FEEDING HABITS, FOOD REQUIREMENTS, AND STATUS OF BERING SEA MARINE MAMMALS

NORTH PACIFIC FISHERY MANAGEMENT COUNCIL
P. O. Box 103136
ANCHORAGE, ALASKA 99510

November 1, 1982

<u>Council Document</u>
#19

Prepared By

Alaska Department of Fish and Game
Fairbanks, Alaska

Alaska Department of Fish and Game
Anchorage, Alaska

and

University of Washington
Seattle, Washington

Funded by NOAA/NMFS

1.0 TITLE PAGE

FINAL REPORT

TO: North Pacific Fishery Management Council
P.O. Box 3136 DT
Anchorage, Alaska 99510

CONTRACT NO.: 81-4

TITLE: FEEDING HABITS, FOOD REQUIREMENTS, AND STATUS OF BERING SEA MARINE MAMMALS

PRINCIPAL INVESTIGATORS: Lloyd F. Lowry[1], Kathryn J. Frost[1], Donald G. Calkins[2], Gordon L. Swartzman[3], and Susan Hills[1]

1 November 1982

[1] Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701

[2] Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage Alaska 99502

[3] University of Washington, Center for Quantitative Science, Seattle, Washington 98195

2.0 PREFACE

The history of human interaction with marine resources shows a consistent pattern of discovery and overexploitation, usually followed by programs of conservation or protection which often result in recovery of depleted stocks. This pattern applies equally well to populations of fishes, shellfishes, and marine mammals. Although many aspects of population ecology of exploited species are poorly known, there is little doubt that human intervention has been a major factor in most population declines.

Observations made during exploitation and subsequent recovery of stocks have provided a considerable body of empirical information which has formed the basis for management programs applied to commercial marine resources. Such single-species management, although preferable to unregulated exploitation, has limited utility since each species obviously interacts with many other organisms and environmental factors. This has led to the widespread adoption of ecosystem-based management as the framework on which to base present and future resource exploitation decisions. Unfortunately, although intellectually appealing and already incorporated into management philosophies, ecosystem-based management has yet to become a practical reality. However, that has not reduced the desire of concerned individuals and agencies to consider ecological interactions among animals and their environment when planning for conservation and management of resources.

In the United States, two relatively recent pieces of federal legislation, the Fishery Conservation and Management Act (FCMA) of 1976 and the Marine Mammal Protection Act of 1972, have had a marked effect on management of marine fisheries and mammals. Although both endorse and encourage ecosystem-based management, the former stresses development of programs for utilization of fishery resources, while the latter emphasizes protection of marine mammal species, a difference which generally reflects prevailing public opinion in this nation. Since many marine mammals feed on commercially exploitable fishes and shellfishes, they obviously may affect and be affected by commercial fisheries and fishery management plans. Although such biological interactions between marine mammals and fisheries undoubtedly occur throughout the waters regulated under the FCMA, much attention has been focused on the situation in the Bering Sea.

The Bering Sea, which supports what is probably the most diverse marine mammal fauna of any of the world's oceans, has long been exploited for its rich fishery resources. As management plans, mandated by the FCMA, began to be developed for those fisheries, attempts were made to incorporate ecosystem-level consideration of interactions between marine mammals and fishery resources. Those considerations were only partially successful due principally to the lack of an organized data base on marine mammals and the absence of a functional framework with which to consider the magnitude and implications of possible interactions. In response, the North Pacific Fishery Management Council, in conjunction with the Marine Mammal Commission, issued a contract to the Alaska Department of Fish and Game to compile, summarize, and evaluate available marine mammal data; examine and evaluate existing Bering Sea ecosystem models; and provide suggestions for directing future research on marine mammal-fishery interactions in the Bering Sea.

Our attempts to attain these objectives have resulted in the lengthy report which follows. For a number of reasons our task has been far from simple. The short time allotted to this project, approximately 9 months, has precluded an orderly consideration of much of the information we have located. For example, in some instances we have had to discover references, request them from foreign scientists, and have them translated before they could be included in species summaries, evaluated, and considered in the development of a research plan. The number of marine mammal species included in this review (26) is largely responsible for the sheer bulk of the report and the intensive effort required for its preparation. Lastly, this is the first review of its type dealing with biological interactions among marine mammals and fisheries in the Bering Sea. The subjects of marine mammal-fishery interactions in general and density-dependent responses of marine mammals have only recently begun to receive significant attention. Available reports on these subjects, although in some instances useful summaries of existing information, fall far short of providing a comprehensive framework with which to evaluate the Bering Sea situation.

We therefore consider this report as a working document rather than a definitive statement which adequately describes or resolves the question of interactions between marine mammals and fisheries in the Bering Sea. Certainly we have missed some existing relevant information and more is being produced virtually daily. Users of the report will undoubtedly differ as to their opinion regarding its usefulness. We have of necessity resorted to generalizations when summarizing available data and assume that those requiring more detailed information can and will access the referenced literature. We hope that our considerations and assessments will serve to focus attention and future research in such a way that concrete progress can be made in the consideration of how marine mammals and fisheries may affect one another. It is disappointing to be able to say at present little more than that marine mammals eat fishes that fishermen would like to catch and that fishermen catch fish that marine mammals otherwise might eat.

3.0 EXECUTIVE SUMMARY

This report is a compilation, summary, and evaluation of available data on feeding habits, food requirements, and status of Bering Sea marine mammals. Included are an annotated bibliography, a research plan designed to fill major data gaps, and a discussion of the utility of data for assessing interactions among marine mammals and commercial fisheries in the Bering Sea/Aleutian Islands region. Considered in the report are 26 species of marine mammals, including eight species of baleen whales, eight toothed whales, eight pinnipeds, and two carnivores.

Although for most species it is possible to generally describe the foods eaten in the Bering Sea, with the exception of the northern fur seal, data are not adequate for determining the quantitative composition of the diet. Estimates of food requirements generated by one of several methods are also usually available but are of unknown reliability in most instances. Measurements of indicators of population status are accompanied by natural and sampling variability, the magnitude of which is often large or unknown.

Although there can be little doubt that some marine mammals compete with commercial fisheries, there is no conclusive evidence to show how marine mammals may affect and be affected by fisheries in the Bering Sea. A variety of techniques can be used for assessing interactions among marine mammals and commercial fisheries. Estimates of quantities of fishes consumed by marine mammals are useful for comparison with fishery harvests and are required as inputs for the NMFS Bering Sea ecosystem model DYNUMES/PROBUB. However, such estimates are not presently reliable due to the usual lack of necessary data and possible variability associated with available information. Attempts to correlate changes in marine mammal population status with activities of fisheries have not to date been successful. Correlations of this type are unlikely to be conclusive due to the difficulty of obtaining needed information with adequate accuracy. Ecosystem models and simulations, while appealing since they could allow predictions of interactions and effects, are not yet adequately developed and tested. Available data are adequate to produce a conceptual assessment of the likelihood of significant interactions with present and potential fisheries based on general considerations of feeding habits and population status of marine mammals. This assessment produced the following categories: high probability of interaction--northern fur seal, Steller sea lion, harbor seal, spotted seal, belukha, harbor porpoise, and sea otter; moderate probability of interaction--gray whale, walrus, Dall's porpoise, ribbon seal, and bearded seal; and low probability of interaction--killer whale, minke whale, beaked whales, polar bear, fin whale, blue whale, sei whale, humpback whale, bowhead whale, right whale, and sperm whale.

The research plan developed dealt only with eight species that feed primarily on fishes and for which the probability of interaction with fisheries was considered moderate or high: fur seal, sea lion, harbor seal, spotted seal, ribbon seal, belukha, harbor porpoise, and Dall's porpoise. Those species may interact significantly with existing fisheries for groundfish, herring, and salmon and potential fisheries for capelin, saffron cod, and shrimps. Areas where the most significant interactions may occur are offshore and coastal regions of the southern Bering Sea and coastal regions of the northern Bering Sea. Data on distribution and abundance in relation to fishery resources, prey consumption in relation to availability, condition indices, and vital parameters should, to the extent practical, be collected for each species in each area. Applicable techniques include aerial and shipboard surveys, examination of specimens from opportunistic and systematic collections, and marking and telemetry of animals. Suggestions are made for coordination and planning of efforts dealing with modeling and ecosystem simulations.

4.0 TABLE OF CONTENTS

5.0 LIST OF FIGURES

6.0 LIST OF TABLES

7.0 LIST OF ABBREVIATIONS

ADF&G - Alaska Department of Fish and Game

AMNWR - Alaska Maritime National Wildlife Refuge, Anchorage, Alaska

BLM - Bureau of Land Management

DYNUMES - Dynamic Numerical Marine Ecosystem Model

IUCN - International Union for the Conservation of Nature, Gland, Switzerland

IWC - International Whaling Commission, Cambridge, England

MMC - Marine Mammal Commission, Washington, D.C.

NMFS - National Marine Fisheries Service

NMML - National Marine Mammal Laboratory, Seattle, Washington

NOAA - National Oceanographic and Atmospheric Administration

NPFMC - North Pacific Fishery Management Council, Anchorage, Alaska

NPFSC - North Pacific Fur Seal Commission, Washington, D.C.

NSF - National Science Foundation

NTIS - National Technical Information Service, Springfield, Virginia

NWAFC - Northwest and Alaska Fisheries Center, Seattle, Washington

OCSEAP - Outer Continental Shelf Environmental Assessment Program

PINRO - Polyarnogo nauchno-issledovatel'skogo instituta morskogo rybnogo khozyaistva i okeanografii (Polar Research Institute of Marine Fisheries and Oceanography)

PMEL - Pacific Marine Environmental Laboratory, Seattle, Washington

PROBES - Processes and Resources of the Bering Sea Shelf

TINRO - Tikhookeanskogo nauchno-issledovatel'skogo instituta rybnogo khozyaistva i okeanografii (Pacific Research Institute of Fisheries and Oceanography)

UA - University of Alaska, Fairbanks, Alaska

USAEC - U.S. Atomic Energy Commission, Washington, D.C.

USFWS - U.S. Fish and Wildlife Service

UW - University of Washington, Seattle, Washington

VNIRO - Vsesoyuznogo nauchno-issledovatel'skogo instituta morskogo rybnogo khozyaistva i okeanografii (All-Union Research Institute of Fisheries and Oceanography)

8.0 ACKNOWLEDGMENTS

Primary financial support for this project was provided by the North Pacific Fishery Management Council and the Marine Mammal Commission (Contract No. 81-4). Support for salaries of project personnel in excess of those included in the original budget was provided by the Alaska Department of Fish and Game, Division of Game. Much of the initial literature search and the collection of data on marine mammals was done with the support of the NOAA Outer Continental Shelf Environmental Assessment Program and the Federal Aid in Wildlife Restoration Program.

We thank our many colleagues in the United States, Canada, Great Britain, and the Soviet Union who have promptly and enthusiastically responded to our requests for literature and other information. Several personnel at the NMFS, NMML were particularly helpful. We especially thank Dr. William Aron, Dr. Michael Tillman, Dr. R. V. Miller, and Ms. Sherry Pearson. Translation services were provided by Dr. Hiro Kajimura (NMFS, NMML) and Mr. Kenneth Coyle (UA). Mr. Jim Branson and Dr. Clarence Pautzke (NPFMC) were extremely helpful in many aspects of the project. Mr. John Burns (ADF&G) was very supportive throughout this work and deserves much of the credit for our present level of understanding of Bering Sea marine mammals. Substantial and valuable comments on the draft report were received from Mr. Clifford Fiscus, Dr. Robert Hofman, Dr. John Hall, and personnel at the NMFS, NMML. Finally, this document could not have been prepared without the expert organizational and editorial capabilities of Kathleen Pearse, whose months of meticulous labor we greatly appreciate.

9.0 INTRODUCTION

9.1 Statement of Problem

Questions regarding the nature and extent of the interactions among marine mammals and fisheries have received increased attention in recent years (e.g., FAO 1978, Mate 1980, IUCN 1981). With few exceptions (Mate 1980), interactions of concern involve commercial fisheries which, in contrast to recreational and subsistence fisheries, typically harvest large quantities of fish or shellfish and often operate in areas which support large marine mammal populations. Such interactions can be conveniently considered as two major types listed below:

1. Direct or operational interactions
   a. marine mammals cause damage to a fisherman's gear and/or catch
   b. marine mammals are injured or killed as a result of contact with fishing gear or fishermen
2. Indirect or biological interactions
   a. predation by marine mammals reduces the quantity of a target species that is available to a fishery
   b. harvests by a fishery reduce the amount of prey available to marine mammals
   c. marine mammals function as hosts for parasites which reduce marketability of commercial fishes

Operational interactions are in most cases readily observed, localized in extent, and comparatively easy to document and quantify. In contrast, indirect interactions are not well documented, occur over broad areas (i.e., entire ecosystems), and are conceptually complex and difficult to quantify (IUCN 1981). In this report we will deal only with the first two types of indirect interactions which primarily involve the dynamic responses of marine mammals and fisheries to changes in fish stock abundance and characteristics. Note, however, that direct interactions may be of great importance and should not be overlooked. For example, Fowler (pers. commun.) suggests that entanglement of northern fur seals (Callorhinus ursinus) in net fragments may result in an annual mortality as high as 5% and may be the primary cause of the current downward trend in fur seal populations.

The area being considered is the Bering Sea, including the waters surrounding the Aleutian Islands. Exploitation of marine mammal and fish populations has been a major factor in the exploration, colonization, and development of the Bering Sea region. Although these resources have been utilized by indigenous peoples for several thousand years, it was not until the 1600's and 1700's that the abundance of seals, sea otters, walruses, and whales was "discovered" by Europeans (Fay

1981). Over the next 2 centuries, populations of several species were harvested to the point of commercial extinction, while at least one, the Steller sea cow (Hydrodamalis gigas), became biologically extinct. Through a series of domestic and international laws and treaties, a framework for the conservation and management of marine mammal populations was slowly developed. Most recently, the Marine Mammal Protection Act (MMPA) of 1972 (PL-92-522) has attempted to provide guidelines for the protection and management of marine mammals in the United States, with the stated primary objective of maintaining the "health and stability of the marine ecosystem."

Commercial exploitation of Bering Sea fish stocks did not begin until after the peak of marine mammal harvests. Small catches of Pacific cod (Gadus macrocephalus) and halibut (Hippoglossus stenolepsis) were made in the late 1800's, but substantial harvests did not occur until early in the 20th century (Pruter 1973). These two species, along with salmon (Oncorhynchus spp.), were the principal target species prior to 1940. After World War II, a major diversification occurred in the fisheries, resulting in exploitation of many additional species, including yellowfin sole (Limanda aspera), walleye pollock (Theragra chalcogramma), Pacific ocean perch (Sebastes alutus), Atka mackerel (Pleurogrammus monopterygius), herring (Clupea harengus), sablefish (Anoplopoma fimbria), shrimps (Pandalus spp.), king crabs (Paralithodes spp.), and tanner crabs (Chionoecetes spp.). Domestic fishing has been regulated primarily by the federal government; after 1960 the State of Alaska developed management programs for salmon, herring, shrimp, and crab fisheries. Foreign fisheries were in some instances regulated by domestic legislation and international agreements which were generally not adequate to prevent overexploitation and decline of stocks (Pruter 1973). The Magnuson Fishery Conservation and Management Act (FCMA) of 1976 (PL-94-265) established a 200-mile Fishery Conservation Zone (FCZ) in seas adjacent to the United States and provided a framework for management of existing commercial fisheries and development of fisheries for species not presently utilized commercially.

Natural history studies of Bering Sea marine mammals have documented the importance of commercially harvested species in marine mammal diets (e.g., Scheffer 1950, Lowry et al. 1979). Preliminary estimates of the quantities consumed indicated that annual consumption of commercially important fishes by marine mammals exceeded the amount harvested by the fisheries (McAlister and Perez 1976). Considering the magnitude of the trophic interaction between marine mammals and commercially important fishes in the Bering Sea, an ecosystem-based approach to management of fish and shellfish populations is obviously desirable. Since ecosystem-based management is encouraged by provisions of both the MMPA and the FCMA (Hammond 1980), an attempt was made to consider marine mammal food requirements in the development of the Bering Sea/ Aleutian Islands groundfish fishery management plan. This attempt was only partially successful due to the lack of adequate data and models with which to analyze and simulate the possible interactions. In response, the North Pacific Fishery Management Council (NPFMC), in conjunction with the Marine Mammal Commission (MMC), entered into a contract with the Alaska Department of Fish and Game (ADF&G) to provide a summary and evaluation of data on foods and population status of Bering Sea marine mammals. Principal objectives of this project were to:

1. Identify all species and, as possible, populations of marine mammals that occur on the continental shelf of the FCZ in the Bering Sea.

2. Compile all available published or publicly reported information on the status (distribution, abundance, trends, and productivity), feeding habits (dietary components, relative importance of various prey species, feeding cycles, etc.), and food requirements of the marine mammal species and populations identified in 1 above.

3. Summarize the data compiled pursuant to 2 above according to species, populations, population subsets (age/sex groups), time of year, and/or location as may be appropriate.

4. Evaluate the data compiled and summarized pursuant to 2 and 3 above to determine their reliability and utility and to identify such additional data on distribution, density, age/sex classes, feeding habits, etc. as may be necessary to determine how marine mammals may affect and be affected by existing or proposed fishery management plans and to serve as input to the DYNUMES/PROBUB Bering Sea ecosystem model.

5. Inventory new or unanalyzed collections of material (stomach samples, etc.), identify their quality and degree of analysis, and specify which data gaps the forthcoming data will fill.

6. Develop and provide the rationale for a research plan to obtain the additional data identified in task 4 but that will not be available from collections identified in task 5.

7. Provide a complete annotated bibliography for all data compiled and evaluated in tasks 1-4 above.

9.2 Description of Bering Sea/Aleutian Islands Area

9.2.1 Physical Characteristics

The Bering Sea is the northernmost peripheral sea of the North Pacific Ocean (Figure 9.2-1) The coasts of Alaska and Siberia provide the eastern and western limits, while the southern boundary is formed by the Alaska Peninsula and Aleutian ridge. The coastline includes three major embayments: Bristol Bay and Norton Sound on the east and the Gulf of Anadyr in the northwest.

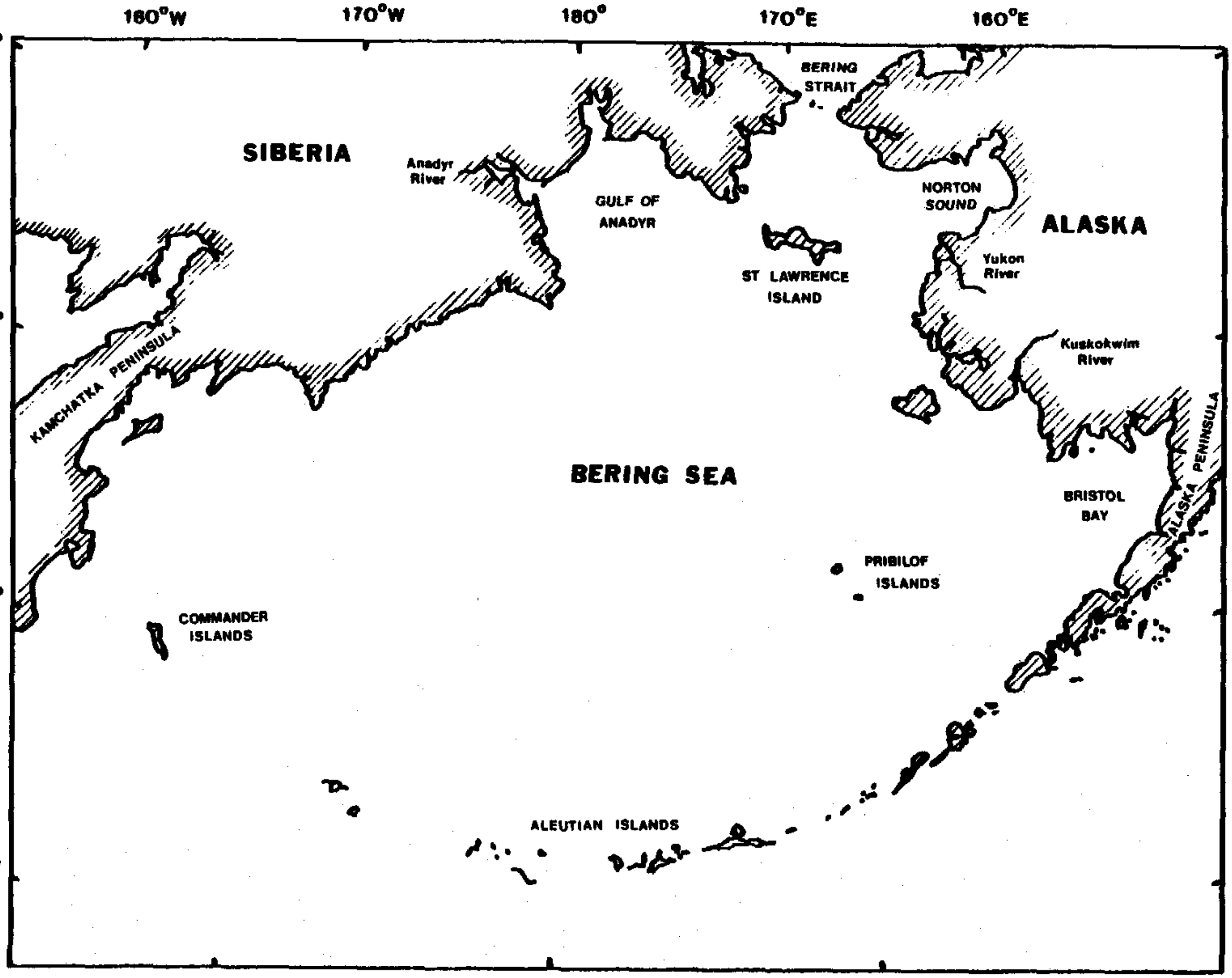

Figure 9.2-1. Map of the Bering Sea and surrounding areas.

The Bering Sea tapers dramatically from south to north: the distance from Bristol Bay to the Kamchatka Peninsula exceeds 2,000 km, while Bering Strait is only 82 km across. Its surface area of approximately 2.3 million km^2 makes it the third largest semi-enclosed sea in the world (Hood 1981). This area is comprised of 44% continental shelf, 43% abyssal depths, and 13% continental slope (Hood and Kelley 1974). The shelf, covering an area of 1.2 million km^2, is most extensive in the northeastern Bering. The shelf and the several islands which occur on it are of great significance to the biological resources of the area. The Aleutian ridge is a complex, 2,000-km long feature produced by the interaction of major tectonic plates. Emergent portions of the string of volcanic mountains form the Aleutian and Commander Islands. The Aleutian Islands are separated by distances of up to 100 km. Deep passes between the islands provide passage for water and animals, while the islands themselves are important bird and mammal habitats. In the north, Bering Strait is of similar importance.

9.2.2 Oceanographic and Meteorological Characteristics

A considerable body of oceanographic data is available for the Bering Sea (Hood and Kelly 1974, Hood and Calder 1981). Studies indicate distinguishable water masses (Ingraham 1981) and a complex flow pattern, including several major gyres (Takenouti and Ohtani 1974) (Figure 9.2-2). Although seasonal fluctuations in flow rate and directions have been recently documented, net annual transport of water through Bering Strait is to the north (Coachman and Aagaard 1981). This outflow is balanced by the flow of North Pacific waters through passes in the Aleutians (e.g., Hughes et al. 1974) and by input from rivers, the three largest of which, the Yukon, Kuskokwim, and Anadyr, drain 77% of the surrounding land area (Ingraham 1981). The majority of the water entering the Bering Sea is of North Pacific origin; Hood (1981) estimates that only 10% of the input is from Alaskan rivers. Oceanographic features important to productivity include vertical transport (upwelling) near passes in the Aleutians (Hood 1981) and hydrographic structures (fronts) which occur along the continental slope and shelf (Kinder and Schumacher 1981).

The Bering Sea, spanning 12° of latitude (1,250 km), is influenced by arctic, continental, and maritime air masses and experiences a wide range of meteorologic conditions. Latitudinal variations in temperature are greatest during winter, while seasonal variations are greatest in northern areas (Overland 1981). The climate fosters the development of seasonal sea ice in a major portion of the Bering Sea, which in turn has a major effect on weather (Konishi and Saito 1974). Ice formation in the northern Bering begins in November, with pack ice coverage progressing southward during winter and early spring. The maximum southward extent, which usually reaches the continental shelf break, occurs in late March. Considerable annual variations in ice coverage occur and are correlated with fluctuations in sea surface temperature, air temperature, and wind direction (Niebauer 1981).

