14.6 cm. Post-spawning mortality is about 90 percent and especially heavy if the surf is high.

Capelin feed mainly on small crustaceans such as euphausiids, copepods, hyperiid amphipods, decapod larvae, and other microzooplankton (Andriyashev 1954). Atlantic capelin, and presumably Pacific capelin, have a highly seasonal feeding cycle. Feeding is intensive prior to spawning, does not occur during spawning, and takes place at a low level over winter. Capelin are important prey of fishes such as salmon, cod, pollock, and flatfishes, of seabirds, especially alcids, and of many marine mammals.

Rainbow smelt

Rainbow smelt are found from Bristol Bay all along the Alaska coast to Point Barrow. During the nonspawning period they are found in brackish estuaries and bays, and during spawning they enter rivers. Barton (1979) found them to be the most abundant of the smelts in Norton Sound, with greatest concentrations in the southern and eastern regions. Wolotira et al. (1979) found them to be widely distributed in northern Bering Sea, occurring in greater than 70 percent of all trawls and comprising about 5 percent of the total fish biomass. They were found nearshore and offshore from breakup to freezeup. Larvae were also widespread. Greatest concentrations were present in a swath from Cape Rodney and south across the entrance to Norton Sound in 20-30 m of water. The greatest number of large fish (>20 cm) was also present in this area. The body length and relative abundance of rainbow smelt decreases from north to south (Macy et al. 1978).

Spawning usually occurs between April and June, although in some areas (Okhotsk Sea) a second spawning run in the fall has been reported (Macy et al. 1978). Large schools enter rivers or low salinity bays just before or soon after the ice breaks up. Spawning occurs at night, when adhesive eggs are deposited on rocks or vegetation. Hatching is dependent on water temperature and requires 8-27 days, after which the larvae drift downriver and grow to 20-40 mm within several months. Smelt in Bristol Bay grow to an average length of about 13-18 cm. In other areas they may grow as long as 36 cm (Macy et al. 1978). Individuals mature at the age of 2 or 3 years and may live as long as 8-12 years.

Food of young capelin includes copepods, amphipods, ostracods, and aquatic insects while in fresh water, and mysids, cumaceans, and amphipods in the marine environment. Adult smelt also eat zooplankton, but in addition prey upon squid and small fishes (Macy et al. 1978). They appear to feed throughout the year, including during migration and spawning.

Sand lance

The Pacific sand lance is found from southern California north to Alaska along the entire Alaskan coast and across Canada to Hudson Bay. Specific details of their distribution in the Bering Sea are poorly known. They have been reported from Bristol Bay and the north side of the Alaska Peninsula (Macy et al. 1978). Barton (1979) found them to be the overall most numerous species in nearshore waters of Norton Sound and northern Bering Sea with greatest abundance near Port Clarence and Grantly Harbor and also near Golovnin Bay and Bluff. They were infrequent and much less abundant in southern and eastern Norton Sound. Mean fish size was 80-84 mm during spring and 60-64 mm in fall. In some parts of their range sand lance live close to the coast in summer and move offshore in winter. Barton caught none in early June or October, indicating this might be the case in northern Bering Sea.

Sand lance are present in a variety of habitats including offshore waters, tidal channels, and along beaches, but they are usually found in shallow water close to land. They form schools near the bottom and frequently burrow in coarse beach sand and fine gravel (Andriyashev 1954). They appear to be euryhaline and eurythermal (Macy et al. 1978). Little is know about life history events in Alaskan populations. Barton found small larvae in Norton Sound in June-July and proposed that spawning occurs in May-early June.

Eggs are adhesive and are deposited on sandy substrate. Development may take 13-33 days, depending on water temperature. The nonfeeding pre-larvae are demersal, remaining buried in sand until they attain a length of 4-5 mm, at which time they become planktonic. Metamorphosis to the juvenile stage occurs at 30-40 mm. Age at sexual maturity is not known for Alaskan sand lance but could be as early as 1 year or as late as 3 years of age. Maximum length attained is about 26 cm, although most are considerably smaller (Macy et al. 1978).

Sand lance larvae feed on small phytoplankton changing to copepod eggs and nauplii as they grow. Adults eat copepods, chaetagnaths, and a variety of other small creatures. Sand lance are important food of sockeye and silver salmon in Bristol Bay, and also of cod and halibut. In addition, they are eaten by a variety of marine birds and mammals.

Sculpins

Many species of sculpins are present in the Bering Sea. There is very little specific information on distribution and abundance as they are not fished commercially and have not been included in fishery resource surveys. Wolotira et al. (1979) listed six species of sculpins among the 20 most abundant fish taxa in Norton Sound, although in total sculpins made up less than 7 percent of the catch of fishes. In northern Bering Sea, north of St. Lawrence Island, five species of sculpins, comprising about 27 percent of the catch, were among the 20 most abundant. A single species, *Myoxocephalus scorpius* made up 20.5 percent of the catch in northern Bering Sea. Among the most abundant species were *Myoxocephalus scorpius*, *M. jaok*, *M. quadricornis*, *Gymnocanthus tricuspis*, and *Enophrys diceraus*. Sculpins in general were least abundant in inner Norton Sound and most abundant throughout northern Bering Sea.

In southeastern Bering Sea sculpins as a group usually made up less than 1 percent of the total catch. In the area south and west of Nunivak Island they comprised almost 6 percent of the total catch (Pereyra et al. 1976).

Sculpins are demersal. Most species spawn in fall or winter (Andriyashev 1954). In general they feed on benthic or epibenthic organisms such as shrimps, amphipods, polychaete worms, isopods, mysids, and mollusks.

Eelpout

Eelpout, like sculpins, are considered "trash fish" in fishery resource surveys and as a result little information is available on distribution and abundance of this group in Bering Sea. In northern Bering Sea the genus *Lycodes* made up 2 percent of the catch, and in Norton Sound about 1 percent. Distribution was patchy with several areas of relatively high abundance north of St. Lawrence Island, off Nome, and in central Norton Sound (Wolotira et al. 1979). In southeastern Bering Sea eelpouts were virtually absent from Bristol Bay and inside about the 50 m contour north to Nunivak. They were most abundant along but inside the shelf break from Unimak Island to northwest of St. Matthew Island, especially northwest of Unimak and west of St. Matthew, where they sometimes made up 4-7 percent of the catch (Pereyra et al. 1976). Some of the commonly encountered species are *Lycodes palearis*, *L. brevipes*, *L. raridens*, *L. mucosus*, and *L. polaris*.

Eelpouts are bottom fishes, preferring muddy bottoms and often burrowing into the bottom tail first. They usually prefer water below or near 0°C with salinity greater than 30 o/oo. Spawning is thought to occur in late fall or winter. Eggs are demersal, as apparently are the larvae (Andriyashev 1954). Little else is known about their life history.

Eelpouts feed on a variety of benthic organisms including polychaetes, bivalve mollusks, crustaceans (especially amphipods), and echinoderms.

Crabs

Brachyuran crabs are widely distributed in the Bering Sea. Two species are important to bearded seals--Chionoecetes opilio and Hyas coarctatus.

In southeastern Bering Sea C. opilio is the most widely distributed and one of the two most abundant invertebrates (20-30% of the total invertebrate biomass). It occurs in a wide band approximately parallel to the edge of the shelf break and is found north into the Chukchi Sea (Pereyra et al. 1976; Feder and Jewett 1978; Wolotira et al. 1979). Wolotira et al. (1979) caught few in Norton Sound and no mature females. Greatest abundance was in a strip from St. Lawrence Island to Bering Strait.

Although published information regarding the life history of C. opilio in the Bering Sea is sparse, there are several accounts for other geographical areas. The reader should refer to Pereyra et al. (1976) or Adams (1979) for detailed accounts.

Female C. opilio mature at 50-60 mm and males at 65-75 mm. Spawning probably occurs in March-April with the eggs being carried about a year. The eggs hatch into zoeae, the first larval form, and rise to surface waters. Eventually (within about 2 months) they metamorphose to the megalop stage, which lasts 1-10 months, and settle to the bottom at the end of that period, at which time they metamorphose to a first instar which resembles the adult (Adams 1979). Molting continues at a frequency inversely proportional to age until maturity is reached (7 to 10 or 12 instar molts) at 6-8 years of age. Individuals may live as long as 12-16 years. C. opilio larvae eat phytoplankton and small zooplankton. Once they metamorphose and settle to the bottom they utilize detritus and benthic organisms. Adults are omnivorous, eating a variety of detritus, polychaetes, brittle stars, bivalve mollusks, fish, and amphipods (Feder and Jewett 1978).

Spider crabs, Hyas coarctatus, are much less abundant than Tanner crabs in Bering Sea and, because they are a small, noncommercial species, data on their distribution and abundance are scarce to nonexistent. Feder and Jewett (1978) found them to make up less than 1 percent of the invertebrate biomass in northern Bering Sea/Norton Sound. They were absent from inner Norton Sound and were most abundant from St. Lawrence Island north and east to outer Norton Sound. Biomass was less than $0.02 g/m^2$ at all but a few stations where it reached $0.16\ g/m^2$.

There is little information on the life history of spider crabs. Ovigerous females are commonly caught throughout Bering Sea.

Spider crabs, like tanner crabs, are omnivorous, eating a variety of detritus, phytobenthos, crustaceans such as amphipods, euphausiids, and shrimps, mollusks, ophiuroids, polychaetes, and in some cases fishes (Feder and Paul 1979; Squires 1967).

Clams

Two genera of clams, Serripes and Spisula, are especially important as food for bearded seals and walruses in the Bering Sea. Little is known about the distribution or abundance of either species there.

Serripes is hermaphroditic and probably spawns in spring after the phytoplankton bloom has begun (Petersen 1978). Settling of larvae probably occurs in late summer-autumn. In Greenland waters some examples of size at age are as follows: 1 year, 3-10 mm; 11 years, 53.4 mm; 14 years, 58.3 mm. They probably grow as large as 10 cm (Clench and Smith 1944).

Little is known about the life history of Spisula. They seem to prefer medium grade sediments of sand and gravel mixture. In southeastern Bering Sea they are found primarily in coastal waters 24-33 m deep. Spisula is probably patchy in distribution, with given patches consisting of clams of a single year class (due to favorable larval settlement and survival in specific areas in a particular year). They are active burrowers, sometimes living as deep as 22 cm. Individuals reach about 13.5 cm, or 16 years of age, with growth until age 8 occurring at a rate of 10-12 mm/year (North Pacific Fishery Management Council, in preparation). There is no information on the reproduction of Spisula in Alaska. Spisula in the North Atlantic are dioecious (sexes separate), unlike Serripes, and spawning probably occurs in summer. Larvae are planktonic for some unknown period of time, then settle to the bottom as miniature adults.

Spisula and Serripes are both filter feeders, removing small particles from seawater.

Shrimps

Three families of shrimps are present and important as marine mammal prey in the Bering Sea: F. Hippolytidae, F. Crangonidae, and F. Pandalidae. The pandalids are of commercial importance in the southern Bering Sea, but no species are commercially harvested in northern Bering Sea. Published information on the noncommercial species is scarce.

Eualus gaimardii is the most widespread and abundant of the hippolytids. In the Canadian arctic individuals probably spawn biennially (Squires 1969). Spawning frequency in the Bering Sea is unknown. Many ovigerous females were found in spring-summer when most of our trawls were made (Frost and Lowry, unpubl.). Eualus eat ostracods, euphausiids, copepods, and phytobenthos.

Pandalus gonuirus and P. borealis are both caught in Bering Sea with the former most abundant in water less than 100 m and the latter in water deeper than 100 m (Frost and Lowry, unpubl.). Pandalus borealis is not common in northern Bering Sea where P. goniurus is the predominant species. Pandalus hypsinotus is also seasonally and locally common in Norton Sound.