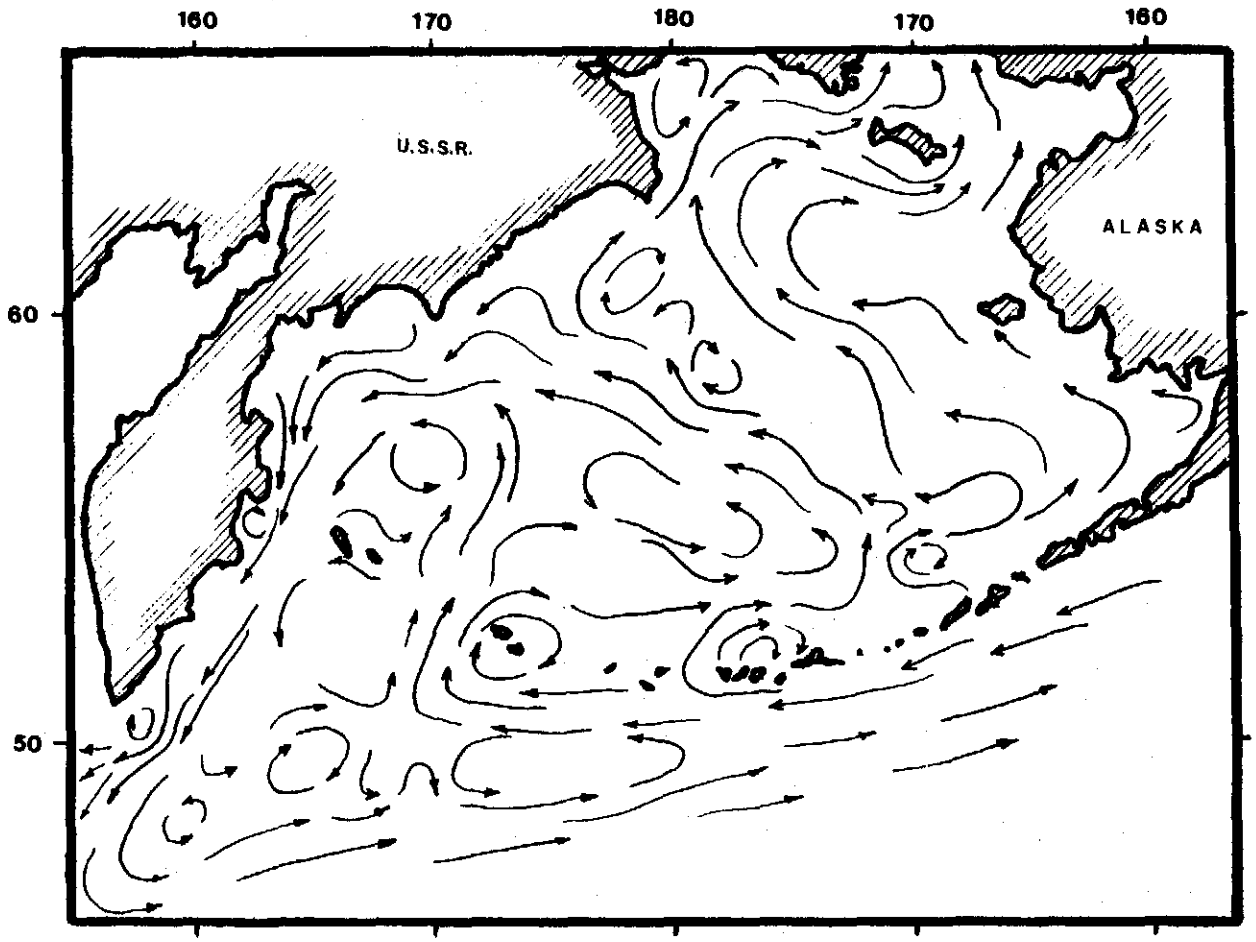

Figure 9.2-2. Schematic diagram of circulation in the Bering Sea and northwestern Pacific Ocean (from Takenouti and Ohtani 1974).

9.2.3 Biological Characteristics

The Bering Sea is an area of high biological productivity, as indicated by abundant invertebrate, fish, bird, and mammal populations. The great biological diversity of the area is in part a result of the mixing of boreal Pacific and arctic faunas.

As previously mentioned, upwelling near passes in the Aleutian Islands and the presence of fronts on the shelf and shelf break provide nutrient regimes and water column characteristics that may favor high primary production. In addition, the presence of sea ice may enhance annual primary production both through the contribution of epontic (ice-associated) algae (McRoy and Goering 1974) and an enhancement of water column stability (Niebauer et al. 1981).

Recent studies have indicated that the eastern Bering Sea can be divided into four "domains" separated by fronts, as shown in Figure 9.2-3. The annual "spring bloom" of phytoplankton begins in the middle and inner fronts, then spreads across the coastal, midshelf, and outer shelf domains. In the initial stages, small diatoms predominate throughout the area and are grazed by small copepods. Flagellates and dinoflagellates dominate later stages of the bloom in the outer shelf domain, probably as a result of removal of diatoms by large calanoid copepods. In the midshelf domain, medium-sized diatoms predominate until summer, when Rhizosolenia alta, a diatom which forms long chains and is capable of growing in low silica concentrations, becomes dominant. Small copepods which dominate the zooplankton of the midshelf and coastal domains cannot effectively graze the medium- and large-sized diatoms, which results in a considerable flux of phytoplankton to the bottom in those areas (Cooney 1981, Goering and Iverson 1981).

The benthic invertebrate fauna of the Bering Sea shelf is well described, with recent summaries available for both infauna (Haflinger 1981, Stoker 1981) and epifauna (Jewett and Feder 1981). The fauna is dominated by boreal Pacific forms with high-arctic species common only in northern regions. Clams, polychaetes, and amphipods dominate the infauna, while echinoderms, crabs, and snails are major components of the epifauna. In the northern Bering Sea (Chirikof Basin), tunicates, sponges, and sea anemones are particularly abundant. Of particular importance to marine mammals and fisheries are the abundant populations of crabs (Jewett and Feder 1981), clams (Hughes and Bourne 1981), and snails (MacIntosh and Somerton 1981). Trophic interactions involving benthic communities have been described by Feder and Jewett (1981).

The fish fauna of the Bering Sea includes approximately 300 species, which can be divided into two major groups: a cold-region fauna consisting primarily of arctic species and associated with negative bottom temperatures found north and west of St. Matthew Island, and a boreal Pacific fauna found in the remainder of the area (Wilimovsky 1974). The three dominant families, Cottidae (sculpins), Liparidae (snailfishes), and Stichaeidae (pricklebacks), contain 45% of the

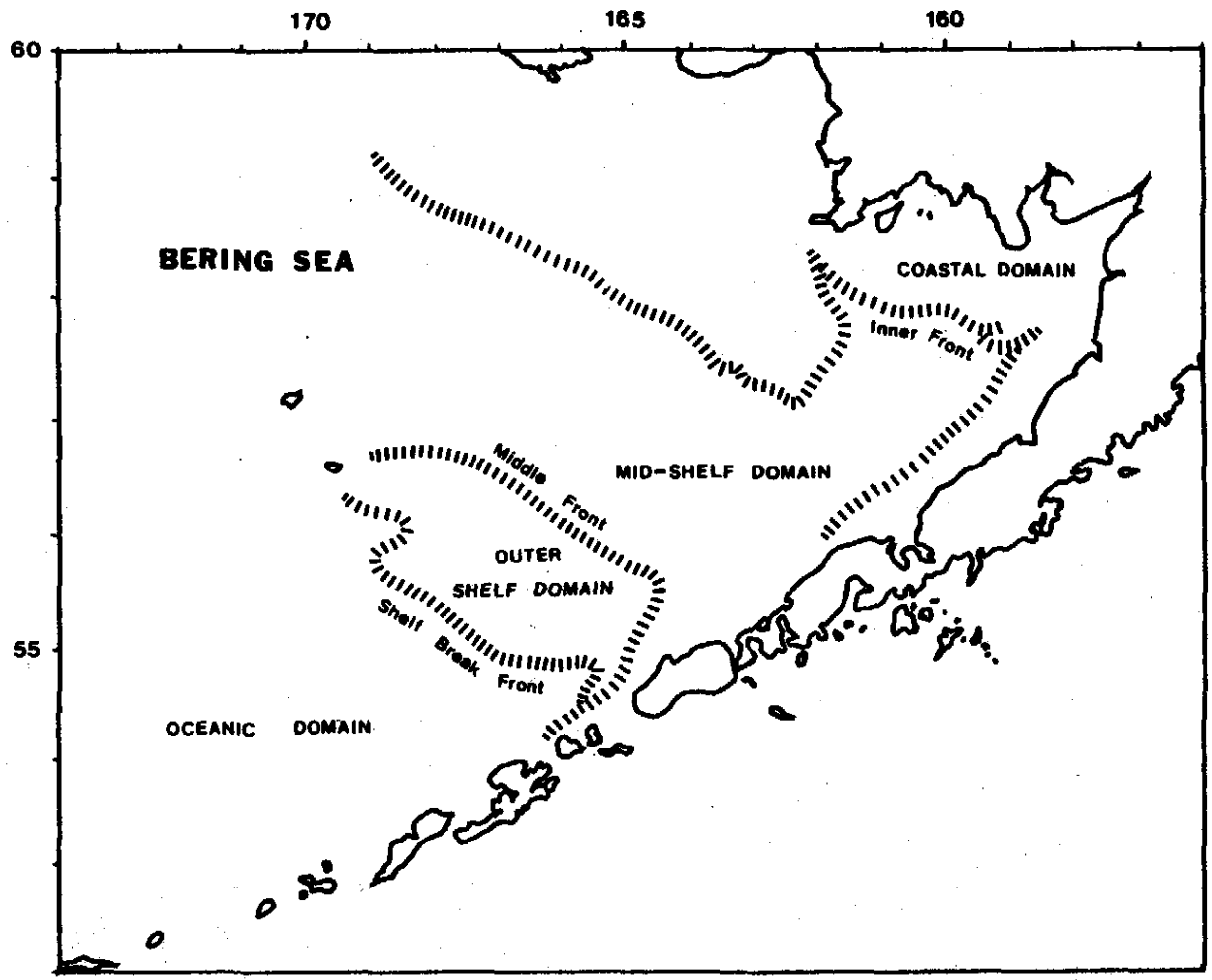

Figure 9.2-3. Fronts and corresponding shelf domains of the eastern Bering Sea (from Goering and Iverson 1981).

known species, none of which are of commercial value. Species of commercial interest are primarily of the families Gadidae (cods), Pleuronectidae (flatfishes), Clupeidae (herring), and Salmonidae (salmon) (see section 9.4).

Seabirds, shorebirds, and waterfowl are all major components of the Bering Sea avifauna (Hunt et al. 1981a, b; Jill and Handel 1981; King and Dau 1981). Seabirds are of primary concern in considerations of the Bering Sea marine ecosystem and possible interactions with fisheries. Many species form large breeding colonies on island and mainland coasts. Major colonies occur on Nunivak, St. Matthew, St. Lawrence, Diomede, King, and the Pribilof islands, and at Cape Newenham. Up to 20.5 million seabirds have been estimated to breed in the eastern Bering Sea (Hunt et al. 1981a). An additional 20 million nonbreeding visitors and immatures of breeding species are estimated to occur in the eastern Bering Sea (Hunt et al. 1981b). Feeding ecology of major species has been described in detail by Hunt et al. (1981c).

9.2.4 Political Characteristics

The land masses bordering and enclosed within the Bering Sea and Aleutian Islands occur entirely within the political boundaries of the United States and the Soviet Union. Under terms of the FCMA, the US controls resources in an economic zone extending seaward for 200 miles. Within 3 miles of the coast, authority is vested in the State of Alaska. The Soviet Union presently claims control of resources within 200 miles of its shores.

Several other nations, particularly Japan, have historical and present involvements in scientific research and exploitation of Bering Sea resources. In addition to the US and USSR, Japan, Canada, Korea, and Taiwan have participated in the groundfish fishery (Bakkala et al. 1981). Catches of large whales have recently been made mostly by the USSR and Japan, while the fur seal harvest is shared among the US, USSR, Japan, and Canada. Major international agreements relevant to conservation and management of Bering Sea marine resources include: US-USSR Environmental Protection Agreement; International Whaling Commission - US, USSR, Japan, Canada, and others; Interim Convention on Conservation of North Pacific Fur Seals - US, USSR, Japan, and Canada; International North Pacific Fisheries Commission - US, Japan, and Canada; and International Pacific Halibut Commission - US, Japan, and Canada.

9.3 Bering Sea Marine Mammal Fauna

9.3.1 Taxonomic Identity

The marine mammal fauna selected for study includes 26 species which occur or may occur in the Bering Sea/Aleutian Islands region.

Included are eight species of baleen whales, eight toothed whales, eight pinnipeds, and two carnivores (Table 9.3-1). Fay (1974) in a similar list includes 25 species: he lists harbor and spotted seals as a single species, includes the narwhal, and does not include the right whale. The list given by Nishiwaki (1974) includes the Zenigata or island seal (Phoca insularis) and the extinct Steller sea cow, and omits the blue whale, killer whale, and spotted seal.

9.3.2 Ecological Characteristics

The presence of sea ice in the Bering Sea has a major effect on marine mammal distribution and ecology. Fay (1974) has discussed in detail the importance of ice in the ecology of Bering Sea marine mammals. For all species it forms a barrier which they must penetrate in order to have access to air to breath and to water where they can feed and escape inclement weather or predators. For pagophilic (ice-loving) species which are adapted to living on and among the ice, this habitat provides protection, transportation, and a substrate on which to rest, socialize, and bear and nurture young. The pagophilic fauna includes eight species: bowhead and belukha whales, walruses, polar bears, and spotted, ribbon, ringed, and bearded seals. The remaining species contact ice only occasionally or virtually never. Within the sea ice habitat, the pagophilic species show associations with ice of particular characteristics (Burns 1970, Burns et al. 1981). Distribution and characteristics of sea ice therefore influence access to resources by marine mammals. For example, the northern limit of sea otters is probably determined by the regular occurrence of ice; gray whales are excluded from their feeding grounds in the northern Bering Sea until the ice pack loosens sufficiently in spring; and shorefast ice excludes all species except ringed seals and polar bears from the coastal zone during winter months. Several of the pagophilic species (bowhead whales, polar bears, and ringed and bearded seals) virtually disappear from the Bering Sea during the open-water season.

In addition to associations with ice, most species appear to have affinities for particular oceanographic or bathymetric regions. These associations may in most cases reflect food availability and feeding strategies of the marine mammal species. A provisional listing of these associations is given in Table 9.3-2. The greatest number of species occurs over the continental shelf and in coastal areas. This association may be in part coincidental for ice-associated species such as bowhead whales, ringed seals, and polar bears but is probably obligatory for benthic feeders such as sea otters, bearded seals, walruses, and gray whales. Most if not all of the seven species listed in the shelf break/continental slope category also range occasionally onto the continental shelf but appear to be concentrated in the shelf break region. Similarly, the six species considered as oceanic range onto the continental slope and perhaps the shelf, but, at least in the case of sperm and beaked whales, their primary range is the deep, oceanic domain.

Table 9.3-1. Taxonomic listing of marine mammal species known to occur in the Bering Sea and Aleutian Islands regions.

PHYLUM CHORDATA SUBPHYLUM VERTEBRATA CLASS MAMMALIA

ORDER CETACEA - Whales, Dolphins, and Porpoises

SUBORDER MYSTICETI - Baleen or Whalebone Whales

FAMILY ESCHRICHTIDAE

Gray whale - Eschrichtius robustus

FAMILY BALAENOPTERIDAE - Rorquals

Fin or finback whale - Balaenoptera physalus

Minke whale - Balaenoptera acutorostrata

Blue whale - Balaenoptera musculus

Sei whale - Balaenoptera borealis

Humpback whale - Megaptera novaeangliae

FAMILY BALAENIDAE - Right Whales

Right whale - Balaena glacialis

Bowhead whale - Balaena mysticetus

SUBORDER ODONTOCETI - Toothed Whales

FAMILY PHYSETERIDAE

Sperm whale - Physeter macrocephalus

FAMILY MONODONTIDAE

Belukha, beluga, or white whale - Delphinapterus leucas

FAMILY ZIPHIDAE

Cuvier's beaked whale - Ziphius cavirostris

Baird's beaked whale - Berardius bairdi

Stejneger's beaked whale - Mesoplodon stejnegeri

Table 9.3-1, cont.

FAMILY DELPHINIDAE

Killer whale - _Orcinus orca_

FAMILY PHOCOENIDAE

Dall's porpoise - _Phocoenoides dalli_

Harbor porpoise - _Phocoena phocoena_

ORDER PINNIPEDIA - Seals, Sea Lions, and Walruses

FAMILY OTARIIDAE - Eared Seals

Northern fur seal - _Callorhinus ursinus_

Steller or northern sea lion - _Eumetopias jubatus_

FAMILY ODOBENIDAE

Pacific walrus - _Odobenus rosmarus_

FAMILY PHOCIDAE - True Seals

Harbor seal - _Phoca vitulina richardsi_

Spotted or larga seal - _Phoca largha_

Ribbon seal - _Phoca (Histriophoca) fasciata_

Ringed seal - _Phoca (Pusa) hispida_

Bearded seal - _Erignathus barbatus_

ORDER CARNIVORA - Carnivores

FAMILY URSIDAE

Polar bear - _Ursus maritimus_

FAMILY MUSTELIDAE

Sea otter - _Enhydra lutris_

Table 9.3-2. Preliminary listing of oceanographic/bathymetric affinities of Bering Sea marine mammals.

Oceanic/deep water	Continental slope/ shelf break	Continental shelf/ coastal
Sei whale	Fin whale	Gray whale
Right whale	Minke whale	Humpback whale
Sperm whale	Blue whale	Minke whale
Cuvier's beaked whale	Dall's porpoise	Bowhead whale
Baird's beaked whale	Stejneger's beaked whale	Belukha
Stejneger's beaked whale	Fur seal	Killer whale
	Sea lion	Harbor porpoise
	Ribbon seal	Walrus
		Harbor seal
		Spotted seal
		Ringed seal
		Bearded seal
		Polar bear
		Sea otter

9.3.3 Abundance

The total number of marine mammals inhabiting the Bering Sea and Aleutian Islands region is not accurately known but is probably between 2 and 3 million. The number and species composition vary seasonally, in large part due to summer replacement of the pagophilic species by those such as the fur seal and gray, humpback, and fin whales which come into the Bering Sea to feed during ice-free seasons.

In Table 9.3-3, we have categorized the numerical and biomass abundance of the Bering Sea marine mammal species based primarily on estimates given by McAlister (1981). The population size of most cetacean species is small in comparison to the pinnipeds: 12 of the 16 cetacean species occur in the Bering Sea in numbers less than 10,000, and 10 of those probably number 1,000 or less. The most numerous species is the Dall's porpoise. In contrast, all pinniped populations are estimated to exceed 10,000 individuals, with five of the eight species numbering in excess of 100,000. Due to the large size of some whales, a consideration of estimated population biomass shows a more equal distribution among taxonomic groups. Species with population biomasses in excess of 100,000 mt include one baleen whale (gray whale), one toothed whale (sperm whale), and one pinniped (walrus). It is obvious that the species contributing the most to marine mammal biomass in the Bering Sea are both abundant and large.

9.3.4 Significance

Apart from their interactions with fisheries, marine mammals of the Bering Sea are of considerable esthetic, economic, and ecological significance. Information on such aspects of marine mammals has not previously been compiled, and the following discussion is therefore preliminary and incomplete.

The esthetic value of marine mammals is indicated by expressed public concern for their welfare, and efforts by the public to view, photograph, and write about them. Federal legislation such as the MMPA and the abundance of interest groups dealing specifically or partially with marine mammals adequately affirm public interest. With specific respect to Bering Sea species, the fur seal and walrus support tourism at the Pribilof and Walrus islands, while gray whales support a similar "tourist industry" in the southern portions of their range. Species which are somewhat "unique" or restricted to arctic areas, such as bowhead whales, walruses, and polar bears, are popular subjects for photography and journalism.

The economic significance of Bering Sea marine mammals is suggested by past and present participation in commercial and subsistence harvests (Table 9.3-4). Virtually all species except polar bears and some of the small toothed whales have at some time been commercially harvested. Commercial harvesting of all pinnipeds and two cetacean species continues

Table 9.3-3. Categorization of maximum numerical abundance and biomass of marine mammals in the Bering Sea.

	Maximum numerical abundance			Population biomass (mt)		
Species	< 10,000	10,000-100,000	> 100,000	< 10,000	10,000-100,000	> 100,000
Baleen whales						
Gray whale		X				X
Fin whale *	X				X	
Minke whale	X				X	
Blue whale *	X			X		
Sei whale *	X			X		
Humpback whale *	X			X		
Right whale *	X			X		
Bowhead whale	X				X	
Toothed whales						
Sperm whale		X				X
Belukha		X		X		
Cuvier's beaked whale *	X			X		
Baird's beaked whale *	X			X		
Stejneger's beaked whale *	X			X		
Killer whale *	X			X		
Dall's porpoise		X		X		
Harbor porpoise *	X			X		
Pinnipeds						
Northern fur seal			X		X	
Steller sea lion		X			X	
Walrus			X			X
Harbor seal		X		X		
Spotted seal			X		X	
Ribbon seal		X		X		
Ringed seal			X		X	
Bearded seal			X		X	
Carnivores						
Polar bear	X			X		
Sea otter		X		X		

* Indicates population estimated at 1,000 or less.

Table 9.3-4. Summary of commercial and subsistence harvesting of Bering Sea marine mammals.

Species	Commercial harvest		Subsistence harvest	
	Past	Present	Past	Present
Baleen whales				
Gray whale	US		US,USSR	US,USSR
Fin whale	US,USSR,J			
Minke whale	US,USSR,J	USSR,J	US	US
Blue whale	US			
Sei whale	USSR,J			
Humpback whale	US		US	
Right whale	US,USSR,J		US	
Bowhead whale	US		US	US
Toothed whales				
Sperm whale	US,USSR,J	USSR		
Belukha	USSR		US,USSR	US,USSR
Cuvier's beaked whale				
Baird's beaked whale	J			
Stejneger's beaked whale				
Killer whale				
Dall's porpoise				
Harbor porpoise				
Pinnipeds				
Northern fur seal	US,USSR,J,C	US,USSR,J,C	US,USSR	US,USSR
Steller sea lion	US,USSR	USSR	US,USSR	US,USSR
Walrus	US,USSR	USSR	US,USSR	US,USSR
Harbor seal	US,USSR,J	USSR	US,USSR	US,USSR
Spotted seal	USSR	USSR	US,USSR	US,USSR
Ribbon seal	USSR	USSR	US,USSR	US,USSR
Ringed seal	USSR	USSR	US,USSR	US,USSR
Bearded seal	USSR	USSR	US,USSR	US,USSR
Carnivores				
Polar bear			US,USSR	US,USSR
Sea otter	US,USSR		US,USSR	

US = United States
USSR = Soviet Union
C = Canada
J = Japan

at present, primarily by the Soviet Union and Japan. All pinnipeds, both carnivores, and several species of cetaceans have in the past supported subsistence harvests. The nations and species involved in subsistence harvests are similar at present: taking is mostly by the US and Soviet Union, with gray, belukha, and bowhead whales; polar bears; walruses; and pagophilic seals of particular importance.

The ecological role of marine mammals in the Bering Sea is a complex topic, which is in part addressed in later sections of this report. Effects on the distribution and abundance of prey stocks and related species are likely to be of great importance. In one well-documented instance (Simenstad et al. 1978), the foraging activities of sea otters have been shown to have a dramatic effect on the dynamics and composition of the nearshore community. Gray whales and walruses disturb the bottom during feeding, and their foraging activities may regulate composition of the benthic community in certain areas (Nerini 1981; Oliver et al., in prep.). Ingestion and defecation by walruses result in a substantial redistribution of sediment (Fay et al. 1977). Recycling and redistribution of nutrients in the feces of marine mammals may be of importance to the ecosystem (FAO 1978), as may materials provided by carcasses of dead animals.

9.4 Bering Sea Fisheries

Commercial fishing by the US in the Bering Sea commenced in 1864, when a single schooner fished for Pacific cod, and has steadily developed and diversified since that time. Bakkala et al. (1976) consider that the development of commercial fishing for demersal fish and shellfish in the Bering Sea can be divided into four major periods. The first two are marked by the beginning of the cod and halibut fisheries, the latter of which began in 1930. The third is characterized by the entry of Asian fishing fleets, initially Japan, followed by the USSR, Korea, and Taiwan, into the eastern Bering Sea. The fourth period began in the 1950's, with the development of crab fisheries by the US and Japan. The diversity of fisheries and fishery resources in the Bering Sea is indicated by the number of species of past, present, or potential commercial importance (Table 9.4-1). Each of the major fisheries is briefly described below, based on reviews by Pruter (1973, 1976), Bakkala et al. (1981), Pererya et al. (1976), and Pennoyer (1979).

Regular annual landings of Pacific cod caught in the Bering Sea began in 1882. The North American handline cod fishery peaked between 1915 and 1919, with annual catches estimated at 12,000-14,000 mt, and declined steadily until this type of fishery terminated in 1950. Japanese and USSR trawl fisheries took 47,000 to 75,000 mt of Pacific cod annually from 1968 to 1974.

Halibut in the Bering Sea were initially harvested by a US setline fishery. When Canadian and Japanese fishermen joined the fishery in

Table 9.4-1. Shellfish and fish species harvested in commercial and subsistence fisheries in the Bering Sea (partially adapted from Bakkala et al. 1981).

Species	Commercially harvested: Consistently targeted	Commercially harvested: Occasionally targeted	Commercially harvested: Incidentally caught	Previously targeted	Subsistence harvest	Potentially harvestable
CRUSTACEANS						
Pink shrimp *Pandalus borealis*				X		?
King crabs *Paralithodes* sp.	X				X	
Tanner crabs *Chionoecetes* spp.	X					
Hair crabs *Erimacrus isembekii*		X				
MOLLUSCS						
Octopus *Octopus* spp.			X			
Squids		X				
Snails		X				
Clams					X	X
FISHES						
Skates *Raja* spp.			X			
Pacific herring *Clupea harengus*	X				X	
Salmon *Oncorhynchus* spp.	X				X	

Table 9.4-1, cont.

Species	Commercially harvested Consistently targeted	Commercially harvested Occasionally targeted	Commercially harvested Incidentally caught	Previously targeted	Subsistence harvest	Potentially harvestable
Capelin *Mallotus villosus*					X	X
Rainbow smelt *Osmerus mordax*					X	?
Eulachon *Thaleichthys pacificus*					X	?
Arctic cod *Boreogadus saida*					X	?
Saffron cod *Eleginus gracilis*					X	?
Pacific cod *Gadus macrocephalus*		X				
Walleye pollock *Theragra chalcogramma*	X					
Rattails *Corphaenoides* spp.		X				
Sand lance *Ammodytes hexapterus*						?
Pacific ocean perch *Sebastes aleutus*	X					
Rockfishes *Sebastes* spp.			X			
Sablefish *Anoplopoma fimbrica*	X					
Atka mackerel *Pleurogrammus monopterygius*			X	X		
Arrowtooth flounder *Atheresthes stomias*		X				

Table 9.4-1, cont.

	Commercially harvested					
	Consistently targeted	Occasionally targeted	Incidentally caught	Previously targeted	Subsistence harvest	Potentially harvestable
Rex sole Glyptocephalus zachirus			X			
Flathead sole Hippoglossoides elassodon		X				
Pacific halibut Hippoglossus stenolepsis	X				X	
Butter sole Iopsetta isolepsis			X			
Rock sole Lepidopsetta bilineata		X				
Yellowfin sole Limanda aspera	X					
Longhead dab Limanda proboscidea			X			
Dover sole Microstomas pacificus			X			
Starry flounder Platichthys stellatus			X			
Alaska plaice Pleuronectes quadrituberculatus			X			
Greenland halibut Reinhardtius hippoglossoides	X					

the late 1950's, catches increased drastically from less than 200 to several thousand mt per year. Peak all-nation catches of about 15,000 mt were taken in 1962 and 1963; since that time catches have ranged from about 4,000 to 8,000 mt annually. Substantial incidental catches of halibut are taken in Japanese and Soviet trawl fisheries and in US pot fisheries.