Pandalid shrimps are protandrous hermaphrodites, that is they reproduce first as males (probably during the first year), then become females and produce eggs when large (1-1/2 to 2-1/2 years) (Butler 1964). Breeding takes place in the fall and the eggs are carried until they hatch in spring. Ovigerous *P. goniurus* were common in early spring trawls but scarce or not present in June-August trawls. Larvae are planktonic during summer and settle to the bottom in late summer or early fall (Charnov 1979). Adult shrimps eat small crustaceans, polychaete worms, and detritus.

Crangonid shrimps which are prey of seals in Bering Sea include three genera: *Crangon*, *Argis*, and *Sclerocrangon*. Two species of *Argis*, *A. lar* and *A. dentata*, are present. *Argis dentata* is usually found in deeper water (>70 m), and *A. lar* in shallower areas (Frost and Lowry unpubl.). Two *Crangons* are also found--*C. communis* and *C. dalli*. As with *Argis*, one is found in deep water (*C. communis*) and one in shallow water (*C. dalli*). *Sclerocrangon boreas* was not numerous and was caught only in northern Bering Sea. Females of all species were ovigerous in spring. Ovigerous *Crangon communis* females were caught in March-April, but not May-August, whereas eggbearing *C. dalli* were caught through July. We caught *Argis lar* which had recently hatched eggs in May and June. Spawning probably occurs over a broad time span, although all probably carry eggs through the winter and hatch them in spring-summer. Crangonid shrimps eat a variety of organisms including phytobenthos and detritus, polychaete worms, small crustaceans, crustacean eggs and larvae, and to a lesser degree foraminiferans, gastropods, and ophiuroids (Squires 1967).

Gammarid amphipods

Gammarid amphipods are a diverse element of the Bering Sea fauna. They are the predominant food of many demersal fishes and regular prey of seabirds, fishes, ringed and bearded seals, and gray whales. Although primarily benthic, several species make use of the inverted substrate provided by the undersides of ice floes (Barnard 1959; George and Paul 1970; Tencati and Leung 1970). *Ampelisca*, *Anonyx*, and *Gammarus* are all important genera to seals and whales.

Ampelisca is probably the single most important species to marine mammals. *Ampelisca macrocephala* lives 1-1/2 to 2 years, with some females living to age 3 and reproducing a second time (Kanneworff 1965). Maximum growth occurs in spring and early summer and breeding takes place in the fall (October). Females carry eggs in a brood pouch until the young are released in about April when feeding conditions are good. *Ampelisca* is both an active predator and a detritus feeder. Prey includes copepods, other small crustaceans, and various detrital plant and animal material. Feeding (as well as growth and gonad development) is most intense during spring and summer when phyto- and zooplankton are abundant.

C. Food Webs and Trophic Relationships

Since the actual species of prey consumed by seals vary greatly, both geographically and seasonally, a single diagrammatic food web dealing with the specific prey species would be extremely difficult to construct or understand. Consequently, we will deal with major types of prey involved in seal, walrus, and belukha food webs. The various types of prey directly consumed by seals and walruses can be divided into six major categories. The prey types and major species included in each are shown in Table 22.

Figure 3 shows a generalized food web for harbor, spotted, ribbon, and ringed seals. Although very few specimens have been examined it appears that belukha whales can be appropriately included in this food web. Only major trophic connections among the various types of organisms are shown. Four prey types are significant sources of food for these species. However, most of the food of each is derived from the pelagic portions of the food web. Energy transfers in the pelagic subsystem are generally very direct. For example, a ringed seal may eat euphausiids which have been feeding on diatoms. This involves only two energy transfers between producer and top consumer. As many as four energy transfers may be involved, as in the following: dinoflagellate → small copepod → hyperiid amphipod → pollock → ribbon seal.

A generalized food web for bearded seals and walruses is shown in Figure 4. Both of these species derive most of their food from benthic organisms. Walruses feed almost exclusively on clams which feed mostly on detritus and phytoplankton. Although bearded seals also derive some of their nutrition from such short energetic pathways, their trophic resource base is more diverse. Bearded seals may feed as many as four energetic steps from producers, as in the following: phytoplankton → clam → tanner crab → sculpin → bearded seal.

From the preceding discussion of food habits and food webs it is obvious that there is considerable overlap in the types and particular species of prey consumed by seals, belukhas, and walruses. Two other species of pinnipeds, the northern fur seal (Callorhinus ursinus) and the Steller sea lion (Eumetopias jubatus), are also abundant in the Bering Sea and compete for food with phocid seals. The relative importance of the various prey types to belukhas and Bering Sea pinnipeds is shown in Table 23.

Bearded seals and walruses are the only pinnipeds in this area that feed predominantly on benthic organisms. Major features of distribution and movements of these two species are also similar. However, competition for food is minimized by the fact that much of the walrus diet is made up of burrowing infaunal clams which are generally not eaten by bearded seals. The two species do compete for Serripes and there are indications that the combined predation on this species is in excess of the sustainable yield. As mentioned previously, the amount of Serripes found in bearded seals taken at Diomede has decreased in recent years. This decrease is closely correlated with an increase in the numbers of walruses summering in Bering Strait (Lowry et al. 1980b).

Gray whales (Eschrichtius robustus) forage in the Bering Sea during summer months. They consume mostly benthic epifauna and nektobenthos (Zimushko and Lenskaya 1970) and compete for food with bearded seals and, to a lesser extent, with ringed seals. In the northern Bering Sea much of the diet of both gray whales and ringed seals consists of gammarid

Table 22. List of major species included within six types of prey directly consumed by seals, walruses, and belukha whales in the Bering Sea.

Prey Type	Major Species
Pelagic and Semidemersal Fishes	Walleye pollock - *Theragra chalcogramma* Saffron cod - *Eleginus gracilis* Arctic cod - *Boreogadus saida* Pacific cod - *Gadus macrocephalus* Capelin - *Mallotus villosus* Rainbow smelt - *Osmerus mordax* Herring - *Clupea harengus*
Demersal Fishes	Eelpout - *Lycodes* spp. Sculpins - *Myoxocephalus* spp., *Gymnocanthus* spp., *Icelus* spp. Flatfish - *Reinhardtius hippoglossoides*, *Limanda aspera*, *Lepidopsetta bilineata*, *Hippoglossoides* spp. Sand lance - *Ammodytes hexapterus*
Pelagic Nektonic Invertebrates	Euphausiids - *Thysanoessa* spp. Hyperiid amphipods - *Parathemisto* spp.
Nektobenthonic Invertebrates	Mysids - *Neomysis rayi*, *Mysis* spp. Shrimps - *Pandalus* spp., *Eualus* spp., *Crangon* spp., *Argis* spp. Gammarid amphipods - *Ampelisca* spp., *Anonyx nugax*, *Gammarus* spp. Octopus - *Octopus* spp.
Epifaunal Invertebrates	Crabs - *Chionoecetes opilio*, *Hyas* spp. Snails - *Buccinum* spp., *Natica* spp., *Polinices* spp., *Neptunea* spp.
Infaunal Invertebrates	Clams - *Serripes groenlandicus*, *Mya truncata*, *Spisula polynyma*, *Hiatella arctica*, *Clinocardium ciliatum* Polychaete worms - *Nephthys* sp., *Lumbrinereis* sp. Echiuroid worms - *Echiurus echiurus* Priapulids - *Priapulus caudatus*

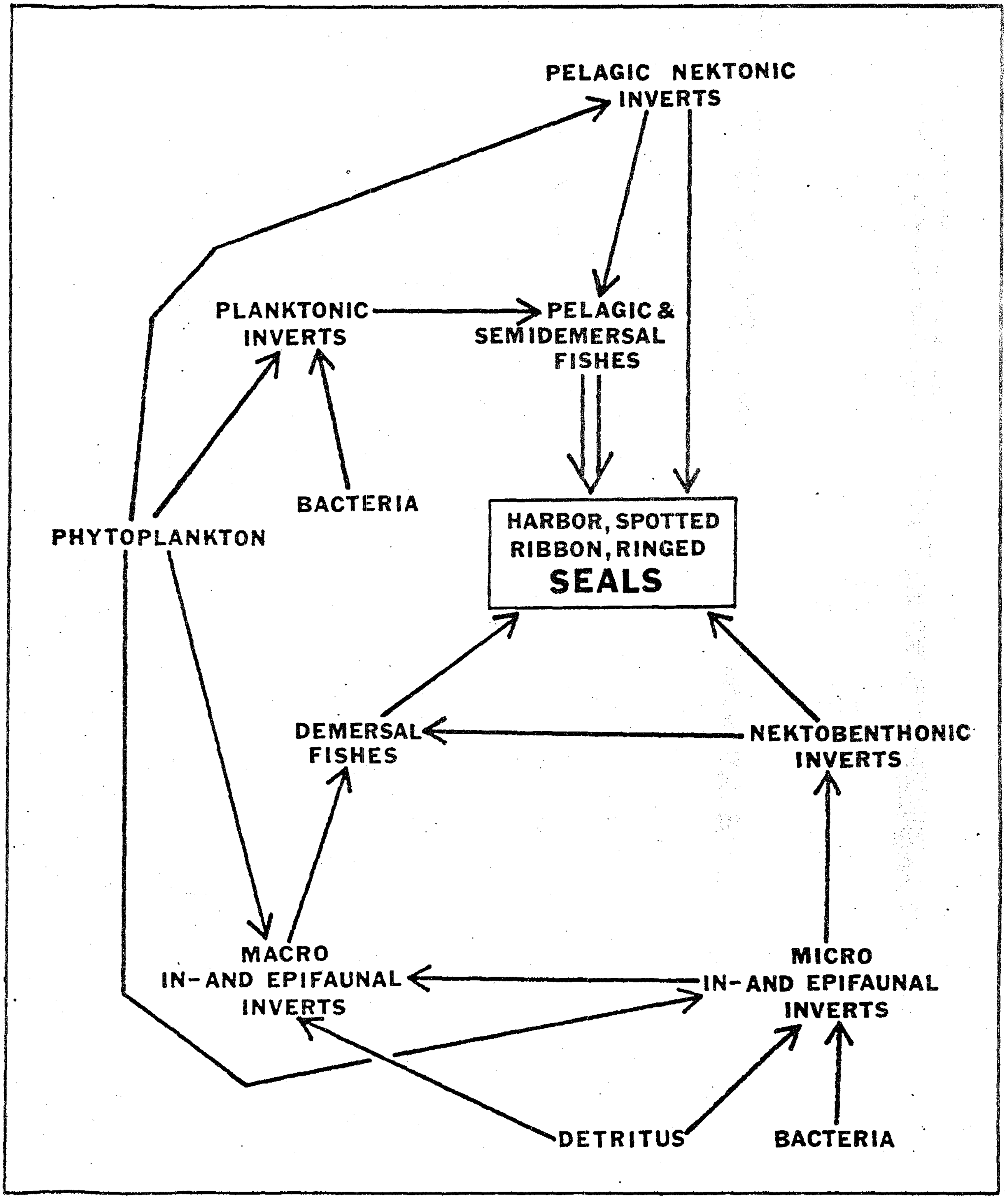

Figure 3. Generalized food web for harbor, spotted, ribbon and ringed seals in the Bering Sea.