The initial development of the Asian participation in Bering Sea fisheries relied upon abundant stocks of groundfish and the development of "mothership" operations which allowed for the efficient processing, freezing, and transport of such large and comparatively distant resources. Japan began trawling in the Bering Sea in 1930. Following a cessation of fishing during World War II, the Japanese, joined in the late 1950's by the Soviets, developed a major bottomfish fishery. From 1958 to 1963, the principal target species was yellowfin sole, with halibut, sablefish, Pacific ocean perch, and several other species also taken. Following the decline of yellowfin sole stocks and the development of processing techniques for minced fish, the fishery shifted emphasis to walleye pollock, which has been the dominant species since then. The Republic of Korea and Taiwan entered the Bering Sea groundfish fishery in 1968 and 1974. The quantities of each major species caught by all nations from 1954 to 1974 are given in Table 9.4-2.

Fishing for shrimp in the Bering Sea commenced in 1961 and involved Japanese and Russian trawlers. The fishery was intensive in the early 1960's, then rapidly declined to negligible levels by 1972. Japanese catches peaked at about 27,000 mt in 1963; Soviet catch data are not available.

Herring stocks in the Bering Sea have been subjected to subsistence as well as domestic and foreign commercial fisheries. The domestic commercial fishery developed in about 1909 in Norton Sound. Catches have fluctuated greatly, with the highest recorded catch of about 7,300 mt taken in 1978. Development of the foreign fishery for herring in the eastern Bering Sea was in part related to depletion of western stocks, which resulted in closure of that fishery by a bilateral USSR-Japan agreement in 1968. Peak foreign catches of 129,000 and 145,000 mt from eastern stocks occurred in 1969 and 1970. Since 1975, total foreign catches have ranged from 9,000 to 25,000 mt.

Commercial harvesting of king crabs in the Bering Sea was begun by Japan in 1930. Principal development of the fishery was delayed until after World War II; the US fishery began in 1947, Japanese fishing resumed in 1953, and the USSR began taking king crabs in 1959. The combined catch peaked at 9 million crabs in 1964, then declined steadily to 3.5 million in 1971 when the USSR ended their harvests. Japanese harvests terminated in 1974. The entire 1975 harvest of 9 million crabs was taken by US fishermen.

Prior to 1964, eastern Bering Sea tanner crabs were harvested incidentally in the king crab fisheries. The fishery developed rapidly,

Table 9.4-2. Total all-nation catch of groundfish (10^3 mt) in the eastern Bering Sea and Aleutian Island waters, 1954-1974 (from Bakkala et al. 1976).

Year	Pollock	Yellowfin sole[1,2]	Flathead sole[2]	Rock sole[2]	Turbot[2]	Halibut	Pacific cod	Sable-fish	Pacific ocean perch	Other fish	Total
1954	--	13	--	--	--	--	--	--	--	--	13
1955	--	15	--	--	--	+	--	--	--	--	15
1956	--	25	--	--	--	+	--	--	--	--	25
1957	--	24	--	--	--	+	--	--	--	--	24
1958	7	44	--	--	--	3	+	+	+	+	54
1959	33	185	--	--	--	5	4	+	+	+	227
1960	26	493	--	--	--	10	6	2	6	10	553
1961	24	610	--	--	--	14	7	26	47	1	729
1962	60	393	--	--	58	15	10	30	20	43	629
1963	112	114	7	3	29	15	14	18	46	6	364
1964	175	93	22	4	62	5	19	6	118	3	507
1965	231	52	6	4	15	4	17	8	127	4	468
1966	263	94	11	8	21	4	19	14	110	7	551
1967	553	153	29	5	24	7	34	16	80	22	923
1968	707	66	27	6	33	6	64	19	84	42	1,054
1969	871	162	19	10	31	6	53	20	56	37	1,265
1970	1,282	119	42	21	18	7	75	14	79	61	1,718
1971	1,761	157	49	42	36	8	50	19	34	56	2,212
1972	1,876	48	14	62	81	5	47	18	41	147	2,339
1973	1,770	79	18	26	51	4	59	10	17	73	2,107
1974[3]	1,554	43	14	20	70	4	65	7	63	87	1,927

+ Indicates small catches of unknown quantity.
1 Includes catches of some other flounders up to 1963.
2 Soviet catches of flounders were prorated by species based on Japanese catches.
3 Preliminary figures.

due in part to agreements reducing Japanese and Soviet king crab catches. Landings peaked at over 24 million crabs in 1969 and 1970. Soviet harvests terminated in 1971, and Japanese takes were reduced by quotas. The 1976 harvest of 18 million crabs was divided approximately equally between US and Japanese fishermen.

The most recently developed fishery in the Bering Sea is that for snails, which was begun by Japan in 1971. From 1972 to 1975, catches were about 3,000 mt of edible meats, representing 12,000-13,000 mt of snails. Several genera are harvested, including primarily *Neptunea* and *Buccinum*.

Salmon stocks in the Bering Sea have been of great importance in both subsistence and commercial fisheries. Five species are harvested: pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), and king salmon (*O. tshawytscha*). Harvests in Alaska began in the late 1800's, with harvests from the western region dominating from 1878 to 1910. Prior to Alaska statehood in 1959, management procedures were inadequate and allowed the depletion of many stocks. Most have now recovered to former levels of abundance and are managed to insure adequate escapement levels. The development of the Japanese high seas gillnet fishery in the 1960's complicated harvesting and management strategies but is now managed through effective international agreements.

The status of present fisheries of the eastern Bering Sea and Aleutian Islands is summarized in Tables 9.4-3 and 9.4-4. Most of the fisheries operating within the 200-mile FCZ are presently managed by fishery management plans prepared by the NPFMC. The groundfish plan covers a variety of species, including pollock, cod, sablefish, flatfishes, and squid (Table 9.4-4). Stocks of most species are considered healthy. Allowable harvest levels for depleted species (e.g., halibut, rockfishes, and sablefish) are designed to allow recovery of the stocks.

It is not possible at present to accurately predict the future development of Bering Sea fisheries. For the next several years the NPFMC expects to work toward a replacement of existing foreign harvests of species such as tanner crabs and groundfish by appropriate domestic fisheries. No major new fisheries are planned. Draft management plans have been developed for shrimp and clam stocks, but these have not been finalized and implemented. It is presently anticipated that harvests of shrimp, if they occur, will be managed by State of Alaska regulations. A clam fishery in the Bering Sea does not appear economically feasible at this time. Nonetheless, in this report we have considered as potential fishery resources several species which are abundant in the Bering Sea and are harvested elsewhere, including principally shrimp, clams, capelin, and saffron cod.

Table 9.4-3. Present fisheries of the eastern Bering Sea/Aleutian Islands region.

Species/ group	Management regime	Status of stocks	Approximate recent harvests	Participating nations
Halibut	IPHC	low but increasing	450 mt	US, Canada
Salmon Terminal	AK	healthy	30,000 mt	US
Salmon High Seas	INPFC	healthy	40,000 mt	Japan
Herring	NPFMC	healthy	20,000 mt	US
King Crabs	NPFMC	declining	9 million crabs	US
Tanner Crabs	NPFMC	healthy	10,000 mt	US, Japan
Snails	NPFMC	healthy	13,000 mt (whole wt)	Japan
Groundfish	NPFMC	mostly depleted	See Table 9.4-4	US, Japan, USSR, Korea, Taiwan

IPHC = International Pacific Halibut Commission
AK = State of Alaska
INPFC = International North Pacific Fisheries Commission
NPFMC = North Pacific Fisheries Management Council

Table 9.4-4. Estimates of maximum sustainable yield (MSY), acceptable biological catch (ABC), and 1975 harvest levels for groundfish in the eastern Bering Sea/Aleutian Islands region (10^3 mt). From Fishery Management Plan for the Groundfish Fishery in the Bering Sea/Aleutian Islands Area, NPFMC (1979).

Species	MSY	ABC	1975 harvest
Pollock	1,100-1,600	1,000	1719.2
Yellowfin sole	169-260	117	65.8
Greenland turbot and arrowtooth flounder	100	90	89.3
Other flatfishes	44.3-76.8	61	45.3
Pacific cod	58.7	58.7	55.1
Rockfishes	107	21.5	25.2
Sablefish	13.2	5.0	5.0
Atka mackerel	33	24.8	13.3
Squid	$\geq$ 10	10	?
Pacific halibut	5	[a]	1.6
Other included species	89.4	74.2	61.9
Total	1724.6-2348.1	1462.2	1719.5

[a] Determined by International Pacific Halibut Commission.

9.5 Assessment of Biological Marine Mammal-Fisheries Interactions

9.5.1 Documentation of Interactions in the Bering Sea

As one would expect, the earliest observations of stomach contents of marine mammals showed that marine fishes and shellfishes were major items in their diets. However, prior to 1950, few studies of marine mammals documented their foods in any quantitative fashion. In the Bering Sea and North Pacific, Soviet commercial harvests of ice-associated seals provided some data on foods of those species (e.g., Arseniev 1941; Pikharev 1941, 1946; Fedoseev 1965; Shustov 1965; Gol'tsev 1971; Kosygin 1971). Other experimental and opportunistic observations added data on foods of fur seals, sea lions, and harbor seals (e.g., Scheffer and Sperry 1931, Imler and Sarber 1947, Scheffer 1950). Interestingly, although several samples were collected at areas and times when salmon were present, fishes of the cod, herring, and smelt families were usually the major prey. Nonetheless, due to acknowledged direct interactions with salmon fisheries and a perceived competition for resources, harbor seals and sea lions in particular were subject to bounties and control programs to reduce their effects on fisheries (see Mate 1980). Such control programs were terminated by 1970. Further studies of foods of pinnipeds generally confirmed the dietary importance of herring, smelts, and cods (see summaries by Lowry and Frost 1981, Perez and Bigg 1981b, Pitcher 1981).

General information on foods of cetaceans became available with the examination of animals taken in commercial harvests (e.g., Tomilin 1957, Zimushko and Lenskaya 1970). This has been supplemented by examination of animals, particularly small cetaceans, which were taken by subsistence hunters (e.g., Seaman et al., in prep.), caught in fishing gear (e.g., NMML 1981a), or washed up dead on shore (Scheffer 1953). In general, zooplankton, squids, and small schooling fishes have been found to be the major prey of cetaceans, and, given the offshore distribution of most species and their observed foods, interactions with fisheries have appeared slight. A notable exception involves belukha whales in Bristol Bay. There, a systematic study (Brooks 1954, 1955, 1956; Lensink 1961) documented the consumption of adult and smolt salmon by belukhas in the Kvichak and Nushagak River estuaries. Calculations indicated that belukhas consumed 2.7% of the sockeye runs in 1954 and 1.0% in 1955, which was considered significant, especially in light of the depleted status of stocks. This led to the development of a nonlethal acoustic system which was used to displace the whales from the rivers at critical times (Fish and Vania 1971). With improved management and recovery of sockeye stocks, use of this system has been discontinued.

Major changes in the pattern of exploitation of Bering Sea fish stocks occurred during the period following the end of World War II (see section 9.4 and Bakkala et al. 1981), of which the development of the groundfish fishery is probably most significant. The aggregate catch of groundfish by all nations increased from 12,500 mt in 1954 to over 2.2 million mt in 1972; the 1972 harvest was 176 times greater than that in 1954. In addition, due at least in part to depletion of stocks of other target species (Pruter 1973), the percentage of pollock in the harvest increased from 0 to 83% during that period (Bakkala et al. 1981). This increase in finfish harvests from the Bering Sea can be partly attributed to human population increases and reduction in the the catch of whales, which have been used as a source of protein and other products, particularly by Japan and the Soviet Union. The percentage (by weight) of whales in the world marine resource harvest decreased from 10.2% in 1949-50 to about 1% in 1973-74 (FAO 1978). This decrease is due both to decreased whale catches and to increased harvests of other marine resources.

The increased harvests of Bering Sea groundfish, particularly pollock, and the improved data base on marine mammal foods suggested a major potential competition for resources (McAlister and Perez 1976, Lowry et al. 1979). Frost and Lowry (1981) documented the presence of pollock in the diet of 11 species of marine mammals and 13 species of seabirds. Calculations by McAlister and Perez (1976) indicated that 2,853,000 mt of finfish were consumed annually by pinnipeds in the Bering Sea, an amount considerably in excess of the harvest by fisheries. Two questions could then be formulated, each of which could be applied either specifically to pollock and their predators or to the entire suite of Bering Sea marine mammals and fisheries. First, is predation by marine mammals impacting the harvests that can be taken by commercial fisheries? Second, is the take by commercial fisheries affecting food availability and therefore population status of marine mammals?

The magnitude of consumption of commercial fish resources by Bering Sea marine mammals is without doubt substantial (McAlister and Perez 1976, McAlister 1981). In fact, food consumption by marine mammals has been judged significant enough that levels of apex predator consumption (including marine mammals, birds, and elasmobranchs) have been used as primary inputs for a dynamic numerical ecosystem model (DYNUMES) of the Bering Sea (Laevastu and Favorite 1977). Predation by marine mammals has not been recognized as a factor resulting in the depletion of commercially important fish stocks. Thus, it has not been included in the model as an interactive variable in fish stock fluctuations, which have instead been considered as regulated by fisheries, environmental factors, and lower trophic level interactions. Observations of sea otters in California (Lowry and Pearse 1973) and walruses in the Bering Sea (Fay and Lowry 1981) demonstrate the ability of those species to deplete at least local stocks of fishable resources, which in these cases are benthic invertebrates. Calculations by Winters and Carscadden (1978) for North Atlantic capelin have assumed that potential yields to fisheries are a direct function of marine mammal abundance.

The question of the effect of fisheries on marine mammals is more complex and is supported by a less well developed array of observations, data, and theory. In order to postulate that the actions of a fishery affect populations of marine mammals, four criteria must be met.

First, the removals of forage species by the fishery, in combination with other predators, must affect forage stocks differently than predation alone. Second, changes in forage abundance must affect intake of food by marine mammals. Third, a change in food intake must result in a change in vital parameters (e.g., growth, survival, reproduction) of individual marine mammals. Fourth, changes in individual parameters must affect population parameters such as abundance and productivity. If these four linkages must be established in order to conclusively demonstrate the existence of a significant interaction between marine mammals and fisheries in the Bering Sea, such interactions have not been documented. Instead, however, attempts have been made to correlate observed population characteristics of marine mammals with observed fisheries or presumed changes in fish stock characteristics. Such studies dealing with fur seals (Swartzman and Haar 1980) and sea lions (Braham et al. 1980a) have not succeeded in conclusively documenting causal relationships.

Despite the lack of adequate documentation for the Bering Sea, information from other areas suggests that marine mammals may respond to changes in their food supply. The evidence is based on the assumption that a reduction in population size of the principal or competing species changes the relationship of the population to its food resources in such a way as to eliminate or reduce the effects of food limitation. Populations should then respond to increased food availability by increased productivity and/or survival, and, in the absence of continued excessive harvesting, the population size should increase. In the North Atlantic, a reduction of the harp seal population during 1952 to 1972 was accompanied by a significant increase in fertility rate (from 85 to 94%) and decrease in mean age at maturity (from 6.5 to 4.5 years) (Bowen et al. 1981). These responses should have increased productivity, and indeed the population size has increased in spite of continued harvesting. A second example involves the antarctic ecosystem, where a single species of krill (Euphausia superba) is the principal food of many species of birds and marine mammals. Recent increases in populations of several krill predators, including penguins (Aptenodytes patagonica and Pygoscelis spp.), minke whales, crabeater seals (Lobodon carcinophagus), and fur seals (Arctocephalus spp.), are thought to be the result of an increase in availability of krill brought about by the reduction of large whale populations which had formerly consumed great quantities of that species (Laws 1977).

Thus, the available information suggests that populations of some marine mammal species can be limited by food availability and that individual and population parameters will respond to changes in levels of available food. It must be noted that the important factor is the relationship between abundance of predator and prey populations rather than the absolute size of either. That is, a reduction in a marine mammal population while abundance of prey remains constant would have a similar effect to enhanced prey abundance with a constant mammal population. In order to facilitate such considerations, many investigators have found it useful to consider this relationship in terms of per capita food availability. Ultimately, of course, the question is one of energetics as measured by the energy derived from a prey item compared to the energy expended to locate, capture, and process it.

9.5.2 Existing Methods for Assessment of Interactions

9.5.2.1 Conceptual and Correlative Assessments

In the absence of numerical data on functional relationships within the Bering Sea ecosystem, a conceptual evaluation of the probable magnitude of marine mammal-fishery interactions can be made using information on the occurrence of commercial species of fishes in marine mammal diets and a general understanding of trophic relationships. Use of conceptual food chain models was suggested by Hammond (1980) as a first step toward ecosystem-based fishery and marine mammal management. Evaluations of marine mammal-fishery interactions based on descriptive food habits data have been presented by Lowry et al. (1979), Fiscus (1979, 1980), and Frost and Lowry (1981), and preliminary food webs involving Bering Sea pinnipeds have been presented in Lowry and Frost (1981).

Conceptual evaluations can be refined somewhat by using estimates of the quantitative composition of the diet of marine mammal species. Such calculations have been made using two somewhat different techniques. Estimates by McAlister and Perez (1976) required the following data inputs for each marine mammal species:

1) population size, summer and winter
2) weight of an average individual
3) average daily food consumption as a proportion of total body weight
4) average annual proportion of prey species in the diet

Estimates in a draft paper by McAlister (1981) allow two major refinements:

1) average individual weight is based on age structure of the population and the relationship between weight and age
2) food intake is based on estimated energetic requirements of marine mammals and caloric values of prey. In addition, differential summer and winter diet compositions are incorporated where data are available. (However, McAlister derived his energetic requirements equation from captive marine mammal studies, using data for species not found in the Bering Sea; and winter diet compositions for otariids are estimates based on summer diet compositions.)

Required inputs are:

1) population size, summer and winter

2) age structure of the population
3) age-weight relationship
4) relationship between energy requirement and body weight
5) relationship between temperature and energy requirement
6) caloric values of prey
7) average annual (or winter and summer) proportions of prey in the diet

Using results of such calculations, comparisons can be made of the importance of various fish species in marine mammal diets and in commercial harvests.

A further possible method of evaluating marine mammal-fishery interactions in the Bering Sea involves correlations of changes in individual and population parameters of marine mammals with changes in fishery activity or fish stock abundance. The difficulty of establishing such correlations is demonstrated by the lack of definitive effects that can be deduced from the extensive data base available on fur seals and Bering Sea fisheries (Swartzman and Haar 1980) and on harp seals in the North Atlantic (Bowen et al. 1981). It should be noted, however, that to date specific studies designed to detect such correlations have not been conducted. Obviously, such studies will require careful documentation of fishery harvests and the characteristics of fish stocks, including abundance, distribution, and size class composition.

9.5.2.2 Existing Modeling and Simulation Efforts

More useful for resource managers and other concerned parties would be the ability to simulate or predict the effects of harvesting strategies on populations of predators and their prey. The basic question being asked is how the sustainable yield available from marine resources is to be apportioned among fisheries and predators (marine mammals, seabirds, and others) and the resultant effects on the predator populations and fishery yields.

Several models are available, at least in developmental stages, which address ecosystem level interactions in areas of significant commercial fisheries. These include a North Sea simulation model, a multi-species estuarine model (GEMBASE), a North Atlantic model (Havbiomodeller), and a complex of models dealing with the North Pacific and Bering Sea (Bulk Biomass Model (BBM), Prognostic Bulk Biomass Model (PROBUB), and Dynamic Numerical Ecosystem Simulation (DYNUMES)) (Larkins 1980). We will consider in detail only the latter model, developed at the Northwest and Alaska Fisheries Center, since it deals with the Bering Sea and includes some consideration of marine mammals.

DYNUMES was built to show the effects of different levels of intensity and regional targeting by fisheries on fish stock abundance. As such, it is only peripheral to the question of marine mammal-fishery interactions since it does not consider how changing fish abundance affects marine mammal consumption and diet. In fact, DYNUMES uses the average consumption by Bering Sea marine mammal, bird, and elasmobranch populations to drive the model. Initial fish stock estimates in DYNUMES are set by running a spatially averaged version of DYNUMES called PROBUB in diagnostic or equilibrium mode (BBM). In this equilibrium mode, top predator consumption and average fishing harvest rates are imposed on initial estimates of fish species biomasses which are then altered in BBM until the consumption rates, average growth rates (represented as biomass growth rates which are dependent on the average age composition of each fish species and the species-specific growth rate computed in a model called BIODIS), and average diets balance with the constant predator consumption and fishing harvest to produce an unchanging, equilibrium mix of fish species.

DYNUMES then starts with these initial fish stocks regionally allocated according to relative abundance as computed from fishing surveys and projects the future abundance and regional distribution of the stocks as they respond to changing temperatures and fishing pressure and <u>unchanging</u> predator consumptions (which are imposed by region). The complexity of the DYNUMES model implemented on the Bering Sea results from the large number of regions (up to 1,000 and generally more than 100) considered. On top of all the diet and consumption paraphernalia in DYNUMES, migration and alteration of growth rates due to high fishing mortality or starvation mortality are also considered. The time step in DYNUMES is 1 month, although the fish migration algorithm may use a smaller time step to assure more stability.

It is clear that DYNUMES does not address the question of marine mammal-fishery interactions. It cannot do so in its present form because it uses estimates of marine mammal consumption and population sizes as constant driving variables, taking a fixed consumption "off the top" despite possible food limitation and competition from other variables. The authors of DYNUMES have presumed that there is no feedback between marine mammals and their fish prey and that in fact fish stock abundance is almost entirely controlled by the marine mammal and bird populations in the Bering Sea. To alter this assumption would require an alternative method to the BBM for computing fish stocks for DYNUMES. In fact, fish stock estimates for the Bering Sea have been estimated by Niggol (1978) using output from the BBM and the assumption that the level of fish stocks is set by the marine mammal and fish population levels and average consumption rates. Nonetheless, a model such as DYNUMES, although perhaps somewhat simplified and modified to include mammal consumption as a dynamic factor, could be used to assess the effects of fisheries and predators on fish stocks.

Other, somewhat simpler types of multispecies and ecosystem-level models have been developed which may be of relevance in examination of marine mammal-fishery interactions. For the antarctic and California current ecosystems, Green (1977, 1978) has constructed compartment models with annual biomass budgets relating the producer and consumer components of the ecosystems. Although quite simplified in many assumptions, such models may be of value in predicting the direction of average changes caused by biomass perturbations at various trophic levels. The utility of such models is limited by the fact that they do not consider characteristics of individual species and the responses of those species to changes in trophic status.

May et al. (1979) have produced models of possible value in devising management schemes for multispecies fisheries. These models depend on the solution of a series of differential equations describing the dynamics of predator and prey populations and can investigate the effects of harvesting on potential yields at various trophic levels. Major assumptions of this type of model are:

1) prey and predator populations are both resource limited
2) prey are consumed at a rate proportional to their density
3) yield to fisheries is proportional to fishing effort and stock density
4) competition among predator species is simple and indirect and depends only on the intensity of combined predation

A model with such simplified assumptions cannot precisely simulate effects of fisheries on marine mammals since it does not account for the actual responses of feeding strategies and individual and population parameters to changing food availability. However, as stated by May et al. (1979), such a "crude caricature of multispecies systems aims to create a basic framework that can be readily understood and that provides insight into the essential scientific problems." As they demonstrate in a consideration of complex ecosystems, their model may explain or predict unexpected effects of harvesting.

9.5.3 Suggested Development of Models

We have formulated the question of marine mammal-fisheries interactions in terms of four composite questions, which taken together address the overall topic while breaking it down into manageable and largely separable units. A major advantage of this breakdown is that information and experience gained in the process of answering each question will also be of value in designing and interpreting conceptual and correlative assessments described in section 9.5.2.1. These questions are considered from the standpoint of how models can prove useful in answering them. These models are organized according to level of detail and comprehensiveness. Generally, they range from models addressing the question from an empirical standpoint to those considering mechanistic hypotheses that can be used to explain or produce a given phenomenon in the model.

The four questions are:

1) How do fisheries and marine mammal (and other top predator) consumption affect the abundance and composition of stocks of

target species and prey?

2) How are the quantities and kinds of prey consumed by marine mammals affected by changes in prey density and composition of prey stocks?

3) What is the effect of a change in food intake (or metabolic status) on individual marine mammal parameters such as growth, maturation, and survival?

4) How do changes in parameters of individuals affect future marine mammal populations?

Since the data review in this report focused only on marine mammal information, question 1, which requires an examination of the combined effect of mammal consumption and fishing, will not be emphasized. Swartzman and Haar (1980) have examined the Bering Sea fish data base with respect to its utility for assessing fur seal-fishery interactions.

Question 1 - Effects of Fisheries and Predation on Stocks of Target Species and Prey.

Level 1

The simplest treatment of this question estimates prey removal by each marine mammal species using the average ration and diet and estimated Bering Sea population biomass, as was done by McAlister and Perez (1976) and McAlister (1981). This can be added to removals by fisheries as indicated by catch statistics.

Level 2

At this level the reproductive and growth capacity of the prey are included by dividing the prey species into size classes treated as dynamic pools (each size class is represented by an average size which all individuals in that class are assumed to have). Maturation and reproduction depend on the number of individuals in the juvenile and adult pools, respectively. Mortality is induced in the prey through size class specific removals by mammals and by the fishery. Natural mortality, which includes predation by other fishes, is also size class specific. At this level no interactions between fish species are explicitly considered.

Level 3

At this level interactions among the prey are considered, including such factors as predation, cannibalism, and food competition. Fish and other prey may compensate for heavy predation by changing their growth rates, their behavior (e.g., schooling characteristics, escape response, etc.), or their population parameters (e.g., age of maturity).

Some of these characteristics are included in the DYNUMES model which was discussed in section 9.5.2.2. While looking at the fish species at level 3, treatment of marine mammal consumption is based only on a static consideration of amounts consumed (although regional differences in mammal populations are considered).

Question 2 - Responses of Marine Mammal Consumption to Changes in Prey Stocks.