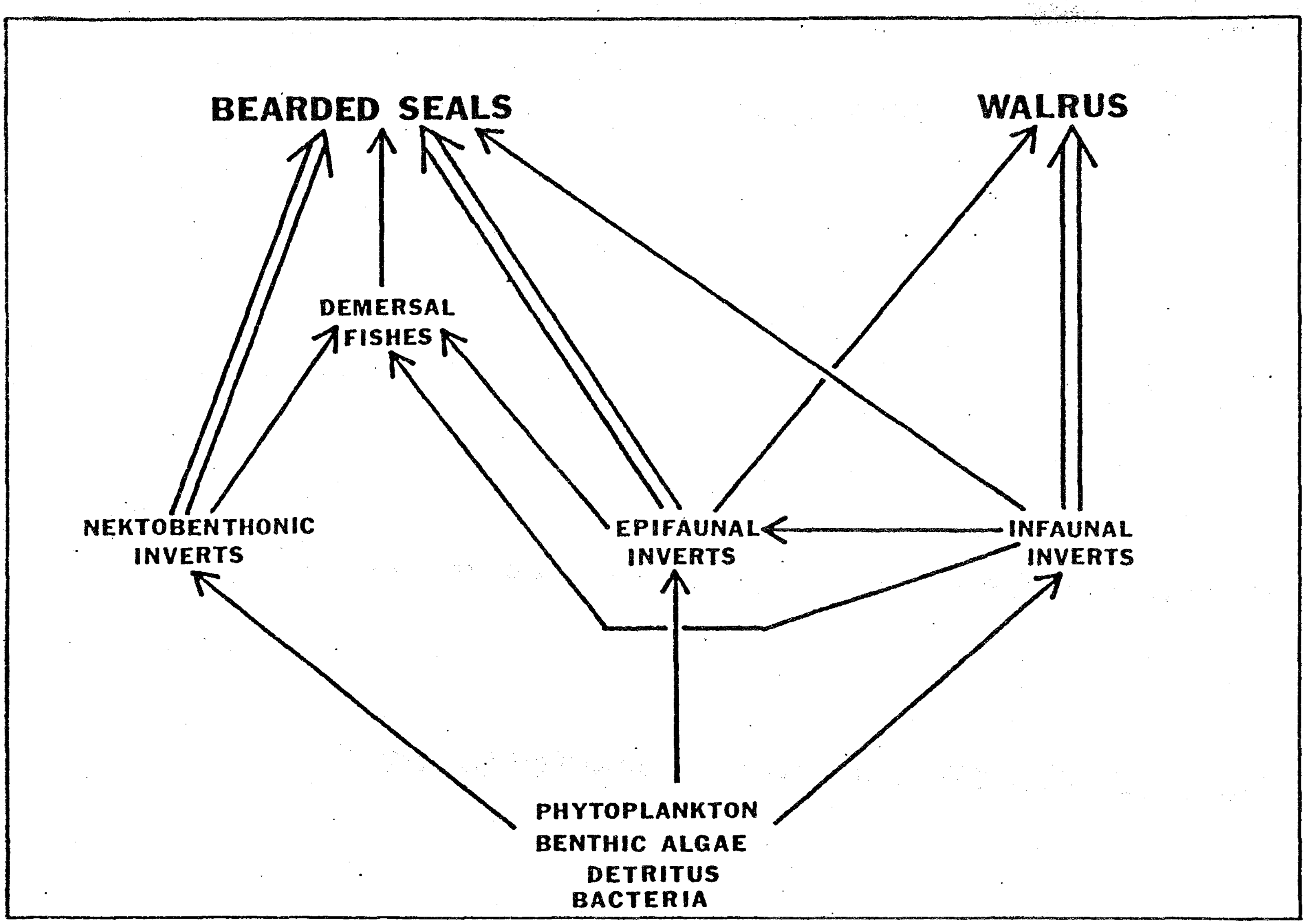

Figure 4. Generalized food web for bearded seals and walruses in the Bering Sea.

Table 23. Relative importance of major prey types in the diet of pinnipeds and belukha whales in the eastern Bering Sea.

Predator Species	Pelagic and Semidemersal Fishes	Demersal Fishes	Pelagic Nektonic Invertebrates	Nektobenthonic Invertebrates	Epifaunal Benthic Invertebrates	Infaunal Benthic Invertebrates
Harbor Seal	Major	Minor		Minor		
Spotted Seal	Major	Minor	Major-Juveniles	Minor-Adults Major-Juveniles		
Ribbon Seal	Major	Major		Minor		
Ringed Seal	Major	Minor	Major	Major		
Bearded Seal		Minor		Major	Major	Major in some areas
Walrus				Minor	Minor	Major
Fur Seal	Major		Major (squids)			
Sea Lion	Major	Minor		Minor		
Belukha Whale	Major	Minor	Minor	Minor	Minor	

amphipods. The combined foraging activities of bearded seals, walruses, and gray whales undoubtedly influence the structure of benthic communities and food webs.

Pelagic and semidemersal fishes comprise a major portion of the diet of all other species of pinnipeds and belukha whales in the Bering Sea. Pollock and capelin are the primary species eaten in the southern Bering, arctic and saffron cod are the major species in the northern Bering, and herring and smelt are important throughout coastal waters. Although foraging activities of many species are geographically or temporally offset, more than 2 million pinnipeds are being supported primarily by this fish resource. In addition, the same species of fishes are consumed in large numbers by some species of whales and dolphins (Frost and Lowry, in press b) and seabirds (Divoky 1977; Hunt 1978). The importance of whales in this system is magnified by the fact that they also consume planktonic and pelagic nektonic invertebrates which are the main foods of pelagic and semidemersal fishes. If the pelagic trophic subsystem is in equilibrium, changes in population size of one consumer species would have direct effects on other consumer populations.

Humans also compete directly with pinnipeds for food. Commercial fisheries can alter not only the total standing stock of fishes (or shellfishes) in a given area but also the proportion of the biomass which is made up by individual fish species. Changes in composition of the fish fauna apparently induced by fishing have been documented for the North Sea (May et al. 1979) and have probably also occurred in the Bering Sea (Pruter 1973). Such changes undoubtedly affect the competitive balance among pinniped populations. It is presently impossible to predict what the effects on pinnipeds might be due to lack of data on the suitability of various prey species and the mechanisms and magnitude of responses to changes in overall availability.

D. Potential Effects of Petroleum Development

This study was designed to develop an understanding of the feeding and trophic interactions of marine mammals, particularly ringed, bearded, ribbon, and spotted seals, in the Bering Sea and to assess the possible and/or probable effects of petroleum exploration and development on the ability of those animals to meet their nutritional requirements. Possible effects fall into two categories: 1) those directly affecting the seals and their access to feeding habitat and 2) those affecting the availability of prey. The potential for and severity of any effects will vary by season and geographic area. Petroleum exploration and development in the Bering Sea will differ substantially from that in more northern waters of the Chukchi and Beaufort Seas. Duration and extent of seasonal sea ice cover are variable, and the ice itself is thinner and less suitable as a platform from which to operate. Unlike the Beaufort Sea where ice provides a stable platform on which to work, the moving pack ice and the thinner fast ice of the Bering may serve to hinder and/or disrupt operations and in some instances may preclude winter exploration.

Winter exploration and development activities, where they occur, are likely to include such things as seismic profiling, construction and operation of drilling facilities, and maintenance activities such as supply and service of facilities. Activity may occur nearshore using landfast ice as a platform from which to operate, or in more southern areas in the moving floes of the ice front.

In Norton Basin during winter ringed and bearded seals and occasionally polar bears are the only resident marine mammals. Bearded seals and polar bears are found mostly offshore in areas of moving broken ice. Ringed seals are also present in the offshore area; however, preferred breeding habitat is the shorefast ice. It is this nearshore area where direct effects on feeding ringed seals are most likely to occur and be of significance. Prime ringed seal habitat coincides with and may be determined by the availability of arctic cod which are abundant nearshore under the fast ice during winter. Spilled oil or high noise levels which may displace ringed seals from this area would in fact be excluding them from their major food source at a time of year when energetic requirements are high and alternate prey are least available.

The nearshore area in Norton Basin is important in winter, not only to ringed seals but to several major prey species. Arctic cod aggregate in autumn-winter and move onshore to spawn during January-February. The schooling of adult arctic cod at spawning time, particularly near narrow cracks in the ice and in slushy "frazil" ice, places them in areas most likely to be contaminated by winter oil spills. It also suggests that in the event of a catastrophic spill or blowout a large proportion of the breeding segment of the population might be affected. Preliminary toxicity studies have shown adult arctic cod to be very sensitive to crude oil at less than 2 ppm (NAFC 1979).

Both the eggs and larvae of arctic cod are pelagic, developing near the undersurface of the ice. The egg stage lasts 1.5-3.0 months, and the larval stage lasts about 2 months. Because the eggs and larvae are in the upper portion of the water column, they are likely to be exposed to surface and underice spills, emulsions, and dispersions. Studies of other members of the cod family have shown eggs and larvae to be highly sensitive to even short-term exposure (5-30 hrs) to crude oil and crude oil extracts (Mironov 1967; Kuhnhold 1970).

Saffron cod also spawn nearshore under the ice in winter. Spawning aggregations form in autumn-early winter near river mouths, bays, and inlets. Unlike those of arctic cod the eggs are demersal and are laid on clean, sandy gravel bottoms. The presence of sinking oil in areas where saffron cod spawn could kill or cause abnormal development of eggs and larvae. Adult mortality occurs within 24 hours when individuals are exposed to the soluble fractions of crude oil at less than 2 ppm at 3°C (Devries 1976).

Other major prey species reproduce in deeper offshore waters during autumn-winter. Sand lance spawn then as do many species of sculpins. Percy and Mullin (1975) found fry of the sculpin *Myoxocephalus quadricornis* to be the most sensitive organisms they tested, with 100 percent mortality occurring after 24 hours in a heavy dispersion of oil. *Parathemisto* breeds in autumn-winter and broods its eggs until spring. A similar pattern occurs in many gammarid amphipods, including *Ampelisca* and

Gammarus, and some shrimps such as Pandalus, Argis, and Sclerocrangon. The crabs Hyas and Chionoecetes carry eggs in autumn and winter and larvae hatch in spring. Water soluble fractions of crude oil can cause loss of eggs by gravid female amphipods (Busdosh and Atlas 1977) and may cause similar effects in shrimps and crabs.

The spring-summer period is a time of increased biological activity. Ringed and bearded seals bear their pups in April. As the ice melts in the southern Bering Sea, seals, walruses, and belukhas move north into Norton Basin with the ice remnants. Most ringed and bearded seals and walruses pass through Bering Strait into the Chukchi Sea where they summer. Spotted seals move to the coast, as do belukhas, and ribbon seals return to southern Bering Sea where they are pelagic during summer. Gray whales move up from Mexico and California to spend the summer feeding around St. Lawrence Island. Some prey species also undergo major movements at this time, moving into or out of nearshore areas to feed and/or reproduce.

By the open water period the two major forage fishes of ringed seals, arctic and saffron cod, have already spawned. Larvae of both species develop in surface waters where exposure to toxic pollutants is most likely, then descend to the bottom in late summer and assume a demersal life similar to adults. Adult arctic cod disperse offshore during spring-summer and are probably least sensitive to oil spills and pollutants at this time. Most saffron cod apparently remain nearshore in areas where exploration and development are likely to occur.

Herring form pre-spawning concentrations in spring and move en masse into lagoons, bays, and inlets to spawn at about the time the ice breaks up. After spawning they remain aggregated and feed intensively throughout the remainder of the summer.

Spawning takes place in two very different habitats: on kelp growing near exposed rocky headlands and on eelgrass (Zostera sp.) growing in shallow, brackish bays, lagoons, or inlets. The latter of these types is probably the most vulnerable to either large- or small-scale discharges of pollutants. Rocky headlands are quite rapidly cleansed of oil as a result of wind and wave action. Such cleansing action occurs more slowly in lagoons, bays, or inlets where wind and wave action are more moderate and hydrocarbons can become entrained in sediments.