A number of alternative hypotheses have been proposed to account for how changing prey abundance and size and species composition affect consumption and diet of different predators. These include: 1) the optimal foraging hypothesis that predators take prey to maximize the caloric value per unit feeding time (Charnov 1973, Eggers 1975); 2) the hypothesis that reduced average prey abundance results in diminished per animal ration which drops as a Michaelis (hyperbolic) or Ivlev (negative exponential) function of total prey density (Ivlev 1963, Andersen and Ursin 1977); 3) that predators are size selective in their feeding (Andersen and Ursin 1977), such that preference for prey depends on the relative size of a predator and its prey; and 4) that when prey abundance is low predators compensate by migrating (Laevastu and Favorite 1978) or by changing their feeding behavior (resulting in altered prey preferences).

These hypotheses suggest mechanisms of how predators respond to changing prey abundance, and the models derived are thus mechanistic (as opposed to empirical). As such, they are more speculative than the empirical constructs and require different kinds of data and experiments for their corroboration. There is more than a single hypothesis available to explain the observed phenomenon of changing diets with changing prey abundance.

Another important aspect of prey abundance is the effect of prey distribution and patchiness (schooling) on consumption. Beyer (1976) and Vlymen (1977) have shown that consumption rates of fishes are highly dependent on the patchiness of their prey. Haar and Swartzman (1982) have demonstrated that assuming average prey densities biases the ration computation when the prey are patchily distributed. Most, if not all, marine mammals are opportunistic predators, and their methods for prey location are not well understood. It is clear, however, that they engage in more than simple random search, which is the only case considered so far in models. Thus, for want of a clear hypothesis for marine mammal prey location methods, no model representing the effects of prey schooling on ration can be considered here.

Question 3 - Effects of a Change in Food Intake on Parameters of Individual Marine Mammals.

Level 1

This level is an empirical model relating some measure of food intake (e.g., blubber thickness or blubber weight as a fraction of body weight) with some individual parameter (e.g., pregnancy probability, age at maturation, or pup mortality).

At this level, empirical evidence is used in a quantitative fashion to suggest a relationship between ingestion and population parameters. For example, evidence that intensive harvest of harp seals has led to a reduction in the age at maturity (presumably through increased ingestion rates) would be included here. Since these data are always incomplete (there are usually no direct ingestion data available), the correlations are indirect and thus of less value for answering this question.

Level 2

This level involves a model based on hypotheses about how changed ingestion rates for an individual could lead to changes in values of vital parameters of that animal and its progeny. The model would consider this question on an energetics basis and would investigate how a single animal (it could be run many times with animals of different weights and ages) with a known (and changeable) ingestion rate allocates energy derived from assimilated food to blubber, lean body mass, and reproduction. Alternate hypotheses for this allocation are: 1) a constant allocation among blubber, reproduction, and lean body mass; or 2) as above, except that when blubber thickness is below a threshold all ingestion goes to blubber, and reproduction is aborted or does not proceed. A hypothesis for determining where energy comes from (i.e., metabolism of blubber or muscle) when metabolic demand exceeds that obtained through ingestion is also needed.

This model can consider such factors as age at maturation, probability of successful reproduction, weight at age, and the probability of survival for the animals in question. Weight at age is a natural output from this model. Age at maturation can change if maturation is made size (weight) and not age specific. To consider the probability of survival and reproductive success, some hypothesis about how these factors are affected by condition of the animal is needed. Animal condition can be related to energetics by using blubber thickness or the ratio of blubber to lean body weight. A condition threshold below which reproductive success and survival probability drop is a plausible initial hypothesis to test within this model. The feasibility of the above hypothesis may be tested, for example, by taking a sample of female seals and correlating blubber thickness with pregnancy.

Question 4 - Effects of Changes in Individual Parameters on Marine Mammal Populations.

Level 1

The effect of changes in the age at maturity, birth probability (birth rate), survival probability (mortality rate), and weight at age on the population age structure can be investigated using a Leslie matrix model (Leslie 1945). This can also be combined with a consideration of the direct effects of harvests on the marine mammals (York and Hartley 1981).

Level 2

By using a Monte Carlo simulation of the model described in level 2, question 3, hypothetical populations of mammals can be generated with a variety of ingestion rates. By running these models for simulated time periods, the changes in the age and size composition of the population through time can be observed. Also, trends in ingestion such as slowly increasing or decreasing ingestion rates can be considered. Unlike level 1, this level does not assume a constant relationship between ingestion rate and population parameters but one that can change with time.

We want to emphasize that all four questions need consideration in order to completely examine marine mammal-fishery interactions. Furthermore, a certain level of model detail is necessary before the most probable links between marine mammals and fisheries can be explored. Thus, calculations of amounts of prey consumed by marine mammals really do not address marine mammal-fishery interactions except to give a general measure of their relative fish consumption. The key question regarding marine mammal-fishery interactions is whether reduced prey density for some marine mammal species will affect its consumption, as Andersen and Ursin (1977) hypothesize for fish, or whether marine mammals take their food "off the top" despite reduced abundances of prey, as Laevastu and Favorite (1978) assumed in DYNUMES. Estes (1979) discusses the question of whether or not marine mammals are food limited and finds fairly conclusive evidence that such is the case only for the sea otter. Examples discussed in section 9.5.1 suggest that food limitation has occurred in some areas. Certainly with a serious enough food shortage the energy intake of mammals must be affected. There is evidence that this is already happening in the Bering Sea with the walrus, which now shows significantly decreased blubber thickness (Fay and Kelly 1980).

Only if a link between the density and stock composition of prey and the diet composition and ingestion rate of marine mammals is established, or is distinctly possible, will questions 3 and 4 be worthwhile examining. Thus, the consideration of question 2 is of supreme importance in the sugggested model hierarchy.

10.0 METHODS

10.1 Literature Search

Four major sources were used for obtaining literature and information on foods and status of Bering Sea marine mammals. Those were:

1. Computerized literature searches
2. Literature in files of State and Federal agencies and those of the principal investigators
3. Bibliographies on marine mammals
4. Direct contacts with marine mammal scientists

The principal investigators have participated in an OASIS (Oceanic and Atmospheric Scientific Information System) SDI (Selective Dissemination of Information) program since 1976. Several data bases, including Biological Abstracts, Bioresearch Index, and Oceanic Abstracts, are automatically searched each month for any citations relating to marine mammals, fishes, and invertebrates in Alaska, other arctic regions, and the North Pacific. A listing of between two and 30 citations has been received each month, and those relative to Bering Sea marine mammals have been included in this report. In addition, in July 1981 we initiated a literature search on Bering Sea marine mammals with the Fish and Wildlife Reference Service of the Denver Public Library. This organization specializes in published and unpublished reports of research emanating from the Federal Aid in Fish and Wildlife Restoration Program and the Cooperative Fishery and Wildlife Units. A total of 112 references was obtained from the search, and relevant ones were annotated and included in the bibliography.

Much of our initial effort was directed to cataloging and annotating information in files of the principal investigators and other ADF&G marine mammal biologists. Those files contained relatively complete collections of literature on walruses, sea otters, polar bears, harbor seals, sea lions, belukha whales, and ice-inhabiting seals. In addition, a complete search was done of the reprint files at the NMFS, NMML. The references obtained there provided much of the available information on fur seals and cetaceans.

Several major bibliographies on marine mammals were used as sources of relevant citations (Table 10.1-1). We also used the lists of translations available from the Fisheries and Marine Service of Canada Translation Series.

In order to uncover as many obscure references as possible, we wrote immediately after finalization of the contract to a number of scientists working on Bering Sea marine mammals. Each of the people listed in Table 10.1-2 was sent a letter requesting copies of publications dealing with food habits, food requirements, and population status of Bering Sea marine mammals, as well as an inventory of any

Table 10.1-1. List of major bibliographical sources.

Gold, J. P. 1981. Marine mammals: a selected bibliography.

Kajimura, H. 1981. Selected references - pelagic sealing.

Magnolia, L. R. 1972. Whales, whaling and whale research: a selected bibliography.

Romanov, N. S. 1959. (Annotated bibliography on far eastern aquatic fauna, flora and fisheries).

Ronald, K., L. M. Hanly, P. J. Healey, and L. J. Selley. 1976. Annotated bibliography on the Pinnipedia.

Severinghaus, N. C. 1979. Selected annotated references on marine mammals of Alaska.

Severinghaus, N. C. and M. K. Nerini. 1977. An annotated bibliography on marine mammals of Alaska.

Table 10.1-2. List of scientists contacted with regard to information on Bering Sea marine mammals.

Japan

Dr. Takeyuki Doi - Tokai Regional Fisheries Research Laboratory
Dr. Mitsuo Fukuchi - National Institute of Polar Research
Dr. Yoshio Fukuda - Far Seas Fisheries Research Laboratory
Prof. Takeo Hoshiai - National Institute of Polar Research
Dr. Tadayoshi Ichihara - Tokai University
Dr. Tetsuo Inukai - University of Hokkaido
Dr. Toshio Kasuya - University of Tokyo
Dr. Akito Kawamura - Hokkaido University
Mr. Saburo Machida - Japan Marine Resources Research Center
Dr. Yasuki Masaki - Far Seas Fisheries Research Laboratory
Mr. Nobuyuki Miyazaki - National Science Museum, Natural History Institute
Dr. Kazuhiro Mizue - University of Tokyo
Dr. Yasuhiko Naito - National Institute of Polar Research
Dr. Masayuki Nakajima - Izu-Mito Sea Paradise
Dr. Keiji Nasu - Japan Marine Resources Research Center
Dr. Takahisa Nemoto - University of Tokyo
Dr. Masahura Nishiwaki - University of the Ryukyus
Dr. Seiji Ohsumi - Far Seas Fisheries Research Laboratory
Dr. Hideo Omura - The Whales Research Institute
Dr. Tervo Tobayama - Kamogawa Sea World
Dr. Kazuo Wada - Kyoto University
Dr. Shiro Wada - Far Seas Fisheries Research Laboratory
Dr. Kazumota Yoshida - Far Seas Fisheries Research Laboratory

United States

Dr. William Aron - NMFS, Northwest and Alaska Fisheries Center
Dr. Robert L. Brownell - U.S. Fish and Wildlife Service
Dr. James A. Estes - U.S. Fish and Wildlife Service
Mr. Clifford H. Fiscus - NMFS, Northwest and Alaska Fisheries Center
Mr. Ancel M. Johnson - U.S. Fish and Wildlife Service

---

new or unanalyzed collections of material of which they were aware. Similar requests were transmitted to Soviet scientists via a State Department telegram sent on 17 July 1981.

10.2 Summarization of Available Data

Critical to the successful completion of this project was the organizational framework for cataloging and filing of literature. Each reference located was classified with respect to marine mammal species included, geographical location, subject matter, reference type, and literature source (Table 10.2-1). The area of specific interest in this project (Bering Sea and Aleutian Islands) was divided into eight regions (Figure 10.2-1), based primarily on the geographical breakdown used in previous reports on Bering Sea marine mammal foods (Frost and Lowry 1980, Lowry and Frost 1981). Citations with accompanying annotations were typed on edge-punch cards and simultaneously entered into a word-processing system with magnetic diskette storage (Lexitron Model VT 1303). This system allowed efficient retrieval of all cataloged information sorted by species, area, subject, etc. In addition, citation cards were filed alphabetically by author to facilitate determination of whether any particular reference encountered had previously been located and processed. Research summary files, which included for each reference the citation, annotation, and a summary of other relevant information, were also created with information filed alphabetically by author.

The majority of papers we located relating to foods and status of Bering Sea marine mammals were either published in English, had accompanying English abstracts or summaries, or had previously been translated. In instances where such was not the case, an initial determination of the relevance of articles was made based on translation of titles and, where necessary, abstracts. Translations of Japanese titles were done by Dr. Hiro Kajimura (NMFS, NMML). Russian-language titles and abstracts were translated by Mr. John Burns (ADF&G) and Mr. Kenneth Coyle (UA, IMS). Several articles in Russian (Table 10.2-2) were selected for complete translations, which were done by K. Coyle. Complete copies of those translations will be made available on request.

One objective of this project was to inventory new or unanalyzed collections of material or data relative to feeding and status of Bering Sea marine mammals. Such an inventory was requested from each of the scientists contacted (Table 10.1-2). Special attention was given to three groups which have recently been active in research on Bering Sea marine mammals: ADF&G, the University of Alaska Institute of Marine Science, and the NMFS National Marine Mammal Laboratory. Information received has been included in section 11.0.

In the summarization of available data, it was necessary to anticipate the utility of various kinds of information for assessment of interactions between Bering Sea marine mammals and fisheries. This

Table 10.2-1. Information categories used to catalog reference material.

Species

1. Sperm whale
2. Killer whale
3. Baird's beaked whale
4. Stejneger's beaked whale
5. Cuvier's beaked whale
6. White whale
7. Harbor porpoise
8. Dall's porpoise
9. Fin whale
10. Minke whale
11. Blue whale
12. Sei whale
13. Pacific right whale
14. Humpback whale
15. Gray whale
16. Bowhead whale
17. Northern fur seal
18. Steller sea lion
19. Harbor seal
20. Spotted seal
21. Ribbon seal
22. Ringed seal
23. Bearded seal
24. Pacific walrus
25. Sea otter
26. Polar bear

Literature Source

1. English
2. Soviet
3. Japanese

Reference Type

1. Review article
2. Major work
3. Anecdotal
4. Bibliography

Geographical Location

1. Bering Sea (general)
2. Northeastern Bering Sea
3. Central Bering Sea
4. Southcentral Bering Sea
5. Southeastern Bering Sea
6. Northwestern Bering Sea
7. Southwestern Bering Sea
8. Western Aleutians
9. Eastern Aleutians
10. Gulf of Alaska
11. Beaufort Sea
12. Chukchi Sea
13. Washington
14. Oregon
15. California
16. North Pacific
17. North Atlantic
18. South Pacific
19. South Atlantic
20. Antarctic
21. Western Canadian Arctic
22. Eastern Canadian Arctic
23. Siberian Arctic

Subject

1. Foods
2. Food requirements
3. Distribution/migration
4. Density/numbers
5. Age structure
6. Reproductive biology
7. Population size/status
8. Methodology
9. Interactions with fisheries
10. Simulation models

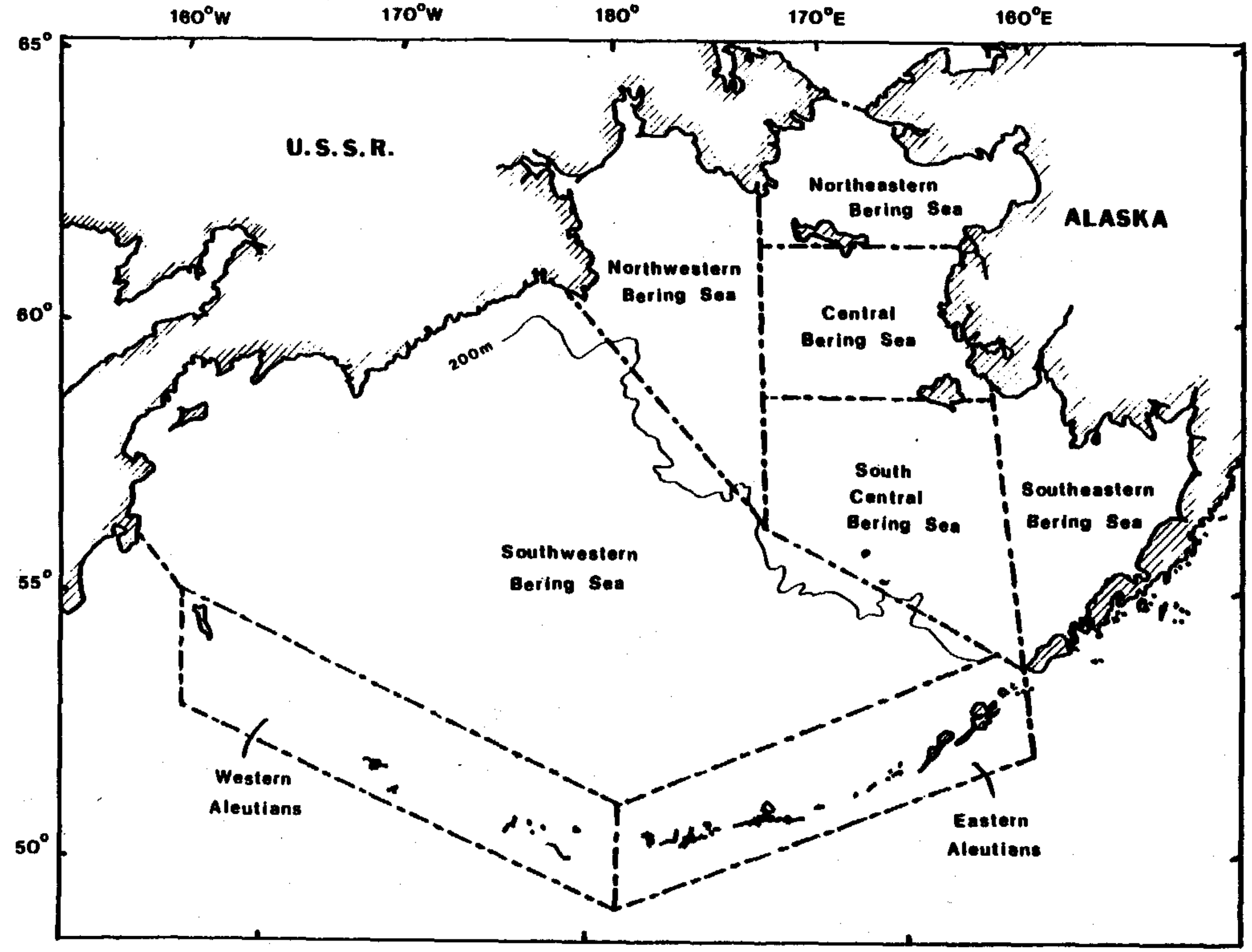

Figure 10.2-1. Subdivisions of the Bering Sea and Aleutian Islands region.

Table 10.2-2. List of Soviet articles translated for this project.

Akimushkin, I. I. 1955. (On the food characteristics of the sperm whale). Doklady Akad. Nauk SSSR 101:1139.

Klumov, S. K. 1956. (Some results of the expedition to the Bering Sea and the Kuril Islands). Bull. Acad. Sci. USSR 5:33-37.

Klumov, S. K. 1961. (Plankton and the diet of baleen whales (Mystacoceti)). Tr. Inst. Okeanol. 51:142-156.

Pikharev, G. A. 1941. (Some data on the feeding of the far eastern bearded seal). Izv. TINRO 20:101-120.

Sleptsov, M. M. 1952. (Bowhead whales). Pages 122-124 in M. M. Sleptsov, ed. (Cetaceans of the far eastern seas). Izv. TINRO 38.

Tarasevich, M. N. 1968. (Food relationships of the sperm whales in the northern Pacific). Zool. Zhur. 47:595-601.

Tarasevich, M. N. 1968. (Dependence of distribution of the sperm whale males upon the character of feeding). Zool. Zhur. 47:1683-1688.

Zimushko, V. V. 1971. (Material on the reproduction of gray whales). Tr. Atlant. NIRO 39:44-53.

---

was based primarily on the discussion of assessment techniques given in section 9.5. Information categories established were as follows:

1. Population status

    a. Distribution
    b. Abundance
        a. present
        b. trends over time
    c. Size, growth rates, and condition measures
    d. Age at sexual maturity
    e. Reproductive rates
    f. Mortality rates
    g. Sex and age structure

2. Diet composition

    a. Description of available samples
    b. Seasonal and regional diets
    c. Age-related dietary differences
    d. Sex-related dietary differences
    e. Prey selection and feeding strategy

3. Food requirements

    a. Daily or annual rations
    b. Energetic requirements

For each of the above categories, all information of direct relevance to each particular species in the Bering Sea was summarized and is presented in section 11.0. Where information directly relevant to the Bering Sea was scant or nonexistent, data from other areas have generally been included, if available.

10.3 Evaluation of Available Data

10.3.1 Utility

An evaluation of utility of data obviously depends on the uses for which the data are intended, which in this case is the assessment of biological interactions between Bering Sea marine mammals and fisheries. As should be obvious from the review of the subject in section 9.5, no single, synoptic method for making such an assessment is presently available. Therefore, it has been necessary to organize and consider possible methods of assessment prior to evaluation of the data base. We suggest that possible assessments belong to three major categories.

1. <u>Conceptual assessments</u> in which general information on marine mammal feeding and population status is combined to assess

the likelihood of significant interactions with present or proposed fisheries.

2. Correlative assessments in which changes in population status are correlated with changes in characteristics of fish stocks or fisheries to determine if interactions have occurred.

3. Predictive assessments in which information on functional interrelationships among ecosystem components are used to investigate the effects of changing levels of fishing pressure and marine mammal predation on fish stocks, fishery yields, and marine mammal populations.

Only information of possible utility for one or more of these categories has been reviewed and summarized in this report. The evaluation of utility of the data base therefore becomes a matter of determining the data required for each type of assessment, whether or not the required data are available, and how difficult missing data will be to acquire. This is done in section 12.2.

10.3.2 Reliability

Part of one of the objectives of this project was an evaluation of the reliability of available data. Although the specific meaning of reliability in this context was not elucidated in the request for proposals or contract for this project, we consider reliability to include at least three major components. First is the question of whether the data and conclusions drawn from them are accurate indications of actual conditions in the environment. To adequately make such an evaluation for a single piece of information requires 1) an examination of the data in their raw form, 2) knowledge of the exact conditions under which they were collected, 3) knowledge of the exact techniques used to collect and analyze the data, and 4) the competency and carefulness of the persons collecting, analyzing, and interpreting the data. To do this for the entire data base on Bering Sea marine mammals is clearly beyond the scope of this project. In fact, since the required pieces of information are rarely presented in available publications, a thorough evaluation of this aspect of reliability is impractical, if not entirely impossible.

The second major aspect of reliability is concerned with precision; that is, how much unexplainable variability is associated with data collected and calculations or extrapolations made from the data? Examination of variability in the data base requires the application of statistical techniques to raw data which, as noted above, were generally not available to us. In instances where statistical confidence limits for parameters have been published, they have been noted and are discussed in section 12.1 in terms of the significance of the variability with respect to assessment of marine mammal-fishery interactions.

The third major aspect of reliability concerns whether available data are adequate to allow extrapolations from samples to the population as a whole or to other segments of the population. No rigorous techniques are available with which to analyze this factor. A subjective evaluation can be made based on observed within- and between-sample variability; geographical, seasonal, and age- and sex-related variability; and general biological characteristics of each species, where such information is available. Available information on these topics is summarized in section 11.0, and a subjective evaluation of this aspect of reliability will be implicit in our determination of availability and utility of data. If the data for a particular characteristic of a given species are considered adequately available for assessment of marine mammal-fishery interactions, that implies that we consider the data of adequate reliability for that purpose.

10.4 Identification of Data Gaps

The existence and significance of data gaps depends on the type of assessment of marine mammal-fishery interactions being considered. The identification of data gaps resulted from the examination of availability of data for various types of assessments given in section 12.1 and the utility of data as discussed in section 12.2. Major data gaps are summarized and discussed in section 12.3.

10.5 Prioritization of Proposed Research

Prioritization of proposed research was done both by topic and species. Prioritization by topics (e.g., relationship between prey abundance and mammal consumption, or effect of ingestion rate on growth and reproduction) was based on the utility of the information that will be produced for refining possible assessments of marine mammal-fishery interactions. For example, topics which will produce information of immediate value for conceptual assessments and of future value for predictive assessments would be given a higher priority than topics of value only for predictive assessments. Prioritization by species is based on a conceptual assessment of the likelihood of significant interactions with fisheries, given in section 12.2.1.

11.0 SUMMARY OF AVAILABLE DATA

11.1 Gray Whale

Population Status

Gray whales are found only in the North Pacific Ocean and adjacent waters of the Arctic Ocean. There are two geographically isolated stocks: the Korean or western Pacific stock, which migrates between South Korea and the Sea of Okhotsk, and the California or eastern Pacific stock, which migrates between Baja California and the Bering and Chukchi seas (Zenkovich 1937, Rice and Wolman 1971).

The eastern Pacific stock of gray whales winters in the warm coastal waters of Baja California and the southern Gulf of California. From late February to May, they begin a northward migration, following the coast closely and occasionally stopping to rest or feed (Pike 1962). They enter the Bering Sea through passes in the eastern Aleutian Islands, particularly Unimak Pass, in March, April, May, and June, and continue moving along the coast of Bristol Bay and southern Nunivak Island, then toward St. Lawrence Island where they arrive in May or June (Pike 1962, Braham et al. 1977). A few gray whales have been sighted near the Pribilofs in April-June (Braham et al. 1977) and may remain in that area throughout the summer. Upon reaching St. Lawrence Island, the whales disperse to spend the summer feeding in the shallow waters (usually less than 50-60 m deep) of the northern and western Bering Sea and the Chukchi Sea. They are found along the coast of the Chukchi Peninsula south to Glubokai Strait and the southwestern Gulf of Anadyr, north and west to Cape Serdtse Kamen', and occasionally to Wrangel Island. On the American side, they are commonly found along the Alaska coast as far as Barrow, occasionally east of there to Barter Island, and in the central Chukchi Sea north to 69°N latitude (Pike 1962, Rice and Wolman 1971). In the northern Bering Sea, gray whales are especially abundant in Mechigmen Gulf; the southwest Gulf of Anadyr; along the Koryak coast, near Cape Navarin; and around St. Lawrence Island and in the central Chirikof Basin (referred to as the "large kitchengarden" by the Soviets) (Zenkovich 1937, Kuz'min and Berzin 1975, Votrogov and Bogoslovskaya 1980, Nerini et al. 1980, Zimushko and Ivashin 1980). Wilke and Fiscus (1961) reported observations of large groups of gray whales in the Chukchi Sea in August 1959. According to observations by the Soviets, most of the whales along the Koryak coast are juveniles, aged 0.5 to 2 years (Zenkovich 1937, Tomilin 1957).

A small proportion of the gray whale population does not migrate to the Bering and Chukchi seas during summer. Those few individuals remain off the coasts of California, Washington, and British Columbia (Rice and Wolman 1971, Hudnall 1981).

Gray whales begin their autumn migration in mid-October (Kuz'min and Berzin 1975). They pass through Unimak Pass between late October and early January, with the peak from mid-November to mid-December, and arrive in Baja California in December and January (Pike 1962, Rugh and Braham 1979, Rugh 1981).