In herring, hydrocarbons cause reduced survival of ovarian eggs prior to spawning, of embryos from the time of fertilization to hatching, and of larvae through the yolk absorption stage (Struhsaker 1977; Kuhnhold 1970; Mironov 1970; Eldridge et al. 1978; Smith and Cameron 1977). In addition, hatching may be delayed and a significant porportion of the larvae may develop abnormally. In the natural environment only 5-10 percent of the herring are estimated to survive beyond the larval stage. The presence of hydrocarbons may aggravate a natural tendency toward embryonic mortality, and it is possible that an entire year class could be eliminated in localized areas. In addition to effects on eggs and larvae, benzene has been shown to cause aberrant swimming and disequilibrium in adults (Struhsaker 1977).

Many invertebrates release their young during spring and summer. Among the major species are the amphipods Ampelisca and Gammarus, the isopod Saduria, the shrimps Eualus, Pandalus, Crangon, Argis, and Sclerocrangon, and the clams Serripes and Spisula. The eggs of Hyas and Chionoecetes crabs also hatch then. Growth and molting of crab larvae are impaired by hydrocarbons even in species in which adults are highly resistant (Mironov 1970; Parker and Menzel 1974; Rice et al. 1976). Pandalid and hippolytid shrimp larvae are sensitive to hydrocarbons. Low concentrations (1-5 ppm) of water soluble fractions cause mortality and cessation of swimming activity (Malins et al. 1977; Brodersen et al. 1977; Craddock 1977).

Water soluble fractions of crude oil cause reduced fertilization of eggs, decreased survival of eggs, sperm, and larvae, and abnormal development of embryos in bivalve mollusks (Scarratt and Zitko 1972; Renzoni 1975). Growth, survival, and recruitment rates in local clam populations remained depressed for 3-6 years after the occurrence of oil spills in Nova Scotia and Maine (Gilfillan and Vandermeulen 1978).

Young amphipods may not colonize oiled sediments. Atlas et al. (1978) found that arctic amphipods occurred less frequently in oiled sediments than in unoiled (control) sediments. Although contaminated sediments were later recolonized, species composition was quite different. If colonization of a species such as Ampelisca, which is a major food not only of ringed seals but also of gray whales and numerous fishes, were discouraged it could have major implications for predators.

In general the literature indicates that many of the fishes, crustaceans, and bivalves (especially their eggs and larvae) which are important prey species in Norton Basin are sensitive to the presence of hydrocarbons in water. Summer is probably the period when reproductive products are most abundant; however, it is also the time of open water and warmer temperatures, which may facilitate dispersal, dilution, and degradation of contaminants. Consequently, the occurrence of an oil spill in summer may be less critical from the standpoint of prey species than a similar spill in winter. The probable exception would be summer spills in areas such as bays, inlets, and lagoons, where water circulation is sluggish, flushing time slow, and abundance of spawning and/or juvenile organisms is very high. Such spawning/nursery areas are very important to maintenance of prey species populations.

Fewer species reproduce during winter but many of the ones that do are major prey of marine mammals. The winter ice cover and accompanying colder water act to reduce dispersion rates, evaporative loss of toxic fractions, and biodegradation rates, and may concentrate pollutants in places of high biological activity such as leads and slush ice.

In the St. George and Navarin Basins spotted, ribbon, and bearded seals and walruses are the resident pinnipeds during ice-covered months. Belukhas and bowhead whales also winter in the pack ice of the Bering. Exact locations are poorly defined but they are probably present in the Navarin Basin. Winter is a time of active feeding for all species except perhaps bowhead whales. With the melting of ice in spring most of the winter marine mammal residents leave the St. George and Navarin

Basins. The exceptions are ribbon seals, which are probably pelagic in the vicinity of the Pribilofs during summer. Spotted seals are present along the coast of Bristol Bay and areas north. Some walruses, perhaps 15,000-20,000 bulls, remain in Bristol Bay, as do an undetermined number of belukhas. From the south there is a great influx of marine mammals including fur seals, sea lions, and several species of whales. Although outside the scope of this report, those species must be considered in any evaluation of potential impacts of petroleum activity. Many swim thousands of miles to summer in the rich feeding grounds of southern Bering Sea.

Most trophic impacts on seals (except bearded seals) in southern to central Bering Sea will be measured in terms of the availability of forage fishes. Those species most important from a trophic standpoint are pollock, capelin, and herring. The sensitivity of herring to hydrocarbons was discussed in the previous pages. Almost nothing is known about the sensitivity of pollock, although DeVries (1977) found in preliminary tests that naphthaline at 4 ppm (+1°C) was lethal to adults after 13 hours. Eggs and larvae of other cods, for example Atlantic pollock (*Pollachius virens*) and Atlantic cod (*Gadus morhua*), are extremely sensitive to crude oil extracts and it is reasonable to assume that walleye pollock are similarly sensitive (Grose, cited in Clark and Finley 1977; Kuhnhold 1970; Mironov 1967).

The effects of hydrocarbons on capelin are largely unknown. We do know, however, that spawning takes place on sandy beaches, where the eggs are buried by wave action until hatching. On such beaches oil may penetrate several centimeters, and the same wave action that buries the capelin eggs will bury oil. Assuming capelin larvae are as sensitive to oil fractions as most fish larvae, a major portion of a year's recruitment on a particular beach or beaches might be destroyed. In addition, coarse sand and gravel beaches are virtually impossible to clean up mechanically, and oil buried months prior to spawning may persist for many years, affecting not just one, but many year classes. See Barton (1979) for further discussion of the susceptibility of different coastal spawning habitats to oil spills.

The previous discussion on the susceptibility of invertebrates in Norton Basin applies also to southern Bering Sea.

Pollutant levels high enough to cause large-scale die-offs of individuals will probably occur only on a very localized basis (except where oil or pollutants are trapped under the ice and transported long distances in a relatively unweathered state). The greatest concern may not be with local catastrophic events but with long-term sublethal effects of pollutants. Individuals may not be killed directly, but instead very low concentrations of pollutants may affect locomotion, metabolism, or reproduction and lead to substantial reduction of populations over several generations (Percy and Mullin 1975). These long-term reductions are of special concern in considering food availability to consumers.