Eastern Pacific gray whales were once severely depleted by commercial whaling but have since recovered to what is probably near the pre-exploitation population size (Scheffer 1976, Blokhin 1979, Rugh and Braham 1979). Ohsumi (1975) estimated an original population of 15,000 and suggested that it declined to a low of 4,400 in 1875. By the early 1970's, population estimates (Table 11.1-1) had risen to about 11,000 (Rice and Wolman 1971, Mitchell 1973). Recent aerial surveys and ground counts during the migration give estimates of 16,500 $\pm$ 2,900 (Reilly et al. 1980) to 18,300 (Herzing and Mate 1981).

Gray whale calves average 4.5 to 4.9 m long and 680 kg at birth, grow to 7 or 8 m at weaning in August, and are a little over 9 m by winter (Zenkovich 1937, Tomilin 1957, Rice and Wolman 1971). Yearling females are about 66% of their mature length and yearling males about 72%. Growth slows as sexual maturity is reached at about 12 m. According to Zimushko and Ivashin (1980), physical maturity is reached at about 10-11 years, whereas Rice and Wolman (1971) propose physical maturity (13 m in males and 14.1 m in females) at about 40 years. Some of this disagreement is due to differing interpretations of age as indicated by laminae in ear plugs. Rice and Wolman believe one laminae is formed each year. A recent analysis by Sumich (1981) suggests that Zimushko's estimates of growth rates fit age:body length relationships of juveniles better than those of Rice and Wolman and that gray whales probably reach 11 m in 4 years rather than 8. Male and female gray whales are approximately the same size at birth, but as adults females are slightly larger (Rice and Wolman 1971). The maximum reported lengths are 15.6 m for females and 14.6 m for males (Zenkovich 1937). The mean size of whales taken in Soviet harvests varies by year but averages about 12 m (Zimushko and Ivashin 1980). Adult gray whales may weigh as much as 34,000 kg (Table 11.1-2).

Most female gray whales first become pregnant at a length of about 12 m, or when they have 11 or 12 ear plug laminations (Rice 1963; Zimushko 1969a, b; Rice and Wolman 1971). By Zimushko's interpretation that would represent an age of 5 or 6 years. According to Wolman and Rice (1979), females reach sexual maturity at 5-11 years, with a mean of 8 years. Males mature at about the same size and age. The oldest reported "age" for gray whales is 70 ear plug laminations (Rice and Wolman 1971).

Breeding occurs from mid-November to early January (Rice and Wolman 1971). Calves are born the following late December to early February (mean birthdate of 27 January), for a total gestation period of a little over 13 months (Rice and Wolman 1971, Rice et al. 1981). Each female bears a single calf. The sex ratio is approximately 1:1 at birth and

Table 11.1-1. Estimates of the population size of the eastern Pacific stock of gray whales, based on annual censuses at Monterey, California (from Reilly et al. 1980).

Year	Estimate	95% confidence limits
1967/68	10,767	8,773-12,761
1968/69	11,384	9,224-13,544
1969/70	11,748	9,579-13,916
1970/71	11,245	9,099-13,390
1971/72	9,637	7,851-11,424
1972/73	13,167	10,753-15,581
1973/74	13,010	10,608-15,412
1974/75	12,069	9,746-14,398
1975/76	14,930	12,316-17,543
1976/77	16,511*	13,628-19,394
1977/78	13,644	11,204-16,084
1978/79	13,460	11,039-15,880

* This was considered by Reilly et al. to be the best estimate of the present-day population.

Table 11.1-2. Weights and lengths of nine gray whales (Rice and Wolman 1971).

Sex	Age	Date	Body length (meters)	Weight (kilograms)
F	Fetus	20 January 1968	4.75	409
?	Immature	10 January 1961	8.53	6,632
M	Immature	30 March 1962	9.65	8,808
M	Immature	28 March 1962	9.90	8,876
M	Adult	29 March 1962	11.72	15,686
M	Adult	27 March 1962	12.40	16,594
F	Adult (pregnant)	23 February 1959	12.70	16,360
F	Adult (pregnant)	19 August 1936	13.35	31,466
F	Adult (pregnant)	14 December 1966	13.55	33,846

probably remains so throughout life. Soviet whalers catch more females than males, but this is probably because the whalers select for larger individuals and female whales average slightly longer than males (Zimushko 1971).

The normal interval between calves is 2 years, although there is evidence that calves are occasionally born in consecutive years (Zimushko 1969b, Rice and Wolman 1971). The mean observed pregnancy rate for mature females ($\geq$ 8 years) was 46% in samples analyzed by Wolman and Rice (1979) and 32-56% in samples analyzed by Zimushko (1969b), for a birth rate equal to 23% of the adult stock. If adults comprise about 56% of the population (Rice and Wolman 1971) the overall birth rate (gross productivity) would be about 13%. Blokhin (1979) estimated a slightly greater annual increment of 16.5-18%, by assuming that 57% of mature females reproduce each year. In one sample, he reported finding 70% of the mature females pregnant.

The only major predators of gray whales are killer whales and humans (Zenkovich 1937, Tomilin 1957, Rice and Wolman 1971, Zimushko and Ivashin 1980). Rice and Wolman (1971) reported that 18% of the whales they examined had healed scars from killer whale attacks. Tomilin (1957) reported a similar percentage with evidence of killer whale attacks.

The gray whale fishery began in the early 1800's. In 1857 Scammon discovered the calving lagoons in Mexico; the whales were hunted heavily there, and by 1875 Scammon predicted that gray whales would soon be extinct (Pivorunas 1979). Over 9,000 gray whales were taken from 1846 to 1900 (Rice and Wolman 1971, Brownell 1977). With the advent of modern whaling techniques in the early 20th century, whaling effort increased again, and almost 1,000 additional gray whales were taken from 1905 until 1948, when the International Convention for the Regulation of Whaling banned further commercial hunting of this species (Rice and Wolman 1971, Brownell 1977). Between 1959 and 1969, 316 gray whales were taken off California for scientific purposes. Since the 1960's the USSR has conducted a regulated annual hunt of gray whales to provide food for coastal Siberian Eskimos; the average annual take is 165 per year (Blokhin 1979, Wolman and Rice 1979, Zimushko and Ivashin 1980). The average annual take of gray whales by Alaskan Eskimos has been less than three per year since 1970, with a maximum of seven in 1975 (Wolman and Rice 1979).

Rice and Wolman (1971) estimated that 44% of the gray whale population is comprised of immature (1-7 years) whales. They calculated mortality rates of 0.081/year for males, 0.095 for all females, and 0.082 for sexually mature females. Size and age data available from early commercial and recent Soviet harvests are considered to be of little utility in determining the age structure of the total population since the harpooners select for larger (older) whales and underrepresent immatures.

Diet Composition

Gray whale calves nurse for 6-7 months (Zenkovich 1937, Tomilin 1957, Rice and Wolman 1971, Zimushko and Ivashin 1980). The milk contains approximately 53% fat (Zenkovich 1939, cited in Tomilin 1957). Upon weaning, the calves eat small crustaceans (particularly amphipods); their stomachs also contain ascidians, polychaetes, algae, and mud (Zenkovich 1937, Zimushko and Ivashin 1980).

Gray whales apparently feed very little along their migration route and while at their breeding grounds (Zenkovich 1937, Rice and Wolman 1971). Stomachs of animals taken along the California coast were almost invariably empty, as were the few stomachs examined from calving lagoons (Scammon 1874). Early whalers noted that the whales were always thinner on their northward trip than on their southward trip. Rice and Wolman (1971) found the total weight loss between the southward and northward migrations to vary from 11 to 29%. However, more recent observations by Gilmore (1961, cited in Ray and Schevill 1974), Sund (1975), Wellington and Anderson (1978), Norris and Wursig (1979), Hudnall (1981), and Cunningham and Stanford (unpubl. ms.) suggest that gray whales feed to some extent south of the regular feeding grounds on small fishes, euphausiids, mysids, and pelagic anomuran crabs. A single whale taken off the California coast and examined by Howell and Huey (1930) in July 1926 had been eating euphausiids.

The organisms found in the stomachs of gray whales on their arctic summer feeding grounds are typically benthic species (Table 11.1-3). Gammarid amphipods comprise the bulk of the food, and concentrations of 14,000-24,000 amphipods/m^2 have been found in the southern Chukchi Sea and northern Bering Sea where the whales feed (Zimushko and Lenskaya 1970, Nerini et al. 1980). The distribution of gray whales during summer is probably determined by the presence of large amphipod beds.

Zenkovich (1934) was the first to report on the food of gray whales in the Bering and Chukchi seas. He found the stomachs of gray whales taken along the Chukchi coast of the Arctic Ocean "packed" with amphipods, including: *Ampelisca macrocephala*, *Lembos arcticus*, *Anonyx nugax*, *Pontoporeia femorata*, and unidentified species of the families Gammaridae, Atylidae, and Lysianassidae. *Ampelisca macrocephala* predominated in the Chukchi and northern Bering seas, while F. Atylidae predominated along the Koryak coast. Stomachs also contained buccinid snails and algae.

Tomilin (1957) examined the stomachs of 30 whales killed in 1934 in the Bering and Chukchi seas and found almost entirely amphipods of the following species: *Ampelisca macrocephala*, *Anonyx nugax*, *Lembos arcticus*, *Pontoporeia femorata*, *Eusirus* sp., and *Atylus* sp., as well as unidentified F. Gammaridae and F. Lysianassidae. Like Zenkovich (1934), Tomilin found *A. macrocephala* to be the major food item in the Chukchi Sea and F. Atylidae along the Koryak coast. Other items

Table 11.1-3. Foods reported from the stomachs of gray whales in the Bering and Chukchi seas. Items of major importance are indicated by XX.

	Zenkovich 1934	Tomilin 1957 n = 30	Pike 1962 n = 2	Zimushko and Lenskaya 1970 n = 70	Rice and Wolman 1971 n = 1	Bogoslovskaya et al. 1981 n = 98
Ampelisca macrocephala	XX	XX	X	XX	XX	XX
A. eschrichti	--	--	XX	XX	--	X
Lembos arcticus	X	X	--	X	--	X
Anonyx nugax	X	X	X	XX	X	X
Nototropis ekmani	--	--	--	X	--	--
Pontoporeia femorata	X	X	--	XX	--	XX
P. affinis	--	--	--	X	--	--
Atylus sp./Atylidae	XX	XX	--	--	X	--
Lysianassidae	X	X	--	--	--	--
Gammaridae	X	X	--	--	--	--
Other amphipods	--	X	--	X	X	X
Ascidians	--	--	X	X	X	X
Gastropods	X	X	X	X	--	X
Isopods	--	X	--	X	--	--
Polychaetes	--	X	X	X	X	X
Mysids	--	X	--	--	--	--
Bivalves	--	--	X	X	--	--
Spider crabs	--	--	X	X	--	X
Algae	X	X	--	X	--	X

found in stomachs included algae, mud, pebbles, mysids, isopods, polychaetes, and buccinid snail eggs.

Pike (1962) examined the stomach contents of two small gray whales taken near Gambell on the west coast of St. Lawrence Island. The stomachs contained Ampelisca macrocephala, A. eschrichti, Anonyx nugax, ascidians, polychaetes, snails, small clams, and spider crabs.

Zimushko and Lenskaya (1970) analyzed the stomach contents of 70 gray whales collected July-October 1965-69 in the coastal waters of the Chukchi Peninsula, Chukchi Sea, Bering Strait, and Gulf of Anadyr. From those samples, they identified 32 species of crustaceans, 10 species of bivalves, and 5 species of gastropods, as well as ascidians, polychaetes, priapulids, sipunculids, sea cucumbers, sea anemones, hydroids, sponges, fishes, and debris such as pebbles, sand, mud, algae, feathers, and wood. Amphipods were the predominant group, with six species accounting for 94% of the total stomach contents by weight: Anonyx nugax (18.3%), Pontoporeia femorata (36.7%), P. affinis (3.0%), Ampelisca macrocephala (16.8%), A. eschrichti (13.4%), and Nototropis ekmani (11.8%). No substantial difference was found between the food habits of young and old whales. The stomachs of seven calves (7.7-9.0 m) contained ascidians, polychaetes, mud, algae, and the amphipods A. nugax, A. eschrichti, and N. ekmani. Foods were found to be similar in Bering Strait and the Gulf of Anadyr, and in males and females.

Rice and Wolman (1971) examined the stomach contents of an immature female gray whale killed southwest of Gambell. More than 95% of that sample consisted of gammarid amphipods, particularly Ampelisca macrocephala and Anonyx sp. Also present were an ascidian, a sea cucumber, a cumacean, and a polychaete.

In 1979, Bogoslovskaya et al. (1981) sampled the stomach contents of 98 whales collected along the coast of the Chukotsk Peninsula. Amphipods were the major food; the predominant species changed by location. Ampelisca macrocephala made up 80-85% of the samples from the Chukchi Sea, whereas Pontoporeia femorata comprised 60-100% of samples from the northern Gulf of Anadyr and Arakamchechen area. Other common species of amphipods were Nototropis brueggeni, Byblis gaimardi, and Anonyx nugax. The samples also contained nearly 25 species of other invertebrates (including polychaetes, sea cucumbers, snail eggs, ascidians, hydroids, spider crabs, and shrimps), fish larvae, sand, mud, algae, wood, and feathers.

Coyle (1981) examined the stomach contents of a single 13-m long female whale from the Chukchi Sea. More than 90% of the contents consisted of Ampelisca macrocephala, with small numbers of Melita dentata, Lembos arctica, Protomedia sp., Pontoporeia femorata, and Anonyx nugax. Animals shorter than 8-10 mm did not commonly occur in the whale's stomach.

Food Requirements

Ray and Schevill (1974) report that the captured gray whale calf, Gigi, ate 900 kg of squid per day and was gaining almost 40 kg/day at about the time of her first birthday (28 January-11 March, a year after capture).

Tomilin (1946, cited in Zimushko and Lenskaya 1970) estimated the daily consumption of newly weaned gray whale calves as 379 kg and that of whales having just reached sexual maturity as twice that. He suggested that the requirements of whales at physical maturity would be about 1,250 kg/day and of "fattening" whales about 2,500 kg/day.

Zimushko and Lenskaya (1970), based on field data, reported that an average gray whale consumes about 300 kg per feeding. Assuming four feeding bouts per day, a rate found in other large baleen whales and supported by their field observations, total daily consumption would be 1,200 kg. Using a residence time in the Bering and Chukchi seas of 130-140 days, they calculated that one whale would consume 170 tons of crustaceans (amphipods) per year and that a population of 5,000 whales would consume 850,000 tons/year. Frost and Lowry (1981a) made similar calculations. They used a residence time of 180 days, a daily ration of 1,000-1,200 kg, and a total population of 15,000 whales, and estimated the consumption of gray whales on their feeding grounds to be 2.7-3.2 x 10^6 tons/year.

There are no experimental data on the energy requirements of gray whales.

New or Unanalyzed Data

We know of no new or unanalyzed data on gray whales. A study of the distribution and feeding ecology of gray whales was initiated in summer 1981 under the OCSEAP program.

11.2 Fin Whale

Population Status

Fin whales are an oceanic species and are worldwide in distribution. They spend the winter in temperate to subtropical waters, where they breed and calve, and migrate toward the poles during the summer to feed. They are distributed widely and abundantly in the North Pacific and are generally considered to comprise two stocks: a North American stock, migrating between Baja California and the Bering and Chukchi seas, and an Asiatic stock, migrating between southern Japan or Korea and the Kuril, Commander, and Aleutian Islands and the western Bering Sea (Omura 1955, Tomilin 1957, Fujino 1960, Nasu 1966). The two stocks probably intermingle to an unknown extent in the northern Bering and southern Chukchi seas. They are most often sighted in the following areas: the western Aleutians, south of the Pribilof Islands, north of Unalaska Island, off Cape Navarin, west of St. Matthew Island, around the Commander Islands, east of the Kamchatka Peninsula, the Gulf of Anadyr, and Mechegmen Gulf.

The northward migration begins in spring. Fin whales are first seen in the eastern Aleutians and Gulf of Alaska from early April to June. They feed throughout the Bering and Chukchi seas from late June to October. The North American stock is widespread during summer; some whales remain south of the Aleutians in the Gulf of Alaska, and some move into the Bering Sea. Of the latter, some move toward Cape Navarin along the shelf break, some go to the Chukchi Sea, and some spread west along the Aleutians toward the Commander Islands. The southward migration out of the Chukchi and Bering seas begins in September and continues through October. Fin whales are still seen off the Commander and Aleutian Islands in October and November (Nikulin 1946, Berzin and Rovnin 1966, Votrogov and Ivashin 1980). Of the Asiatic population, some whales go to the Commander Islands, some to the eastern Aleutians, and some move northward along the Asiatic coast and perhaps into the Chukchi Sea (Berzin and Rovnin 1966).

The exploitable fin whale population in the North Pacific, including both Asiatic and North American stocks, is estimated at 14-19,000 and the total population at 21-29,000 (Nishiwaki 1966, Tillman 1975, Gambell 1976). The population decreased until 1975 from an original estimate of 42-45,000 individuals. By 1980, it appeared to be increasing (Wada 1981).

Fin whales in the North Pacific are slightly smaller than those in the Antarctic. The average newborn is about 6 m in length and weighs about 1,250 kg (Tomilin 1957, Ohsumi et al. 1958). Calves grow to 11-13 m by weaning at about 6 months and to about 16 m at 2-1/2 years (Ohsumi et al. 1958). Fin whales are sexually dimorphic, with females slightly larger than males. Maximum reported length for Pacific fin whales is 24.4 m for females and 23.8 m for males (Tomilin 1957). Physical maturity is attained at about 25 years and is reached at a little over 20 m in females and about a meter shorter in males (Rice 1963, Ohsumi et al. 1958). Some whole weights are available for fin whales; an 18.5-m male in May weighed 36,900 kg, a 19.8-m pregnant female in August weighed 48,070 kg, and 20.8-m female weighed 53,800 kg (Nishiwaki 1950, Lockyer 1976b). There is a seasonal cycle in fatness. Fin whales are thinnest in May-June and fattest in October-November. Weight gain may be 10-30% from spring to autumn (Tomilin 1957).

North Pacific fin whales become sexually mature at about 6 years of age (probably down from 10 years prior to heavy exploitation) and 18.4-18.8 m in females and 17.5-17.8 m in males (Omura 1955, Ohsumi et al. 1958, Rice 1963). There is some confusion over the number of ear plug laminations laid down each year and therefore over the actual age at sexual maturity. Females apparently continue to ovulate throughout life. Maximum reported age is 50 years (100 laminations) in females and 51 years (101 laminations) in males (Ohsumi et al. 1958). However, whales older than 24 years are rare in the North Pacific.

Breeding occurs over a relatively prolonged period, mostly from November to March, with a peak in December. Calves are born about 1 year later (Tomilin 1957, Ohsumi et al. 1958). Most births are single; however, multiple foetuses have been reported at a rate of 0.43% (Ohsumi et al. 1958). The sex ratio of foetuses is 1:1 (Tomilin 1957).

The normal interval between calves is approximately 2 to 2-1/2 years (Sleptsov 1955a). The observed pregnancy rate for mature females may vary from 0.35 to 0.70 and probably averages about 0.39 (Omura 1955, Rice 1963). Because of the maximum size restrictions on harvested whales, and selection by hunters for larger animals, it is difficult to determine the ratio of adult:immature whales or to estimate gross productivity.

Killer whales and humans are the major known predators of fin whales. Predation rates by killer whales in the North Pacific are unknown. In the Antarctic, Shevchenko (1975) reported that 53% of the fin whales he examined had scars from the bites of killer whales.

From about 1940 to 1962, fin whales comprised over 80% of the total North Pacific harvest of whales. There were five major areas for hunting: off the Kamchatka Peninsula to near Attu Island, the south side of the Aleutians, north of Unalaska Island, west of St. Matthew Island, and near Cape Navarin (Nasu 1963). From 1954 through 1962, the harvest of fin whales was about 1,560 per year (Nishiwaki 1966). Harvest since then has been: 1963 - 2,503; 1964 - 3,991; 1965 - 3,165; 1966 - 2,885; 1967 - 2,272; 1968 - 1,942; 1969 - 1,276; 1970 - 1,012; 1971 - 802; 1972 - 758; 1973 - 455; 1974 - 413 (Tillman 1977). Fin whales are no longer commercially harvested in the North Pacific.

Estimated mortality rates for North Pacific fin whales are generally similar to those reported for antarctic and Iceland whales (Lockyer and Brown 1979). For whales from Kamchatka and the eastern Aleutians, Fujino (1960) calculated values of 0.062-0.127, based on ear plug laminations, and 0.091-0.209, based on counts of corpora albicantia. Nemoto et al. (1968) reported a range of 0.037 to 0.052 and a mean of 0.046. Those values do not include juveniles.

Diet Composition

Fin whale calves nurse for about 6 or 7 months, or until they are about 11-13 m in length (Tomilin 1957, Ohsumi et al. 1958). During the nursing period they consume about 70 kg of milk per day and gain over 50 kg/day. The milk is approximately 42-44% fat (Tomilin 1957).

Fin whales in the North Pacific consume pelagic crustaceans, primarily euphausiids and copepods, in large quantities, along with a variety of shoaling fishes and sometimes squids (Table 11.2-1). In the Bering Sea, *Thysanoessa inermis* is the most important euphausiid prey of fin whales, as well as of most other baleen whales. *T. inermis* forms extensive swarms over the continental shelf margin from July to September (Nemoto 1959, 1970). Three other species, *T. longipes*, *T. spinifera*, and *T. raschii*, also form swarms; their importance to fin whales varies depending on the geographic area and oceanographic regime. There is a major concentration of *T. inermis* southwest of the Pribilof Islands (Nemoto 1959) which coincides with an abundance of fin whales.

Copepods of the genus *Calanus* are also important foods of fin whales. Two species, *C. cristatus* and *C. plumchrus*, are abundant north of the Aleutian Islands, where *C. plumchrus* is usually the most abundant copepod in plankton tows. Although it is an important prey of fishes, it does not form dense swarms and hence is of minor importance to fin whales. *Calanus cristatus* is the most important copepod prey of fin whales in the Bering Sea (Nemoto 1957, 1959). Only the copepodite-5 stage, an immature form which is present in near-surface waters, is eaten by fin whales. Adult *C. cristatus* are found south of the shelf in waters more than 500 m deep, which is deeper than the whales typically dive to feed. Nemoto (1957) reported that copepodites of *C. cristatus* are most abundant in near-surface waters of the Bering Sea in spring and early summer, when water temperatures are low; they comprise a major part of the stomach contents of fin whales at that time. Later in the summer, when copepods become less abundant, euphausiids assume greater dietary importance for these whales.

In years when euphausiids and copepods are not abundant in the southern Bering Sea, and in areas farther north in the Bering and Chukchi seas (north of 58°N), fishes are of major importance in the diet of fin whales (Klumov 1963, Nemoto 1959, Kawamura 1980). The species of greatest importance are herring, capelin, and pollock. Pollock are the most important at or near the shelf break. In general, fin whales take pollock less than 30 cm long, herring about 25 cm long, and capelin about 15 cm long (Nemoto 1959).

Table 11.2-1. Major foods of fin whales in the Bering Sea and North Pacific Ocean.

Area	Foods	Source
North Pacific, in general	Euphausiids (64%[1]), copepods (26%), fishes (5%), squids (1%)	Nemoto 1959, Kawamura 1980
Eastern Aleutians	Euphausiids, copepods	Nemoto 1959
Western/Central Aleutians	Copepods, euphausiids, capelin, pollock	Nemoto 1963, Klumov 1963
Shelf Break - Bering Sea	Pollock	Nemoto 1959
Kuril Islands	Euphausiids, copepods, pollock, anchovy[2], Atka mackerel, saury[3], squids	Tomilin 1957, Nemoto 1959
Commander Islands	Euphausiids, copepods, capelin, pollock	Tomilin 1957, Nemoto 1959, Klumov 1963
Olyutorskiy Bay	Euphausiids, herring, capelin	Tomilin 1957, Nemoto 1959
Cape Navarin	Euphausiids and capelin	Nemoto 1959
Gulf of Anadyr	Euphausiids, arctic and saffron cod, capelin	Tomilin 1957
Chukchi Sea	Arctic cod, euphausiids	Tomilin 1957, Klumov 1963, Kawamura 1980

1 Percentage of the total number of stomachs with food.
2 Engraulis japonica
3 Cololabis saira

Fin whales also eat arctic cod, saffron cod, Pacific cod, Atka mackerel, rockfishes, smelt, and salmon (Tomilin 1957). Arctic and saffron cod are eaten most commonly in the northern Bering Sea and the Gulf of Anadyr (Tomilin 1957, Klumov 1963).

Fin whales probably are the most polyphagous of baleen whales. In the Bering Sea they consume a larger number of species than in the Antarctic, where they eat almost exclusively euphausiids (Nemoto 1957). Their diet appears to change from year to year and from location to location, depending on whether euphausiids, copepods, fishes, or squids are most abundant.

Food Requirements

According to Nemoto (1959), the stomach of a fin whale from the northern North Pacific usually contained 100-700 kg of food. Maximum reported weight was 759 kg in a 17.5-m male that had been eating pollock. Lockyer (1976c) reports that a North Pacific fin whale measuring 18-19 m consumes about 450 kg/meal. She cites Kawamura (1971) and Klumov (1961) in suggesting that fin whales feed a maximum of twice per day and consume a total of 1,000-1,500 kg/day in the North Pacific. Brodie (1975, 1977) estimated the average daily consumption of an antarctic fin whale as 1,000 kg of euphausiids per day, or 3-1/2 to 5 times the total body weight per year.

Lockyer (1976c) presents a rather complex analysis of the growth and energy budget of antarctic fin whales. She calculates total caloric intake, resting and active metabolic rates, growth increments, the energy stored in blubber, and assimilation efficiencies for nursing calves, juveniles, young adults, and pregnant females. The results are summarized in Table 11.2-2. The applicability of these calculations to North Pacific fin whales is unknown. In all probability, values for feeding rates, duration of the summer feeding period, and food intake during winter may differ substantially from those for the Antarctic.

New or Unanalyzed Data

We know of no new or unanalyzed data. Fin whales are no longer commercially harvested in the North Pacific; consequently, there are no new biological samples being collected.

Table 11.2-2. Energy budgets for antarctic fin whales (Lockyer 1976c).

	Nursing calves	At puberty		Young adult		Pregnant female	
	males and females	males	females	males	females	yr 1	yr 2
	k cal/day	19.5 m	20.2 m	20.8 m	22.2 m	64,500 kg	
		43,500 kg	47,500 kg	51,500 kg	62,000 kg	$\times 10^8$ kcal	
		$\times 10^8$ kcal		$\times 10^8$ kcal			
Caloric Intake (summer)	--	1.8	2.03	2.17	2.03	2.71	2.74
Possible Caloric Intake (winter)	--	0.37	0.42	0.44	0.54	0.55	0.57
Total Intake	299,105	2.17	2.45	2.61	3.18	3.26	3.31
Growth Increment (meat and blubber)	79,500	0.09	0.10	0.02	0.03	0.07	
Metabolic Expenditure	200,000	1.71	1.83	2.05	2.41	2.50	2.50
Total Energy Utilized	279,500	1.80	1.93	2.07	2.44	5.73	
Energy Temporarily Stored		0.76	0.82	0.87	0.98	2.72	
Input-Output-Feces	19,605	0.37	0.52	0.54	0.74	0.84	
Gross Efficiency	26.5%	4.0	4.0	0.7	0.9		
Assimilation Efficiency	93.0%	83	79	79	77	87	
Net Growth Efficiency	28.5%	5.0	5.2	1.0	1.2		

11.3 Minke Whale

Population Status

Minke whales inhabit both the northern and southern hemispheres. Pacific minkes are widely distributed in inshore waters, often within a few km of the coast, as well as in the southern edge of seasonal pack ice (Omura and Sakiura 1956, Tomilin 1957). They occur from the Chukchi Sea (to 67°N) and Bering Strait south to Korea and China on the Asiatic side and to California on the American side (Tomilin 1957; Sleptsov 1961a, b; Ivashin and Votrogov 1981a). They are most abundant in the Aleutians and off the Alaska coast from May to July. Fiscus et al. (1981) reported 34 sightings of minke whales in the Aleutians during June and July 1979, most of which occurred near Amlia in the Andreanof Islands. Some probably migrate south to winter off Washington and California, and some may remain year round in the Bering Sea (Tomilin 1957, Ivashin and Votrogov 1981a). Minke whales are abundant along the Asiatic coast, especially off the coasts of Japan (Tomilin 1957).

Population estimates are not available for minke whales. According to Braham et al. (1977), they are one of the four most commonly observed cetaceans in the Bering Sea.

Minke whales are the smallest of the baleen whales. At birth calves are about 2.1-2.8 m; at 6 months, 4.6 m; at 1 year, 5.5 m; and at 2 years, 7.1 m (Omura and Sakiura 1956, Tomilin 1957). Maximum size of adults is about 10 m; they become physically mature at about 8 m (Tomilin 1957). Off Japan females average 7.2 m and males 7.3 m (Omura and Sakiura 1956). Tomilin reports the following weights: 3.2 m - 295 kg (suckling); 3.9 m - 522 kg; and 6.9 m - 6,074 kg.

Minke whales taken off Japan were sexually mature at about 7.4 m in females and 6.8 m in males (Omura and Sakiura 1956). Mating occurs from at least December to March. Calves are born in December-January; some are also apparently born in June-July, suggesting that mating and calving may take place year round (Omura and Sakiura 1956, Tomilin 1957). The gestation period is 10-11 months. In the Antarctic many females ovulate during lactation, suggesting an annual reproductive cycle (Lockyer 1981a). Omura and Sakiura (1956) also suggest that sexually mature cows produce one calf per year. Annual pregnancy rates are unknown, as are the age at sexual maturity, age composition of the population, and sex ratio.

Mortality rates for minke whales are unknown. They are preyed upon by killer whales (Hancock 1965, Rice 1968) and hunted by humans. Ivashin and Votrogov (1981a) report that Soviet pelagic whalers took 21 minke whales from 1933 through 1979 in the Bering Sea. During the same time period 94 were taken in coastal operations off the Kuril Islands.

Diet Composition

Minke whale calves probably nurse for 6 months, or until they are about 4.5 m in length (Omura and Sakiura 1956).

In the North Pacific, euphausiids and shoaling fishes are major foods of minke whales; pelagic squids and copepods are of lesser importance (Nemoto 1959, 1970; Klumov 1963). In the Gulf of Anadyr, Olyutorskiy Bay, Kronotskiy Bay, and Peter the Great Bay, Kawamura (1980) found that herring, capelin, saffron cod, and the euphausiid *Thysanoessa inermis* were the main foods. In the Sea of Okhotsk, herring, pollock, euphausiids, sand lance, saury, and sardines (*Sardinops sagax*) were eaten (Nemoto 1959, Kawamura 1980). Off Japan, Omura and Sakiura (1956) found euphausiids, some copepods, pollock, sand lance, anchovy, herring, and occasionally squids in the stomachs of 14 whales. Tomilin (1957) stated that fishes and pelagic crustaceans were the major foods in the Far Eastern seas, Peter the Great Bay, and around the Kurils. Fishes included pollock, saffron cod, herring, capelin, and sand lance. Frost and Lowry (1981a) reported on the stomach of a minke whale stranded on Unalaska Island; it contained only pollock. In the northern Bering and Chukchi seas, arctic cod are the major forage species (Tomilin 1957; Sleptsov 1961a, b; Klumov 1963).

Food Requirements

Lockyer (1981a) estimated that a minke whale eats about 4% of its body weight per day in summer (more if feeding conditions are good) and 1-1.5% in winter. Based on that estimate, she calculated that a mature 6-year-old female would require 57.0×10^6 kcal/year for annual growth and maintenance, and 6.2×10^6 kcal and 7.6×10^6 kcal for pregnancy and 4 months lactation (assuming 80% assimilation efficiency). She estimated that a calf consumes 11 kg of milk/day and grows 7.3 kg/day.

New or Unanalyzed Data

We know of no new or unanalyzed data on minke whales.

11.4 Blue Whale

Population Status

Blue whales inhabit both the northern and southern hemispheres, wintering in warm subtropical waters and migrating toward the poles to feed in colder water in summer (Tomilin 1957). In the North Pacific they are more common on the North American side than on the Asian side. They winter off Mexico, California, Taiwan, Japan, and Korea. Some remain in temperate waters off Japan and Korea year round; the remainder migrate north in spring to Alaska (Gulf of Alaska, Aleutians, and Bering Sea), the Kuril Islands, Kamchatka, and the Chukchi Peninsula, where they spend the summer feeding (Tomilin 1957, Berzin and Rovnin 1966). In recent years they have been rare in the Bering Sea (Berzin and Rovnin 1966, Nishiwaki 1966). In the 1930's and 1940's they were most abundant along the Aleutians from 170°E to 175°W and 170°W to 160°W; southeast of Kodiak; and in the northeastern Gulf of Alaska south to Vancouver Island.

The North Pacific population of blue whales originally numbered an estimated 4,500-5,000 whales (Ohsumi and Wada 1972, Tillman 1975, Gambell 1976). Blue whale stocks were severely depleted by commercial hunting in the early 1900's, and the North Pacific population is now estimated at 1,400-1,900 (Gambell 1976, NMFS 1981b). The population has apparently increased since 1966, when commercial hunting was banned (Ohsumi and Wada 1972).

Blue whales are the largest of all whales. Calves are usually 7-8 m long at birth (Tomilin 1957). Individuals reach physical maturity at 10-11 years old and lengths of 26-27 m in females and 24-25 m in males (Tomilin 1957). Rice (1963) presents somewhat different figures for females of 25-46 ear plug laminations and 16.5-18.9 m. Blue whales in the North Pacific reach a maximum size of about 28 m. The largest whale caught off Kamchatka from 1923 to 1939 was 26.5 m and off the American coast from 1919 to 1929, 27.5 m. Females average about 70 cm longer than males (Tomilin 1957). Some lengths and weights of antarctic blue whales are as follows: 22m - 62 tons; 26 m - 109 tons; 27 m - 114 tons; and 29 m - 140 tons (Lockyer 1976). A single arctic blue whale reported by Nishiwaki (1950) was 23.7 m and 63 tons.

Sexual maturity occurs at 21.7-23 m in females and 22 m in males (Tomilin 1957). Ohsumi and Wada (1972) estimated the mean age at recruitment off Japan as 10 years. In the Antarctic, mean age at sexual maturity is about 5 years. Reproductive parameters of blue whales are best known from the Antarctic. Mating and calving are protracted but occur mainly in the autumn, with a gestation period of approximately 1 year. One calf per female is usual; however, twin fetuses have been reported in the Antarctic at a rate of 0.64%. The sex ratio of fetuses is close to 1:1, with a slight prevalence of males. The normal calving interval in the Antarctic is one calf per 2 or sometimes 3 years. Simultaneous pregnancy and lactation are rare (Tomilin 1957). Pregnancy rates in the North Pacific are poorly known but are estimated by Ohsumi and Wada (1972) as 0.35 for exploited and 0.25 for unexploited populations.

Mortality rates have been estimated as 0.071 in blue whales younger than 10 years, 0.049 in those from 10 through 21 years; and 0.073 in those from 22 through 31 years (Ohsumi and Wada 1972).

Diet Composition

Blue whale calves nurse for about 7 months or, in the Antarctic, until they are about 16 m long (Tomilin 1957, Lockyer 1976). They gain an average of 81 kg/day during that time and consume about 90 kg milk/day (Tomilin 1957, Lockyer 1976). The milk of blue whales is about 35-50% fat (46% in whales taken off Kamchatka), with an energy value of 3,657-4,305 kcal/kg (Tomilin 1957, Lockyer 1976).

In most of the North Pacific, blue whales are primarily euphausiid eaters (Nemoto 1957, 1968, 1970; Kawamura 1980). Whales examined from the Kuril and Commander Islands, Kamchatka, the eastern Aleutians, and Kronotskiy Bay all had been eating euphausiids, including *Thysanoessa inermis*, *T. longipes*, and *T. spinifera* (Betesheva 1961, Klumov 1963, Kawamura 1980). Other prey items eaten less commonly include *Calanus* copepods, *Parathemisto* sp., *Limacina* sp., *Clione* sp., the pelagic squid *Ommatostrephis*, and occasionally pelagic fishes such as sardines, capelin, and sand lance (Sleptsov 1955a, Tomilin 1957, Klumov 1963). According to Nemoto (1959), in years when euphausiids become abundant early in the season, blue whales migrate early into the Bering Sea. If the bloom is delayed, so is the migration.

Food Requirements

Blue whales, like the other baleen whales, exhibit a seasonal cycle in feeding and therefore blubber content. Whales caught off California yield an average of 50 barrels of oil per whale, while those taken off Alaska yield 70 barrels (Tomilin 1957). Klumov (1963) estimated that baleen whales consume 30-40 g of food per kilogram of body weight daily during the feeding season, or about 3.5 to 5 times their body weight per year. Based on that estimate, Lockyer (1976c) then calculated the energy budget for blue whale calves, juveniles at puberty, sexually mature young adults, and pregnant females. She calculated that calves consume 3.7×10^5 kcal/day and have a gross growth efficiency of 32.6%, an assimilation efficiency of 86%, and a net growth efficiency of 37.8%. At puberty, Lockyer estimates daily intake for males and females as 2,500 and 3,000 kg/day or 3.6×10^8 and 4.3×10^8 kcal/year. For young, sexually mature adults, intake is 3,400-4,000 kg/day or $4.9 - 5.8 \times 10^8$ kcal/year, and for pregnant females 4,130 - 4,170 kg/day or 6×10^8 kcal/year.

New or Unanalyzed Data

We know of no new or unanalyzed data on blue whales.

11.5 Sei Whale

Population Status

Sei whales, like fin whales, migrate from warm temperate or subtropical waters, where they breed and calve, to colder northern regions to feed. During January and February, most are found at 20°N to 23°N latitude. They migrate north in spring, arriving at 35°-40°N latitude in May or early June. Some continue northward to 50°N or, rarely, to 60°N to spend the summer feeding. The southward migration begins in August or September (Masaki 1976). Sei whales sometimes enter the Bering Sea, but they do not pass through Bering Strait. Most are found south of the Aleutians and off the eastern Kamchatka Peninsula to south of the Commander Islands (Nasu 1963, Nishiwaki 1966).

Population estimates range from 8,600 (Tillman 1977) to 21,000 (Gambell 1976). The original stock size has been estimated at 42-50,000 (Tillman 1975, 1977; Gambell 1976). Tillman (1977) estimated that the population declined from 26,000 in 1968 to 10,000 in 1973. According to Wada (1981), the population decreased through 1976 but may now be increasing.

Sei whale calves are about 4.4 m at birth and grow to 8-9 m by weaning (Tomilin 1957, Masaki 1976). During the first year there is a 10-fold gain in weight. At sexual maturity, individuals are at about 75% of their final body weight and 88-90% of their final length (Masaki 1976). Females are slightly larger than males; maximum and mean lengths for North Pacific sei whales are 18.6 m and 13.3 m for females and 17.1 m and 12.6 m for males (Tomilin 1957). Physical maturity is reached at about 25-30 years or 15.2 m for females and 14.3 m for males (Masaki 1976). As in other baleen whales, there is a seasonal cycle of fasting and feeding; the whales are fattest in autumn just prior to their southward migration. On the average, blubber comprises 18-25% of whole body weight (Omura 1950a). Calculated whole weights for sei whales, based on actual weights of 23 whales, are: 10.8 m - 7,630 kg; 12.6 m - 10,550 kg; 13.8 m - 14,050 kg; 15.4 m - 18,150 kg; and 16.9 m - 22,880 kg (Omura 1950a).

Sexual maturity is reached by 6-7 years (Masaki 1976) or 10-14 ear plug laminations (Rice 1963) and lengths of about 13.7 m in females and 12.9 m in males (Omura 1950b, Masaki 1976). Prior to the 1930's, sexual maturity was not obtained until about 10 years (Masaki 1976).

Most breeding occurs from October to March, with a peak in late December. Most births occur in September to February, with a peak in early November, for a total gestation period of about 10.5 months (Masaki 1976). Multiple foetuses occur at a rate of about 0.52% (n = 3,686). The sex ratio at birth is 1:1 but may be skewed slightly toward males in adult whales (Masaki 1976). The average interval between calves is 2 years, with a range of 12-40 months. However, the determination of actual pregnancy rates is complicated by the ban on hunting cows with calves. According to Masaki (1976), the ovulation rate changes with age, averaging about 0.604 in females younger than 23 years and 0.438 in females older than 24 years. At 10 years it is about 1.0 and at 40 years about 0.3. Reported pregnancy rates range from 0.33-0.84 (Omura 1955). Rice (1977) found 68% of the mature females he examined to be pregnant. Tillman (1977) estimated a recruitment rate for sei whales of 0.06-0.15.

Predators of sei whales include killer whales and humans. Tomilin (1957) believed killer whales were probably not a major cause of mortality. In the Antarctic, Shevchenko (1975) found that 24% of the sei whales he examined had scars from killer whale bites.

Sei whales in the North Pacific were not significantly exploited until 1963 (Tillman 1977). The annual harvest prior to World War II was about 450 per year and from 1954 to 1963 about 1,250 per year, including both Japanese and Soviet take (Masaki 1976). Since 1963 the harvests have been as follows: 1963 - 2,590; 1964 - 3,642; 1965 - 3,172; 1966 - 4,406; 1967 - 6,053; 1968 - 5,740; 1969 - 5,157; 1970 - 4,503; 1971 - 2,993; 1972 - 2,327; 1973 - 1,856; and 1974 - 1,280, for an average of about 4,000 per year (Tillman 1977).

Natural mortality rates for the entire North Pacific population of sei whales have been calculated as 0.060 for females and 0.054 for males. This does not include juveniles, which are underrepresented in the catch due to a minimum size restriction on the harvest (Masaki 1976). These rates are similar to the 0.073 and 0.077 reported by Lockyer and Brown (1979) for sei whales taken off Iceland.

Diet Composition

Sei whale calves nurse for about 5-7 months (Tomilin 1957, Brodie 1969, Masaki 1976). They are weaned during the summer feeding period when they attain a length of 8-9 m.

Since few sei whales enter the Bering Sea to feed during summer, there is little specific information on their foods there. In general, in the North Pacific they eat mainly *Calanus* copepods and some euphausiids, squids, and fishes (Tomilin 1957, Klumov 1963). Among the fishes eaten are smelt, sand lance, arctic cod, rockfishes, greenlings (*Hexagrammos* sp.), pollock, capelin, and sardines. According to Nemoto (1959), they prefer copepods to euphausiids. He examined approximately 800 stomachs (about 40% contained food) collected throughout the North Pacific in 1952-58 and found that copepods were the primary food; a very few euphausiids and fishes were also eaten. Off the western Aleutians a few had eaten saury. The diet showed little year-to-year variation. Off the Kuril Islands, squids and copepods (*Calanus plumchrus*) were the main dietary components (Betesheva 1954, cited in Tomilin 1957; Nemoto 1959). Copepods were the major food off Kronotskiy Bay along the Kamchatka Peninsula, capelin and pollock were eaten near the

Commander Islands, and arctic cod were reported from Providenya Bay and Mechigmen Inlet (Tomilin 1957, summarizing other reports).

Kawamura (1980) summarized the foods of approximately 12,000 sei whales collected in the North Pacific and found that copepods (mostly Calanus plumchrus) comprised 83% of the diet; euphausiids - 13%; fishes - 3%; and squids - 1%.

Food Requirements

Nemoto (1959) reported that the average sei whale stomach from the Kuril Islands contained 100-400 kg of food. He cites Betesheva (1954) in reporting a maximum weight of contents of 600 kg.

Lockyer (1976c) reported the average weight of stomach contents for sei whales in the Antarctic as 180-230 kg for whales 13-17 m in length.

Zenkovich (1969, cited in Lockyer 1976c) suggested that sei whales may feed up to five times per day and consume as much as 1,500 kg/day in the Antarctic.

New or Unanalyzed Data

We know of no new or unanalyzed data on sei whales. With the cessation of commercial hunting of whales, biological samples have become unavailable.

11.6 Humpback Whale

Population Status

Humpback whales occur in both the northern and southern hemispheres. Three isolated populations exist, one in the southern hemisphere and one each in the North Atlantic and North Pacific (Wolman 1978). Unlike blue, fin, and sei whales, they migrate between shallow coastal waters and oceanic islands. In the North Pacific there are three main winter concentration areas: in the western Pacific around the Mariana, Bonin, and Ryukyu Islands and Taiwan; around the Hawaiian Islands; and in Mexican waters along the coast of Baja California (Tomilin 1957, Berzin and Rovnin 1966, Baker and Herman 1981).

Humpback whales begin to migrate north along the American coast in March and April and arrive in the Gulf of Alaska and Aleutian Islands in April, May, and June; Bristol Bay and around Cape Newenham in July; and the Chukchi Sea in July to September (Tomilin 1957, Zenkovich 1955). During summer they are found from Vancouver Island to the southern Chukchi Sea. In the Bering Sea they are most numerous south of Nunivak Island, close to Cape Newenham, between the Pribilofs and Cape Newenham, near Cape Navarin, in the Gulf Anadyr, and north of St. Lawrence Island. They are seen less frequently south and east of the Pribilofs, near Olyutorskiy Cape and Bay, west of St. Lawrence Island, and in Mechigmen Bay. In the early 1960's they were most numerous in the eastern Aleutians and north of the Pribilof Islands (Fiscus, pers. commun.).

On the Asian side they migrate north to the Sea of Okhotsk and Kamchatka; some go north to the Gulf of Anadyr, Olyutorskiy Bay, or through Bering Strait to the Chukchi Sea (Tomilin 1957, Berzin and Rovnin 1966). They begin their southward migration in October.

North Pacific humpback whale populations were greatly depleted by commercial whaling in the 1950's and the early 1960's and were not completely protected until 1966 (Tillman 1975). The pre-exploitation North Pacific population is estimated to have been about 15,000 (Wolman 1978). The present North Pacific population is estimated at 1,200–1,600 (Gambell 1976, NMFS 1981b).

Humpback whales grow to about 16 m; mean size is about 12 m (Tillman 1975). The largest North Pacific humpback reported in the literature is a 15.9-m female taken in Bering Strait (Tomilin 1957). Physical maturity occurs at about 35 ear plug laminations, or 14.8 m in females and 13.6 m in males (Rice 1963). The following weights have been recorded: 12.9 m - 27.7 mt and 13.9 m - 32.4 mt (Nishiwaki 1950, Tomilin 1957). New calves are 4.5–5 m long and weigh about 2 mt (Tomilin 1957).

Sexual maturity occurs at 8–14 ($\bar{x} = 10$) ear plug laminations, or about 12 m in females and a little less than 12 m in males (Rice 1963).

Mature males average 48 cm shorter than females (Tomilin 1957). Most breeding takes place from October to April, with a peak in December. Calves are born after a gestation period of about 11-11.5 months (Tomilin 1957, Rice 1963). Rice (1963) found an ovulation rate of 0.40 per ear plug lamination and an observed pregnancy rate of 0.60, which he corrected to a true rate of 0.43. Although Rice reported no multiple pregnancies and no instances of simultaneous pregnancy and lactation, Tomilin (1957) reported both (0.5% twin fetuses). Tomilin estimated the reproductive cycle at one calf per 2 years or, in some instances, two calves per 3 years.

Nothing is known about the natural mortality rates of humpbacks or about the age and sex structure of the population.

Diet Composition

Humpback whale calves nurse for about 5-6 months, or until they are about 8 m long. Saffron cod was found in the stomach of a 7.3-m "suckling" (Tomilin 1957). The milk is about 38% fat, and the calf eats about 43 kg/day (Tomilin 1957).

In the North Pacific, both euphausiids and fishes are major foods of humpbacks (Nemoto 1957, 1959, 1970; Tomilin 1957; Klumov 1963; Kawamura 1980). In the northern part of the North Pacific, Nemoto (1957, 1959) found only euphausiids in 238 of 308 stomachs containing food. Fifty-three stomachs contained only fishes, and the remainder a combination of fishes and euphausiids. Squids were present in only two stomachs. South of Nunivak Island in July, Nemoto (1978) observed a group of humpbacks feeding on *Thysanoessa raschii*. In areas west of Attu and south of Amchitka, humpbacks fed almost exclusively on Atka mackerel 15-30 cm long (Nemoto 1957, 1959); at other sites along the Aleutians they fed on euphausiids and pollock (Nemoto 1978). Other fishes eaten by humpbacks include herring, capelin, sand lance, smelt, cods, salmon, rockfishes, saffron cod, and arctic cod (Nemoto 1957, Tomilin 1957, Klumov 1963). According to Klumov (1963), humpbacks in the Bering and Chukchi seas are found near aggregations of arctic cod, herring, and capelin. Tomilin (1957) identified mysids (*Mysis oculata*) as the primary prey in Bering Strait and the southern Chukchi Sea; pelagic amphipods (*Parathemisto libellula*), shrimps (*Eualus gaimardi* and *Pandalus goniurus*), and arctic and saffron cod were also eaten. Klumov (1963) listed *Calanus* copepods as prey, but Nemoto (1959) maintained that humpback whales do not ordinarily eat copepods because of the coastal distribution of the whales and the oceanic distribution of the copepods.

In Olyutorskiy Bay in September, Tomilin (1957) found that humpback whales ate capelin, herring, sand lance, *Thysanoessa inermis*, *Mysis oculata*, and *Anonyx nugax*. Off Kamchatka they ate herring in summer and capelin in autumn, in addition to sand lance, *T. inermis*, *A. nugax*, and *M. oculata*. Off the Alaska coast they ate 40-cm cod and euphausiids.

Food Requirements

The maximum amounts of stomach contents reported in the literature are 500 kg of *Thysanoessa longipes* in a 14.3-m female and 600 kg of saffron cod in a male of unspecified size (Tomilin 1957).

New or Unanalyzed Data

We know of no new or unanalyzed data on humpback whales.

11.7 Pacific Right Whale

Population Status

Pacific right whales occur from Alaska and the Aleutian Islands south to Oregon and California, and from the Gulf of Anadyr and Sea of Okhotsk to the Yellow and China seas (Tomilin 1957). In the eastern Pacific they summer (April-September) mostly north of 50°N latitude, particularly in the Gulf of Alaska from 145° to 151°W longitude (Berzin and Rovnin 1966). Some enter the Bering Sea, where they have been sighted as far north as Bering Strait. They are found mostly in the southeast corner in the area bounded by a line from Atka to St. Matthew Island to Nunivak Island; in the past, small groups were found between the Pribilof Islands and Bristol Bay, and between the Pribilofs and Nunivak Island (Berzin and Rovnin 1966). The wintering grounds of these eastern whales are poorly known. They apparently occur off the coasts of Oregon and California, south to about 28°N, and may be present around the Hawaiian Islands (Tomilin 1957, Berzin and Rovnin 1966, Rice and Fiscus 1968). On the Asian side, Pacific right whales are found from May to September off Japan, the Kuril and Commander Islands, Kamchatka, and the Sea of Okhotsk (Omura 1958, Omura et al. 1969). They winter south to 20°N latitude, around the southern Japan Islands and the Yellow Sea (Tomilin 1957, Omura 1958, Nishiwaki 1967).

Pacific right whales have been hunted nearly to extinction (Nishiwaki 1967). Stocks were depleted by the late 1800's and have been completely protected since the early 1900's (Tomilin 1957, Rice and Fiscus 1968, Berzin and Doroshenko 1981). The North Pacific population is estimated to number about 150 (100-200) whales (Gambell 1976, NMFS 1981b). Recovery of the population since protection has been extremely slow if it has occurred at all.

Pacific right whale calves are about 4.5-6 m at birth (Tomilin 1957, Gilmore 1978). Adults grow to 15-18 m (Tomilin 1957, Omura 1958, Tillman 1975). Omura reports a 17.8-m individual taken off southern Kamchatka to be the largest on record. Right whales are far heavier than other whales of the same length. Representative weights at length are as follows: 11.7 m - 22.9 mt; 12.6 m - 28.9 mt; 14.7 m - 52.9 mt; 16.6 m - 63.1 mt; and 17.4 m - 106.5 mt (Omura et al. 1969).

There is little information in the literature about the biology of Pacific right whales. Age and size at sexual maturity are unknown, as are pregnancy rates. By analogy with other right whales, the gestation period is probably 1 year, with breeding and calving occurring in winter (Tomilin 1957). Sex ratio, age structure of the remaining population, and mortality rates are all unknown.

Diet Composition

Pacific right whales, like other right whales, feed in surface waters on planktonic crustaceans, primarily copepods. *Calanus cristatus* and *C. plumchrus* are the species most commonly eaten (Omura 1958, Klumov 1963, Nemoto 1968). *Euphausia pacifica* is also eaten (Omura et al. 1969).

Food Requirements

Nothing is known about the food requirements of Pacific right whales.