VIII. Conclusions

Spotted seals are winter residents of southern Bering Sea (including St. George Basin and sometimes the Navarin Basin and North Aleutian Shelf), during which time they feed mostly on pollock (southcentral) and capelin (southeastern). In spring they move north with the receding ice, and then to the coast where they spend the summer feeding and hauling out on the shore. In northern Bering Sea arctic cod are the major food, in addition to saffron cod, capelin, herring, and sculpins. During summer and fall spotted seals feed on coastal runs of spawning fishes such as herring, smelt, and capelin and perhaps on anadromous species.

Belukhas are found in the pack ice of the Bering Sea during winter during which time their diet is unknown. Since they are largely fish eaters it is presumed that they eat a variety of forage fishes including pollock and arctic cod. During summer when they inhabit coastal regions they utilize much the same prey as spotted seals; small to medium-sized forage fishes make up most of the diet. In Norton Sound they are known to eat saffron cod and herring. Aggregations of those fishes which occur in coastal waters during summer and fall probably influence the distribution of both spotted seals and belukhas.

Bearded seals are abundant residents of the Bering Sea during months when sea ice is present. They eat mostly shrimps, brachyuran crabs, and clams. Tanner crabs are especially important in southern Bering Sea. The diet varies on a seasonal basis with clams important only during summer and only in some locations. Young seals eat more shrimps while older seals eat more clams, crabs, and echiuroid worms.

Ribbon seals spend the entire year in the Bering Sea. They are associated with sea ice during winter-spring and become pelagic during open water months. Our data, which are from the period March-June, indicate that pollock and eelpout are the major foods of ribbon seals in southcentral and central Bering Sea and arctic cod are important in northern Bering Sea. Food habits during the open water period and in early winter are unknown.

The Pacific walrus population winters in southern and central Bering Sea. They migrate through Norton Basin on their way to and from summer feeding grounds in the Chukchi Sea, and at least part of the population remains in Norton Basin throughout the summer. Foods of walruses consist mostly of clams with lesser amounts of snails, priapulids, polychaete worms, echiuroid worms, other miscellaneous invertebrates, and occasionally seals. Walruses may compete for food with bearded seals in areas such as Nome and Diomede where clams are, or used to be, a major component of the bearded seal diet.

Ringed seals are very abundant in Bering Sea in ice-covered months and they compete with and provide food for other marine species. Arctic cod and some saffron cod are their main foods in winter. Shrimps and other crustaceans, as well as arctic and saffron cods, are major foods in March through June. Ringed seal pups eat more small crustaceans (amphipods, mysids, and euphausiids) than do older seals, while older seals eat slightly more fish. Ringed seals eat many of the same fish species consumed by spotted and ribbon seals and belukhas. However, they also utilize crustaceans in significant quantities and therefore have a more diverse food resource base.

Available information on the distribution, abundance, and natural history of most invertebrate prey species and some of the fishes, particularly arctic cod and capelin, is inadequate. Information on hydrocarbon sensitivity of all but a few species is totally lacking. However, based on what information is available, a real potential for detrimental effects on prey populations exists, especially in species such as herring, capelin, and arctic cod which aggregate to spawn in habitats susceptible to contamination by oil. Changes in abundance of prey can be expected to influence populations of marine mammals.

IX. Needs for Further Study

The data included in this report on spotted seals cover only part of the year (spring) and limited geographic range. Needs for additional data are as follows: 1) information on food habits in summer and autumn, when spotted seals utilize coastal regions and presumably feed on anadromous fishes and/or aggregations of spawning fishes such as herring, smelt, and capelin which are also utilized by humans; and 2) additional samples from St. George Basin. Pollock are presumed to be the major prey but at present that presumption is based on a single seal.

Our data on ribbon seals, as well as the limited other data available from Soviet studies, were collected from a single time period (spring) when the seals are pupping, breeding, and molting, are hauled out on the ice for long periods of time, and when feeding activity is minimal. We have no information on times of year when major feeding activity takes place. This data gap may be difficult or impractical to fill in the near future given the pelagic nature of the seals during open water months, and the complete lack of precise information on distribution and abundance during all but the spring months.

With the exception of winter months and offshore areas, data on ringed seals and bearded seals should be adequate for OCSEAP purposes.

Foods of walruses are poorly documented. Some data are available from northern Bering Sea during spring. Winter food habits are unknown. In light of an increasing walrus population and upcoming petroleum exploration and development in walrus feeding habitat, it is important that base-line data be gathered to facilitate reevaluation at a future date of competitive interactions and/or the effects of human disturbance on what may already be a stressed population.

An area/season matrix of major data gaps for the above species is given in Table 24.

Few data are available on food habits of belukhas in Alaska, although they apparently utilize many of the same species eaten by spotted seals. A combined study of the two, with localized collection and examination of spotted seal stomachs, and analysis of the timing of movements and

Table 24. Major gaps in the data base on foods of phocid seals and walruses in the Bering Sea. For each area-season combination, species listed are those for which data are inadequate at the descriptive level.

Season	Area: Southeastern	Southcentral	Central	Northern
Autumn Sept.-Nov.	Harbor Walrus	Ribbon	Ribbon	Walrus
Winter Dec.-Feb.	Harbor Spotted Bearded Walrus	Spotted Ribbon Bearded Walrus	Bearded Ringed Spotted Ribbon Walrus	Walrus
Spring Mar.-May	Harbor Ringed Bearded Walrus	Bearded Walrus	Ringed Bearded Walrus	
Summer June-Aug.	Harbor Spotted Walrus	Ribbon	Ribbon	

distribution of both species, as well as analysis of coastal fisheries information, should provide preliminary data on prey utilization.

In areas (such as Nome or Diomede) where walruses and bearded seals coexist and utilize the same foods, additional specimen collections are desirable in order to further evaluate interspecific competition. There is evidence, based on limited historical collections from Diomede, that the diet of bearded seals has changed over the last 20 years as the walrus population has increased.

We strongly urge a systematic study of arctic cod, the single most important forage fish in northern Alaskan waters.

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