New or Unanalyzed Data

We know of no new or unanalyzed data on Pacific right whales.

11.8 Bowhead Whale

Population Status

Bowhead whales occur only in arctic and subarctic waters and are concentrated in areas which may represent distinct stocks: 1) Spitzbergen west to east Greenland; 2) Davis Strait, including Baffin Bay, James Bay, and Hudson Bay; 3) Sea of Okhotsk; and 4) the Bering, Chukchi, and Beaufort seas. We will discuss only the latter stock, which is commonly referred to as the western arctic population.

Some aspects of the distribution and migration of western arctic bowheads are quite well known. In spring, whales move northward through Bering Strait and along the northwestern coast of Alaska, passing Point Barrow and moving eastward to Banks Island and Amundsen Gulf (Braham et al. 1980b, c). They summer in Amundsen Gulf and the eastern Beaufort Sea (Fraker and Bockstoce 1980), then move westward along the northern coast of Alaska (Frost and Lowry 1981d), apparently moving offshore at Barrow toward Wrangel Island. Specifics of the autumn migration and wintering areas are poorly known.

Although in the late 1800's and early 1900's some bowheads remained in the Bering Sea during ice-free months, recent surveys indicate that few, if any, do so at present (Dahlheim et al. 1980). It is likely that much of the population is in the Bering Sea from November or December through April. Wintering areas occur in the pack ice from St. Lawrence Island south to the Pribilof Islands (Braham et al. 1980b, c).

Estimates of present abundance of bowhead whales are based on counts of animals passing Point Barrow during the spring migration. Braham et al. (1979a), based on counts conducted in 1978, estimated the population to number at least 2,264. Based on counts made in the spring of 1982, Dronenburg et al. (in press) estimated the population to number between 3,125 and 3,987 whales. Both of these are undoubtedly underestimates of the total population size since for a variety of reasons not all whales are counted. The size of the bowhead stock prior to commercial whaling has been estimated as 14-26,000 (Breiwick et al. 1981). Commercial whalers killed approximately 19-21,000 whales during the period 1848-1915 (Bockstoce 1980). Eberhardt and Breiwick (1980) have estimated that the minimum population size, which occurred in about 1912, was not less than 600.

Bowhead whales are about 4 m long at birth and 14-18 m at sexual maturity (Tomilin 1957). Adult females are generally somewhat longer than males. We have located no data on weights of bowhead whales. Some information is available on yields of blubber and oil from animals taken during commercial whaling (e.g., Tomilin 1957, Bockstoce 1980).

Vital parameters of bowheads are poorly known. Females mature at a length of approximately 12 m (Johnson et al. 1981). Marquette (1978) indicates that both sexes reach sexual maturity at about 4 years of age. Based on calf counts, Braham et al. (1979a) estimated a gross recruitment rate of 2.5-3.5%. Age structure and mortality rates are not known.

Diet Composition

All available data on foods and feeding of bowhead whales have recently been reviewed (Frost and Lowry 1981a, d). No samples are available to indicate food of bowheads in the Bering Sea. Frost and Lowry (1981a) speculate that bowheads feed little, if at all, during winter months. The only substantial information on foods of bowheads is from whales taken in Eskimo subsistence harvests at Point Barrow and Kaktovik. Those samples indicate that the primary foods eaten in the Alaskan Beaufort Sea are calanoid copepods and euphausiids of the genus *Thysanoessa* (Lowry et al. 1978, Lowry and Burns 1980, Frost and Lowry 1981d).

Food Requirements

Based on comparisons with other whale species, Frost and Lowry (1981a, d) estimated that bowheads consume 3% of their body weight in food each day during the feeding season. Marquette (1978) estimates a daily food demand of about 4% of the total body weight or about 2 tons of food per day for a 15-m whale. Based on energetics calculations, Brodie (1980) estimated that an average whale (about 46 mt) would consume 500-600 kg of crustaceans per day during a 6-month feeding season, which suggests a daily intake of 1.1-1.3% of the total body weight.

New or Unanalyzed Data

The NMFS NMML has been collecting information and specimens from bowhead whales taken in the Eskimo subsistence harvests. Analysis of specimens such as reproductive tracts may increase the available data on reproductive rates and age at sexual maturity.

11.9 Sperm Whale

Population Status

Sperm whales occur worldwide. In the North Pacific they occur from equatorial waters to the northern Bering Sea, at least as far north as Cape Navarin, but not to Bering Strait (Tomilin 1957, Berzin and Rovnin 1966, Nishiwaki 1966). At least two, and perhaps three, separate stocks are recognized in the North Pacific (Best 1975, Horwood and Garrod 1980, IWC 1980). The eastern or American stock migrates between wintering grounds in the waters south of 35°N between the northern Hawaiian Islands and California, and summer feeding grounds in the waters of British Columbia, the Gulf of Alaska, the Alaska Peninsula, and the Aleutian Islands (Tomilin 1957, Berzin and Rovnin 1966). The western or Asian stock winters in the waters around the Bonin Islands, southern Japan, and the Kuril Islands and moves north in summer. Males of these two stocks may mingle at northern latitudes during summer (IWC 1980).

The social structure of sperm whales is complex. Herds consisting of females attended by harem bulls are segregated from herds of bachelor bulls, which may be immature. Females are not usually found north of about 45°N latitude (rarely 51°), but males are found as far north as 65°N (Omura 1955, Tomilin 1957, Sleptsov 1961, Ohsumi 1965, Berzin and Rovnin 1966). From July to September only males have been reported in the Bering Sea, usually in deep waters of the western portion, off the continental shelf, and north of the Aleutian Islands eastward to Unimak Pass. They are most common along the shelf break midway between the Pribilofs and Cape Navarin, south of the Pribilofs, north of Atka Island, and in the western Bering Sea in an area centered at 59°N and 175°E. Sperm whales usually appear off Kamchatka and the Aleutians in April or May and leave in September-November (Tomilin 1957, Berzin and Rovnin 1966).

Estimates for the exploitable (>12 years) North Pacific population of sperm whales are around 200,000 for the eastern stock and 700,000 for the western stock (Horwood and Garrod 1980, IWC 1980, NMFS 1981b). Of the eastern stock, an estimated 70-90,000 are males and 125,000 are females (Tillman 1975, Gambell 1976). Ohsumi (1965) and Best (1975) estimate that 40-60% of the mature males (20-30% of the entire mature population) spend the summer at high latitudes. Best (1975) estimated that about 38,000 exploitable males were present north of 50°N in 1971.

In the eastern North Pacific, sperm whale populations are somewhat reduced from pre-commercial whaling days. Females are thought to be at about 80-90% of the original population size and males at between 45% (Tillman 1975, Gambell 1976, Ohsumi 1980) and 70% (Horwood and Garrod 1980) of original levels.

Sperm whales are the largest of the toothed whales. They are about 4 m long at birth (3.5-5 m), 6 m at 1 year, and 8 m at 3 years

(Berzin 1964b, Ohsumi 1965, Lockyer 1976a). After about the 3rd year, males grow markedly faster than females and attain a larger size. Females become physically mature at about 11 m (15-17 years, assuming 2 tooth layers per year) and grow to a maximum length of about 12 m (Tomilin 1957, Berzin 1964b). Comparable lengths in males are 16 m (23-25 years) and 20 m. Maximum weight for a male in the Bering Sea is about 55 mt (Tillman 1975). Some examples of weight-at-length data are as follows: 4 m (calf) - 1 mt; 10.9 m - 13.5 mt; 12.4 m - 16.1 mt; 13.5 m - 22.7 mt; 14.6 m - 26.1 mt; 16.4 m - 30.8 mt; 17.2 m - 40.3 mt; and 18.0 m - 53.4 mt (Nishiwaki 1950, Tomilin 1957, Lockyer 1976a).

The maximum reported age of sperm whales is 77 years (Ohsumi 1965). There appears to be some uncertainty in the literature over whether a year's growth is represented by one or two layers in the teeth. Thus, Berzin (1964b), who assumes two layers per year, reports a maximum age of 35 to 45 years. This confusion also causes problems with length-at-age data.

Females attain sexual maturity when they are 9-10 m in length (Omura 1950b, Rice 1963, Lockyer 1976a) and about 9-13 years of age (Rice 1963, Lockyer 1976a, Horwood and Garrod 1980, IWC 1980). Males become sexually mature at about 10-12 m in length and probably 10-15 years of age (Nishiwaki and Hibiya 1951, Lockyer 1976a, Horwood and Garrod 1980, IWC 1980). However, they do not become socially mature until they reach about 14 m and are 26 years old (Lockyer 1976a). Mating apparently occurs from February to August, with a peak in April (Rice 1963, Ohsumi 1965, Masaki 1980). Calves are born from June to October (or perhaps December) with a peak in August, for a total gestation time of about 14-1/2 to 16-1/2 months (Rice 1963, Ohsumi 1965, Doi et al. 1980, Masaki 1980, Shimadzu 1981). The sex ratio at birth is 1:1. A single calf is usual, although twin fetuses are found at a rate of 0.45% (Ohsumi 1965). Estimated pregnancy rates for mature females (mostly based on the Asiatic stock) range from about 20 to 29% (Ohsumi 1965, IWC 1980, Masaki 1980). The pregnancy rate is greatest at age 15-20 years; it is slightly less but quite constant from 20-60 years. The entire reproductive cycle lasts 3-4 years. About 8% of the females sampled are both pregnant and lactating (Ohsumi 1965). Actual annual recruitment to the population is about 0.05 (Ohsumi 1980).

Annual mortality in North Pacific sperm whales has been estimated at about 0.05-0.06 (Chapman 1980b, IWC 1980, Ohsumi 1980). It may be as high as 0.096 in juveniles (Doi et al. 1980). Killer whales are apparently not major predators of sperm whales (Lockyer 1976a).

Commercial hunting for sperm whales has occurred in the North Pacific since the early 1900's. In the early 1970's the fishery was taking 8-10,000 per year (Tillman 1975). In 1979-1980 the IWC quota was approximately 2,700 sperm whales (Wada 1981).

Diet Composition

Sperm whale calves nurse for up to 25 months (Ohsumi 1965, Shimadzu 1981), growing from an average of 4 m and 1,000 kg to 6.7 m and 2,800 kg during that time (Lockyer 1976a). They consume an average of 20 kg of milk per day.

Throughout the North Pacific, sperm whales eat mainly cephalopod molluscs, particularly squids of the family Gonatidae (Table 11.9-1). As many as 15 species of cephalopods have been found in a single stomach (Tomilin 1957). In the Bering Sea, gonatids and onchoteuthids are the most prevalent families. Fishes are generally less important than squids in the diet; however, fishes are quite important in the Gulf of Alaska, the eastern Bering Sea (east of 170°W), and along the shelf break (Berzin 1959, 1971; Okutani and Nemoto 1964, Kawakami 1980). Fishes occur in 1-9% of the stomachs from Japanese waters, 31% from Kuril Islands waters, 6-47% from the Bering Sea and Aleutian coast west of 180°, 7-29% in the Bering Sea and Aleutian coast between 180° and 160°W, and 68% from the Gulf of Alaska (Kawakami 1980). According to Berzin (1959) fishes occur in 20%, 36%, and 47% of stomachs from the waters of the Commander Islands, Olyutorskiy Bay, and the northern part of the Bering Sea. Tarasevich (1968a) found that fishes were eaten more frequently in spring than in summer and suggested that is because squids do not become plentiful until summer. He also found that males ate fish more often than did females. The fishes most commonly eaten include rockfishes, cod, sharks, skates, lancetfish, lumpfish, and rattails.

Sperm whales are capable of diving to great depths; males dive deeper than females and feed more heavily on deepwater fishes and cephalopods (Tarasevich 1968a). A study off South Africa using radio telemetry showed that, although sperm whales can dive to over 3,000 m, dives usually are about 350 m (Lockyer 1977a). It is not clear whether the whales usually feed at great depths or eat deepwater creatures that migrate to the upper 200 m of water at night (Nemoto 1957, Sleptsov 1961).

Food Requirements

Estimates of the daily consumption of food by sperm whales range from 1 ton to 2-3 tons/day for a 13- to 14-m whale, or 2-4% of body weight per day (Kawakami 1980). Based on stomach capacities, Lockyer (1976a) assumed 3% of body weight per day for most whales, except for large 40- to 50-mt bulls for which she assumed 3-1/2% per day. With those assumptions she calculated an annual energy budget for sperm whales of various ages (Table 11.9-2). Daily consumption ranged from 190 kg/day, or about 70 mt/year for a 8.7-m female weighing 6.4 mt, to 1,500 kg/day and 550 mt/year for a 15.9-m male weighing 43.6 mt. Since the number of individuals entering the Bering Sea and the average residence time there are unknown, it is not possible to estimate the total food consumed by sperm whales in the Bering Sea.

Table 11.9-1. Foods of sperm whales in the North Pacific and Bering Sea.

Area	Food	Source
Japan Coast	Mostly squids (*Histioteuthis*, *Ommastrephes*, *Moroteuthis*, *Gonatus*, *Gonatopsis*), some octopus, pollock, Pacific cod, rockfishes, saury, sardines, mackerel	Omura 1950b, Mizue 1951, Kawakami 1976, Okutani et al. 1976
Kuril Islands	Primarily squids (*Gonatus*, *Gonatopsis*, *Galiteuthis*, *Histioteuthis*); secondarily lancetfish[1], lumpfish[2], rattails, skates, Pacific cod, Atka mackerel, rockfishes; occasionally salmon, saury, sharks, pollock, octopus	Akimushkin 1955, Betesheva 1961, Sleptsov 1973
Commander Islands, Kamchatka, and Olyutorskiy Bay	Mainly squids (*Gonatus*, *Moroteuthis*); also rockfishes, skates; occasionally tanner, spider, and king crabs	Tomilin 1957, Berzin 1959, Kawakami 1980
Vancouver Island/ British Columbia	Squids (*Moroteuthis*, *Berryteuthis*, *Gonatus*, *Gonatopsis*) and rockfishes	Clark and McLeod 1980, Kawakami 1980
Gulf of Alaska	Squids (*Galiteuthis*, *Gonatus*, *Chiroteuthis*), octopus, rattails, lancefish, rockfishes	Kawakami 1980
Aleutian Islands	Squids (*Gonatus*, *Taonius*, *Galiteuthis*), rockfishes, lancetfish, lumpfish	Tarasevich 1968a, Kawakami 1980
Pribilof Islands/ Bering Sea Slope	Squids (*Galiteuthis*, *Gonatus*) and fishes	Kawakami 1980

1 *Alepisauris* sp.
2 F. Cyclopteridae

Table 11.9-2. Summary of energy budget for sperm whales (modified from Lockyer 1976a).

Sex	Male or female	Female	Male	Male	Male	Female	Male
Stage of development	1st year suckling calf	Puberty/sexual maturity	Puberty	Sexual maturity	Social maturity-harem status	Physical maturity	Physical maturity
Body length (m)	6.00	8.70	9.65	12.00	13.65	10.90	15.85
Body weight (*tons*)	2.00	6.35	9.40	18.00	27.40	13.50	43.60
Calories of yearly growth (kcal)	3.99×10^6	1.99×10^6	3.63×10^6	3.63×10^6	5.08×10^6	No data	No data
Yearly metabolic energy expenditure (kcal)	1.58×10^7	4.23×10^7	5.61×10^7	11.33×10^7	17.23×10^7	8.97×10^7	31.79×10^7
Approximate total energy utilization in a year (kcal)	1.98×10^7	4.43×10^7	5.97×10^7	11.69×10^7	17.74×10^7	$> 8.97 \times 10^7$ allowing for some growth	$> 31.79 \times 10^7$ allowing for some growth
Mean *food* intake per day throughout the previous year (kg)	20	190	270	555	870	420	1,505
Yearly food intake over 365 days (kg)	7,300	69,350	98,550	202,575	317,550	153,300	549,325
Calories of yearly food intake at 800 kcal/kg (kcal)	2.80×10^7	5.55×10^7	7.88×10^7	16.21×10^7	25.40×10^7	12.26×10^7	43.95×10^7

New or Unanalyzed Data

We know of no new or unanalyzed data on sperm whales.

11.10 Belukha or White Whale

Population Status

Belukhas are widely though not uniformly distributed throughout seasonally ice-covered waters of the northern hemisphere. They are probably circumpolar, occurring off North America, Europe, and Asia, including the White, Barents, Kara, Laptev, and East Siberian seas; throughout the North Atlantic, off Spitsbergen, Greenland, and across the eastern Canadian Arctic; the Beaufort, Chukchi, and Bering seas; the Sea of Okhotsk; and Cook Inlet in the Gulf of Alaska (Kleinenberg et al. 1964, Gurevich 1980, Seaman and Burns 1981). Based on a knowledge of seasonal patterns of movement and concentration areas, the presence of major though not complete geographical barriers, and the differences in size of adult animals among areas, it is likely that the population can be divided into a number of somewhat discrete stocks (Sergeant and Brodie 1969, Gurevich 1980).

Belukhas throughout their range spend the winter in ice-covered offshore waters. They are unable to make and maintain breathing holes in any but the thinnest ice (Fay 1974) so are found in areas where geographical, oceanographical, or meteorological factors cause ice motion and the formation of leads. In spring, as soon as the ice begins to break up and move offshore, belukhas move toward the coast, some making extensive northward migrations in excess of 2,000 km and some moving relatively short distances toward shore. Most belukhas appear to spend the summer in coastal waters, concentrating in shallow bays or estuaries of large rivers, although an unknown proportion of some populations remains associated with offshore pack ice. In late summer to late autumn, they move generally south, ahead of or with advancing pack ice (Kleinenberg et al. 1964, Fay 1974).

Belukhas in Alaska are considered to comprise two stocks. One ranges throughout the northern Gulf of Alaska from at least Kodiak Island to Yakutat Bay. The center of abundance of this stock is in Cook Inlet, where an estimated 300-500 whales are present (Klinkhart 1966, Harrison and Hall 1978).

A second, much larger, stock of belukhas ranges seasonally through the Bering, Chukchi, and Beaufort seas. During winter these whales occur throughout the ice fringe and front from the Alaska coast to Siberia, as well as in more northerly regions of the Bering and Chukchi Sea pack ice where open water regularly occurs (Kleinenberg et al. 1964, Fay 1974, Seaman and Burns 1981). As the ice recedes in spring, a large segment of the population moves north, some of them passing Point Hope and Point Barrow during May (Fay 1974, Braham and Krogman 1977, Fraker 1979, Seaman and Burns 1981). Those belukhas are thought to migrate eastward through offshore leads in the Beaufort Sea, then south along the west coast of Banks Island to the Mackenzie River estuary, where they appear in late June and remain until August (Sergeant and Hoek 1974, Fraker et al. 1978, Fraker 1980). An unknown proportion of the belukhas wintering in the Bering Sea moves north through Bering Strait and west into Siberian coastal waters for the summer (Kleinenberg et al. 1964). Other belukhas migrate less extensively and are seen in coastal waters of the Bering and Chukchi seas from shortly after ice breakup in spring until freeze-up in October or November. Belukhas leave the coastal zone in late summer to late autumn. Animals in the northern part of their range move southward ahead of and with the advancing ice pack, most of them passing through Bering Strait and into the Bering Sea (Bailey and Hendee 1926, Fay 1974, Seaman and Burns 1981).

Virtually the entire Bering-Chukchi-Beaufort stock of belukhas overwinters in the Bering Sea. It is unknown what proportion of these whales remains in the Bering Sea during summer (Fay 1974, Braham and Krogman 1977). Major summer concentrations occur in Bristol Bay, particularly inner Bristol Bay near the Nushagak and Kvichak rivers (Brooks 1954, Klinkhart 1966); in Norton Sound and off the mouths of the Yukon River (Fay 1974; Seaman and Burns 1981; ADF&G, unpubl.); and in the Gulf of Anadyr, particularly the Anadyr estuary and to a lesser extent Kresta Bay and Kresta Gulf (Kleinenberg et al. 1964).

The areas and times in which belukhas appear in large numbers are consistent from year to year and are probably related to the presence of sequentially abundant and highly available forage fishes such as salmon, herring, smelt, and arctic and saffron cods (Seaman and Burns 1981; ADF&G, unpubl.). It has also been suggested that warm water temperatures in estuary systems confer a thermal advantage to newborn young, as well as to other age classes (Sergeant 1973, Sergeant and Brodie 1975, Fraker et al. 1978), but this may be less the case in the generally warmer Bering Sea than in colder, more northern regions (Seaman and Burns 1981).

Specific information on the age and sex composition of belukhas present in concentration areas is not available, but evidence from harvest data, local residents, and aerial observations shows that adult males; lactating, post-partem, and pregnant females; juveniles; and calves are all present (Lensink 1961; Klinkhart 1966; ADF&G, unpubl.).

Although records of sightings of belukhas in Alaskan, Canadian, and Soviet waters are numerous, no comprehensive surveys have been undertaken to estimate total abundance. Estimation of the size of the Bering-Chukchi-Beaufort stock of belukhas is complicated by their large and seasonally variable range. Assuming limited interchange among animals in summer concentration areas, a minimum estimate can be derived from available counts and observations. Reliable estimates from aerial surveys suggest 5-6,000 belukhas, not including dark-colored juveniles, occur annually in July in Mackenzie estuary (Fraker 1977). Estimated numbers increased from 1,500-2,000 in 1972 and 3,500-4,000 in 1973 and 1974 to 5,500-6,000 in 1976 and 1977. The increase may be an artifact of improved counts or may reflect year-to-year differences resulting from variable ice conditions. Preliminary analysis of data from 1979 aerial counts suggests a total of about 7,000 adult animals (Fraker 1980). Several thousand belukhas occur along the Alaskan Chukchi Sea coast during summer. Seaman (pers. commun.), based on aerial surveys and aerial photographs, estimated that approximately 2,400 belukhas (2,100, excluding neonates and yearlings) were present in the waters of Kasegaluk Lagoon in July 1979. As many as 1,000 belukhas may be present in Kotzebue Sound during June and/or July (Seaman, pers. commun.; ADF&G, unpubl.). However, it is unknown whether these are the same whales later sighted near Kasegaluk Lagoon. The combined observations of biologists and local residents suggest a conservative estimate of 1,000-1,200, and perhaps as many as 2,000, belukhas using the Norton Sound-Yukon River mouths area (ADF&G, unpubl.) and 1,000-1,500 in Bristol Bay (Brooks 1954; Lensink 1961; ADF&G, unpubl.). Abundance in Bristol Bay apparently varies considerably from year to year (Brooks 1955, 1963). The number of belukhas summering along the coast of Siberia is less well known but may be 4-5,000. In combination, these estimates suggest a total of at least 15-18,000 belukhas in the Bering-Chukchi-Beaufort stock. Since belukhas are also present along and in pack ice during summer, this estimate can be considered conservative. Although local changes in summer distribution have accompanied increases in human activity in the coastal zone of some areas, there is no evidence to suggest that there have been any marked changes in stock size.

Full-term fetuses and newborn calves measure about 150-160 cm in length and weigh approximately 80 kg (Brodie 1971; Sergeant 1973; Ognetev 1981; ADF&G, unpubl.). Growth rates for animals in the Bering Sea stock are not available, but in the eastern Canadian Arctic and northern Europe belukhas grow to about 216 cm and 188 kg by the end of their first year and to 250 cm and 268 kg by age 2 (Brodie 1971, Ognetev 1981). Physical maturity is reached at about 10 years (Brodie 1971, Ognetev 1981). Belukhas are sexually dimorphic; males are somewhat larger than females (Doan and Douglas 1953; Brodie 1971; ADF&G, unpubl.). The average maximum size attained by individuals varies regionally, with members of the Bering Sea stock intermediate in size between those from Churchill and the White Sea (Sergeant and Brodie 1969). In the Beaufort Sea, Sergeant (1962) reported an average maximum size for males and females of 4.6 and 4.0 m. The largest individual measured by Fraker (1977) was a male 5.7 m long and at least 25 years old. Preliminary analysis of data collected from belukhas harvested in Alaska gives a size range of 3.2-4.4 m for adult males (estimated weight 520-1,200 kg) and 3.1-3.6 m for females (480-700 kg) (ADF&G, unpubl.). Over 40% of the body weight may be blubber (Sergeant and Brodie 1969), which can be as thick as 12 cm on large individuals (ADF&G, unpubl.). Blubber thickness varies considerably in females; pregnant and lactating individuals are especially fat. In males, reproductive status seems to have little effect on fatness (Sergeant and Brodie 1969). Blubber is used as an energy reservoir when food is scarce, and animals trapped in areas without food for long periods of time become exceedingly thin.

Methodological problems, including controversial interpretation of growth rings in teeth and analysis of ovarian structure, have complicated the determination of the rate of production of young and the age structure of belukha populations. Recent thorough studies have largely resolved these questions, allowing valid interpretation of the data. It is generally agreed that belukhas deposit two dentine layers (each comprised of a light and dark band) in the teeth each year (Sergeant 1973). Tooth wear resulting in loss of rings causes underestimation of age in older animals; however, this is of comparatively little importance provided that reliable ages can be determined up to the age of sexual maturity. In many belukhas, more than one ovulation can occur during the breeding period, which may result in the presence of accessory corpora lutea in the ovary (Brodie 1971). These accessory bodies were previously erroneously interpreted by Soviet researchers as evidence for annual breeding (Kleinenberg et al. 1964).

The reproductive cycle of belukhas in Alaskan waters is similar to that reported for eastern Canada (Brodie 1971, Sergeant 1973). Female belukhas first ovulate and are capable of breeding just prior to their fourth or fifth birthday and give birth for the first time the following year (Seaman and Burns 1981). Reproductive activity commences in males at about age 8 (Brodie 1971, Sergeant 1973). Most breeding activity occurs in April and May (Lensink 1961; Brodie 1971; Seaman and Burns 1981), followed by a gestation period of about 14.5 months (Brodie 1971). Most females give birth in July or early August, although some births apparently occur from mid-May to the first part of September (Lensink 1961, Fraker 1977, Seaman and Burns 1981). A single calf is usually born and nursed for a 2-year period (Brodie 1971, Sergeant 1973). It appears that few females ovulate in the estrous cycle which follows 10 months after calving; most do not become pregnant again until the following year. Therefore, the breeding cycle is basically triennial, although in some instances pregnancies may occur more or less frequently (Seaman and Burns 1981). In a group of sexually mature female belukhas examined during early summer, one should find approximately one-third about to calve, one-third recently pregnant, and the remainder not bred in the year of collection and accompanied by year-old calves which they are nursing. Since all females capable of ovulating may not become pregnant, actual pregnancy rates will probably be somewhat less than predicted.

Biases associated with hunting and collecting of belukhas complicate estimation of sex ratio and age structure of the population. For example, only six of 68 female belukhas taken in western Alaska in 1977-79 were less than 6 years of age (ADF&G, unpubl.). Braham et al. (1980b) found an adult-to-juvenile ratio of 3.2:1 at Point Hope in 1977. Available data from Alaska suggest that the ratio of males to females does not significantly deviate from unity (1.1:1 for fetuses ($n = 15$); 1.2:1 for non-fetuses ($n = 195$) (Seaman and Burns 1981; ADF&G, unpubl.). However, in the Mackenzie estuary males may comprise up to 80% of the harvest (Fraker 1980). Such skewed harvests may have resulted in more adult females than adult males in the present population, which would increase productivity.

The annual production rate in the Bering-Chukchi-Beaufort belukha stock is unknown. In the eastern Canadian Arctic, Sergeant (1973) has calculated an annual birth rate of 11-14% and found it to agree well with field counts of calves. Using similar methods, Fraker et al. (1978) calculated rates of 12-14.4% for the Mackenzie belukhas, depending on the ratio of females to males.

Mortality rates for belukhas cannot be calculated from the available harvest data since age samples are biased toward older whales. Known causes of mortality in belukhas include predation by polar bears (Freeman 1973) and killer whales (Sergeant and Brodie 1969), human hunting, and occasional entrapment by sea ice and fishing gear. From 1970-79, the combined harvest by humans in Alaska and western Canada averaged about 320 belukhas per year (Table 11.10-1). No recent data are available for the Soviet harvest, but average annual take has been estimated at 100-200 belukhas (Sleptsov 1961a; ADF&G, unpubl.). An additional 25-35% of those harvested are killed but not retrieved (Fraker 1977, Seaman and Burns 1981), bringing the total annual harvest from the Bering-Chukchi-Beaufort stock to 500-700 belukhas, or 2.8-4.6% of the total estimated population of 15-18,000. These harvests are considerably lower than historical levels (Fraker 1977, Seaman and Burns 1981).

Maximum ages recorded for belukhas are 30-34 years, but these are probably underestimated due to tooth wear (Brodie 1971, Seaman and Burns 1981). The relatively low rate of production and large proportion of older animals in harvests suggest that natural mortality rates are low.

Diet Composition

Most belukha calves nurse for about 2 years (Brodie 1971, Sergeant 1973). During the first year, the calves rely mostly on milk. Later, they supplement milk with captured food such as shrimps and other small fishes (Brooks 1955, Brodie 1971).

Although the foods eaten by belukha whales in some parts of their range have been described in detail (e.g., Vladykov 1946, Kleinenberg et al. 1964), the only significant recent information on foods used in the Bering Sea is from studies in inner Bristol Bay (Brooks 1954, 1955). Other scattered collections or observations have been made by local residents or biologists from Bristol Bay to Norton Sound. Brooks (1954) and Lensink (1961) found a close relationship between prey abundance and belukha distribution and movements. Belukhas are present in Kvichak and Nushagak bays in large numbers from May through August. They are attracted to these rivers in early May by large concentrations of outmigrating smelt. At the end of May, whales shift from eating smelt to sockeye salmon (*Oncorhynchus nerka*) fingerlings, which begin to migrate downstream at that time in dense schools.

Table 11.10-1. Annual harvests of belukhas in Alaska and the Mackenzie River estuary, 1970-79.

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	$\bar{x}$
Alaska[1]	200	250	180	150	--	--	--	247	177	138	192
Mackenzie estuary[2]	105	82	113	177	122	142	154	140	121	--	128

1 Seaman and Burns (1981)

2 Fraker (1977) and Hunt (1979)

Downstream salmon migrants continue to be the predominant prey until about mid-June (Table 11.10-2). Brooks (1955) estimated that 150 belukhas feeding on the fingerling salmon run for 19 days would eat approximately 3 million fish. In mid-June adult salmon heading for their upstream spawning grounds become the primary prey. The frequency of occurrence of different species of salmon is directly correlated to their abundance; sockeye salmon predominate in stomachs in the first 3 weeks of July and other salmon species predominate in late July and August. Brooks (1955) estimated that each belukha would eat five salmon per day over a 7-week period; other prey reported by Brooks included flounder, sole, sculpins (F. Cottidae), blennies (F. Stichaeidae), lamprey (Lampetra tridentatus), two types of shrimps, and mussels (Table 11.10-3). Lensink (1961) found that eight belukhas taken 11-25 September 1959 and 1960 had eaten small shrimps, flounders, and a lamprey.

The stomach of a single belukha caught in a fishing net at the mouth of the Naknek River in May 1980 contained remains of 70 rainbow smelt (490 ml), 2 flatfish (77 ml), and 10 shrimp (13 ml) (Seaman et al. 1982).

A variety of observations (summarized in Seaman et al. 1982) indicates a close relationship between groups of belukhas and schools of herring and saffron cod. Three whales taken at Elim on 12 June 1977 had eaten mostly saffron cod (Seaman et al. 1982). The stomach contents of the three were similar and consisted of a combined total of 887 ml of partially digested fish (including at least 3,900 saffron cod, 55 sculpins, and 5 herring) and 381 ml of pebbles (mostly 2 cm or less in diameter). Saffron cod eaten averaged 16.5 cm long (range 6.5-29.1 cm) and 40.0 g in weight (range 1.6-168.4 g); sculpins averaged 35.6 cm (range 22.9-51.0 cm) and 524.6 g (range 119.6-1,362.2 g) (Seaman et al. 1982).

Middendorf (1869, cited in Kleinenberg et al. 1964) reported that belukhas from the Bering Sea ate primarily two species of cuttlefish, Onychia spp. Nikulin (1951, cited in Kleinenberg et al. 1964) believed that belukhas overwintering in the northern Bering Sea fed on arctic cod.

Frost (unpubl.) observed numerous belukhas in association with schools of saffron cod near Golovin Bay in late September 1981. Informants from several villages in Norton Sound have reported salmon in belukha stomachs in July and early August. Fishermen from Elim who annually fish near the northern Yukon Delta frequently see belukhas near the mouths of this river while salmon are present. One fisherman reported taking belukhas with recently ingested chum salmon in their stomachs. It appears that salmon are important to belukhas when available, but that saffron cod are probably of greater importance because they are available and abundant over a longer period of time.

Table 11.10-2. Stomach contents of 37 belukhas from the Kvichak River and its estuary, 22 May-17 June 1954 and 1955 (Brooks 1954, 1955).

	Number of stomachs in which food items occurred	Percent of stomachs in which food items occurred	Average number of food item per stomach in which it occurred
Smelt	34	92	107
Red salmon fingerlings	32	86	643
Flounders	3	8	1
Lamprey	1	3	2
Blenny	1	3	24
Stickleback[1]	3	8	2
Dolly Varden[2]	1	3	1
Shrimp	6	16	12

1 *Gasterosteus* sp.
2 *Salvelinus malma*

Table 11.10-3. Stomach contents of 78 belukhas from Kvichak and Nushagak bays, 1 July-18 August 1954 and 1955 (Brooks 1955).

Food	Number of stomachs in which food items occurred	Percent of stomachs in which food items occurred	Average number of food item per stomach in which it occurred
Salmon (red)	38	49	4
Salmon (chum)[1]	28	36	2
Salmon (pink)[2]	18	23	4
Salmon (silver)[3]	14	18	2
Salmon (king)[4]	5	6	2
Salmon (unid.)	5	6	4
Salmon (all species combined)[5]	57	73	6
Blenny	13	17	15
Sculpins	7	9	3
Smelt	3	4	7
Flounder	3	4	4
Unidentified small fishes	3	4	3
Shrimps	12	15	10
Milk	3	4	
Empty	12	15	

1 *Oncorhynchus keta*.
2 *O. gorbuscha*.
3 *O. kisutch*.
4 *O. tshawytscha*.
5 All salmon listed were adults.

Foods reported from the Sea of Okhotsk were generally similar to those reported for Bristol Bay and Norton Sound and included pink and chum salmon; small gregarious fishes, particularly saffron cod and herring; and invertebrates, especially the shrimp Crangon septemspinosa (Arsen'ev 1936, cited in Kleinenberg et al. 1964). Arsen'ev found the presence and abundance of belukhas to be strongly correlated with the availability of prey and suggested that belukhas can feed regularly only when food is present in large concentrations; the percentage of empty stomachs increased markedly in the absence of migratory fishes.

Age-related differences in feeding were reported by Arsen'ev (1936). He found that the stomachs of sucklings contained only milk. Young gray belukhas had eaten primarily benthic invertebrates (particularly the shrimp Crangon); subadult belukhas ate mostly small gregarious fishes such as herring and saffron cod; and adults ate larger fishes such as chum and pink salmon (Table 11.10-4). Vladykov (1947) and Seaman et al. (1982) also found that older whales ate larger fish.

Seaman et al. (1982) reported on the contents of 115 belukha stomachs containing food from the Chukchi Sea. Spring foods at Point Hope included arctic cod, shrimps, and octopus. In coastal areas such as southeastern Kotzebue Sound and Kasegaluk Lagoon, summer foods included saffron cod, sculpins, herring, smelt, capelin, salmon, char (Salvelinus alpinus), shrimps, and octopus. Saffron cod was the primary prey species in southeastern Kotzebue Sound in June. Other species of fishes are eaten in relation to their seasonal patterns of distribution and abundance.

Elsewhere in their range, belukhas eat foods similar to those reported from the Bering, Chukchi, and Okhotsk seas (Table 11.10-5).

There is little information on sex-related differences in the diets of belukhas. The limited data available suggest that males, which are significantly larger than females (Sergeant and Brodie 1969), eat larger fish than do females and juveniles (Vladykov 1947; Kleinenberg et al. 1964; Seaman et al. 1982).

There are no published data on the foods of belukhas in the Bering Sea in winter. Seaman et al. (1982) speculate, based on a knowledge of the distribution and abundance of prey, that pollock is probably a major food of belukhas in the ice front during winter and that arctic and saffron cods are important farther north. The winter movements of belukhas are closely tied to the distribution of arctic cod in other parts of their range (Kleinenberg et al. 1964). During autumn and winter, residents of St. Lawrence Island associate the presence of belukhas with an abundance of saffron cod (Seaman et al. 1982).

There are several possible sources of error in the analysis of belukha food habits based on stomach contents. The importance of benthic invertebrates as prey may be overrepresented. Many may be secondary food items, having been released from the stomachs of fishes

Table 11.10-4. Age-related differences in the diets of belukhas from the Sea of Okhotsk (Arsen'ev 1936, cited in Kleinenberg et al. 1964). Numbers represent percent frequency of occurrence.

	Yearlings	Subadults	Adults
Crustaceans (mostly _Crangon_)	43.5	8.8	8.9
Saffron cod	30.4	20.6	11.1
Chum salmon	4.4	55.9	60.0
Fish and crustaceans	21.7	14.7	4.5
Salmon, other fishes, and crustaceans	--	--	15.5

Table 11.10-5. Summary of information on foods of belukha whales throughout their circum polar range. Items of major importance are indicated by XX.

		White Sea	Kara Sea	Barents Sea and Novaya Zemlya	Gulf of St. Lawrence	Hudson Bay and eastern Canadian Arctic	Greenland/ Spitsbergen	Sea of Okhotsk	Mackenzie Estuary/ Amundsen Gulf	Bristol Bay	Norton Sound	Chukchi Sea
Cod	<u>Gadus</u>	XX	--	--	XX	X	X	--	--	--	--	--
Saffron cod/navaga	<u>Eleginus</u>	XX	X	XX	--	--	--	XX	X	--	XX	XX
Tomcod	<u>Microgadus</u>	--	--	--	XX	--	X	--	--	--	--	--
Arctic cod	<u>Boreogadus</u>	XX	XX	XX	--	XX	--	--	X	--	--	XX
Haddock	<u>Melanogrammus</u>	XX	--	--	--	--	X	--	--	--	--	--
Flatfish	F. Pleuronectidae	XX	--	--	--	--	X	X	--	X	--	--
Herring	<u>Clupea</u>	XX	--	XX	--	--	--	XX	--	--	XX	--
Capelin	<u>Mallotus</u>	XX	X	--	XX	XX	X	--	--	--	--	X
Smelt	F. Osmeridae	X	X	X	X	--	--	X	X	XX	--	XX
Sand lance	<u>Ammodytes</u>	--	--	--	XX	X	X	--	--	--	--	--
Whitefish and cisco	<u>Coregonus</u>	X	XX	XX	--	X	--	X	X	--	--	X
Salmon	<u>Oncorhynchus</u>	X	--	X	--	--	--	XX	--	XX	X	X
Sculpins	F. Cottidae	--	--	--	XX	X	X	X	--	X	X	X
Char	<u>Salvelinus</u>	--	X	XX	--	XX	--	X	--	--	--	X
Lamprey	F. Petroyzontidae	X	--	--	--	--	--	X	--	X	--	--
Skate	<u>Raja</u>	--	--	--	--	--	X	--	--	--	--	--
Pike	<u>Esox</u>	--	X	--	--	X	--	--	--	--	--	--
Eelpout	F. Zoarcidae	--	--	--	--	--	--	X	--	--	--	X
Lumpfish	<u>Cyclopterus</u>	X	-	--	--							
Blennies	F. Blennidae	--	-	--	--	--	--	X	--	X	--	--
Crustaceans	<u>Crangon</u>, <u>Hyas</u>, <u>Mesidothea</u>	X	X	X	X	XX	--	XX	--	X	--	X
Polychaete worms	<u>Nereis</u>	--	--	--	XX	XX	--	X	--	--	--	X
Cephalopods (squid, octopus, cuttlefish)		--	--	--	XX	XX	--	X	X	--	--	X
Molluscs		--	--	--	X	--	--	--	--	X	--	X

References:

White Sea: Tomilin 1957, Kleinenberg et al. 1964 (citing others)
Kara Sea: Tomilin 1957, Kleinenberg et al. 1964 (citing others), Medvedev 1971
Barents Sea and Novaya Zemlya: Kleinenberg et al. 1964 (citing others)
Gulf of St. Lawrence: Vladykov 1947
Hudson Bay and eastern Canadian Arctic: Doan and Douglas 1953, Sergeant 1962, 1963
Greenland/Spitsbergen: Tomilin 1957, Kleinenberg et al. 1964, Gurevich 1980 (all citing others)
Sea of Okhotsk: Tomilin 1957, Kleinenberg et al. 1964 (citing others)
Mackenzie Estuary/Amundsen Gulf: Fraker 1977, Fraker et al. 1978
Bristol Bay: Brooks 1954-56, Seaman et al. 1982
Norton Sound: Seaman et al. 1982
Chukchi Sea: Johnson et al. 1966, Seaman et al. 1982

consumed and digested by the whales (Kleinenberg et al. 1964; Seaman et al. 1982). Since many of the stomachs examined by investigators contain little or no freshly ingested food, the measures of numbers or relative proportions of prey in the stomachs may be biased.

Some investigators suggest that belukhas may regurgitate stomach contents in the course of being pursued and killed (Doan and Douglas 1953; Fraker et al. 1978). However, Seaman et al. (1982) found that in a sample of 43 belukhas driven for over 2 hours 95% contained some food in their stomachs.

Food Requirements

The energetic requirements of belukha whales have not, to our knowledge, been studied. Arsen'ev (1936, cited in Kleinenberg et al. 1964) stated that the full stomach of a belukha may weigh 20-25 kg and contain 6-10 average-sized chum salmon (2 kg each). The maximum amount of food he found in an adult male was 4.8 kg. Sergeant (1969) summarized data on feeding rates of Delphinoidea in captivity. Records from six belukhas held in aquaria indicated that they consumed 4-7% of their body weight per day, with the highest rate for a calf (Table 11.10-6).

New or Unanalyzed Data

The only unanalyzed data on Bering Sea belukhas that we are aware of are with ADF&G. Included are data from 402 belukhas examined from 1958-1981. There are physical measurements from 256 animals, reproductive data from 54 males and 155 females, and age data from approximately 300. Most of the specimens are from animals taken by coastal subsistence hunters in the Chukchi Sea at Point Hope and Elephant Point (Eschscholtz Bay). It is expected that results of analyses of all specimens will be presented in a report to be completed in spring 1982.

Table 11.10-6. Summary of data on feeding rates of belukhas in captivity (Sergeant 1969).

Number of animals	Length (m)	Weight (kg)	Food weight per day (kg)	Food as percent body weight
1	3.2	approx. 300	23.0	4.1
1	2.44	223	11.5	6.9
4	3.05–3.96	318–909[a]	18–27	
	$\bar{x}$ = 3.43	$\bar{x}$ = 567	$\bar{x}$ = 23	4.1
4	3.05–3.96	$\bar{x}$ = 369[b]	$\bar{x}$ = 23	6.2

[a] Estimated weights.
[b] Same animals as the preceding four, with actual weights from an earlier date used.

11.11 Cuvier's Beaked Whale

Population Status

Cuvier's beaked whales occur worldwide except in the Arctic and Antarctic. In the North Pacific they are found along the shores of North America from Baja California north to the Aleutian and Pribilof Islands; along the Asiatic side, they have been reported from the China Sea, the Sea of Okhotsk, the Sea of Japan, around the Japan Islands, and north to the Commander Islands and Bering Sea (Tomilin 1957, Nishiwaki 1967, Mitchell 1968). Distributional records for Alaska are based mainly on strandings; peak strandings there have occurred from February to September in the Aleutian Islands (Mitchell 1968).

There is no information about the number of Cuvier's beaked whales in the Bering Sea, nor are there population estimates for the North Pacific. According to Rice (1978), Cuvier's beaked whales are the most widespread and frequently sighted of all the beaked whales. Fiscus (pers. commun.) considers them rare in the Bering Sea and more common south of the Aleutians in the North Pacific Ocean.

Very little is known about the biology of Cuvier's beaked whales. Females apparently grow somewhat larger than males. Adult females range from about 5.8 to 7.1 m; males are about 5.5 to 6.8 m (Omura et al. 1955). Tomilin (1957) reports that some individuals may attain a length of about 8 m. Two individuals measured by Kenyon (1961) were 6.6 m (female) and 5.4 m (male) in length and had 24-28 and 13 layers in the dentine of the teeth. It is uncertain how many dentine layers are deposited annually. The 6.6-m female weighed 2,953 kg.

Based on samples from Japanese harvests in the late 1940's and early 1950's, females are sexually mature at a length of 5.5 m and males at 5.5-5.8 m. Births occur over a protracted period, with a peak in autumn (Tomilin 1957). There are no other data on the reproductive parameters of these whales.

Mortality rates are unknown. Killer whales are probably not major predators since beaked whales can escape by diving to great depths. There has been limited hunting by the Japanese, particularly in the late 1940's and 1950's (Tomilin 1957). Nothing is known about the sex and age structure of the population. Males comprised 60% of the Japanese catch (Omura et al. 1955).

Diet Composition

Data on the food habits of Cuvier's beaked whales are almost entirely lacking. Tomilin (1957) reports the presence of cephalopod molluscs in the stomachs of some whales taken near Bering Island. Rice (1978) reports finding the remains of some medium-sized squid in one stomach. Kenyon (1961) found squids in the stomachs of three Cuvier's beaked whales stranded in the Aleutians.

Food Requirements

Nothing is known about the food requirements of Cuvier's beaked whales.

New or Unanalyzed Data

We know of no new or unanalyzed data on Cuvier's beaked whales.

11.12 Baird's Beaked Whale

Population Status

Baird's beaked whales are oceanic whales found only in the North Pacific, north to the Pribilofs and St. Matthew Island (Tomilin 1957), and possibly into the Chukchi Sea (Sleptsov 1961a, b). They are found along the Japan coast, north to the Kuril Islands, the Sea of Okhotsk, Kamchatka, as far as Olyutorskiy Bay, rarely to Cape Navarin (Tomilin 1957, Nishiwaki 1967), and off British Columbia, along the Alaska Peninsula, and in the Bering Sea. They are usually seen in pods of three to 17 animals (Rice 1978). They are seen off Kamchatka from April to November. They apparently arrive in the Bering Sea in spring, are most numerous there until September, and then migrate south in October-November to Japan where they spend the winter (Tomilin 1957).

There are no estimates of the population size of Baird's beaked whales in the North Pacific or Bering Sea.

Baird's beaked whales are the largest of the beaked whales. Calves are about 4.5-4.6 m long at birth (Omura et al. 1955, Tomilin 1957). Females are apparently slightly larger than males, reaching 10.5-12.9 m in length and averaging about 11 m. Males measure 10.2-12.0 m and average slightly less than 11 m (Omura et al. 1955, Rice 1978). In Kronotskiy Bay on the Kamchatka Peninsula, the largest reported female was 11.1 m and the largest male was 11.3 m. A 10.8-m female weighed 7.5 tons (Tomilin 1957).

Baird's beaked whales become sexually mature at about 10.1-10.5 m in females and 9.8-10.1 m in males (Omura et al. 1955, Tomilin 1957). The age corresponding to these lengths is unknown. Omura et al. (1955) suggested sexual maturity occurs at 3+ years; Rice (1978) suggested 8-10 years. Beaked whales may live to be 70 years old (Rice 1978). Mating occurs over a period of at least 6 months, from about December to June, with a peak in February (Omura et al. 1955, Tomilin 1957) and possibly in October-November (Rice 1978). Omura et al. (1955) and Tomilin (1957) report peak calving in December. McCann (1975) reports calving in spring and early summer. (Both Omura et al. and McCann are discussing whales in Japanese waters.) Rice (1978) also states that calving occurs in spring (March and April). There is some disagreement over the length of the gestation period; both 10 months (Omura et al. 1955, Tomilin 1957, McCann 1975) and 17 months (Rice 1978) have been proposed. In a sample of 24 fetuses the sex ratio was 62% males:38% females (Omura et al. 1955). We know of no data on pregnancy rates, length of the reproductive cycle, mortality rates, adult sex ratio, or age composition of the population.

There has been some limited hunting of Baird's beaked whales off Japan. From 1965 to 1978 the take was 13-39 ($\bar{x}$ = 26) whales per year (Rice 1978).

Diet Composition

The length of the nursing period is unknown. Tomilin (1957) reported that a 5.8-m calf had milk in its stomach.

Baird's beaked whales are known to eat squids, octopus, and occasionally fishes. Betesheva (1961) reports that 12 whales taken in the North Pacific (location unspecified) had eaten four species of cephalopods. Rice (1963, 1978) examined the stomachs of animals from California waters and found mostly medium-sized squids; rays, deepwater fishes, octopus, and crustaceans were also eaten. McCann (1975) examined a single stomach from Japanese waters and found squids and small rockfishes. Tomilin (1957) lists cephalopods (particularly the squid *Gonatus fabricii*), saffron cod, and octopus as foods.

Food Requirements

Nothing is known about the food requirements of Baird's beaked whales.

New or Unanalyzed Data

We know of no new or unanalyzed data on Baird's beaked whales.

11.13 Stejneger's Beaked Whale

Population Status

Stejneger's beaked whales are found only in the North Pacific (Moore 1968). They occur in the Bering Sea north at least as far as the Pribilof Islands, in Bristol Bay, along the Gulf of Alaska, off Washington and Oregon, and south to Cardiff, California (Jellison 1953; Tomilin 1957; Nishiwaki 1967; Loughlin et al., in press). In the western Pacific they are found from Akita Beach, Japan, north to the Commander Islands and into the Bering Sea (Nishiwaki 1967; Loughlin et al., in press). They are known mostly from stranding records, although Loughlin et al. (in press) saw a total of 52 off the central Aleutians in June-July 1979.

There is no published information on the numbers of Stejneger's beaked whales in the North Pacific or Bering Sea. They are rarely sighted, probably because they are difficult to see and may avoid ships.

The biology of Stejneger's beaked whales is little known. Tomilin (1957) reported on three adult males which measured 5.0 to 5.2 m in length. Loughlin et al. (in press) found two stranded individuals measuring 4.5 m and 4.1 m on Tanaga Island. Rice (1978) states that, all beaked whales of the genus _Mesoplodon_ are small, ranging from 3.7 to 5.5 m. We know of no information on the growth rates, age at sexual maturity, reproductive rates, mortality rates, or age structure of Stejneger's beaked whales. Rudimentary data on a North Sea member of this genus, _M. bidens_, suggest that mating and parturition occur in late winter and spring, with gestation lasting about 1 year. Calves are about 2 m long at birth and grow to 3 m by the time they are weaned at about 1 year of age.

Diet Composition

Essentially nothing is known about the diet of Stejneger's beaked whales. Tomilin (1957) suggests that like other beaked whales they probably eat squids. They also apparently chase, and perhaps feed on, schools of salmon in Japan (Tomilin 1957).

Food Requirements

Nothing is known about the food requirements of Stejneger's beaked whales.

New or Unanalyzed Data

We know of no new or unanalyzed data on Stejneger's beaked whales.

11.14 Killer Whale

Population Status

Killer whales are cosmopolitan in distribution. In the North Pacific, they occur from the Chukchi Sea to Baja California and the coasts of China and Japan (Dahlheim 1981). There is little specific information available on their distribution in the Bering Sea. They are known to be common near the Aleutian and Pribilof Islands (Murie 1959, Dahlheim 1981). Braham et al. (1977) recorded several sightings in Bristol Bay. They occur along the Soviet coast of the western Bering Sea, especially near Arakamchechen Island, Kresta Gulf, and Mechigmen Bay, and are seen near the Diomede and King Islands (Ivashin and Votrogov 1981). Their distribution is undoubtedly affected by seasonal sea ice, which excludes them from most of the northern and eastern Bering Sea during winter. No population estimate is available for the Bering Sea.

Killer whales are medium-sized odontocetes. Calves are 2-2.5 m long and weigh 160-180 kg. Adult males are about 8.2 m long and weigh 8,000 kg; adult females are about 7.0 m long and weigh 4,000 kg. Maximum reported lengths are 9.4 m for males and 8.2 m for females (Dahlheim 1981). Weight-at-age data are not available. Age at sexual maturity is not known, but it occurs at lengths of about 4.9 m in females and 6.7 m in males. Time of breeding is not well known but, according to Nishiwaki and Handa (1958), extends from May through July in the North Pacific. In Puget Sound, breeding has been reported in September (Dahlheim 1981). Using data from British Columbia and the North Atlantic (summarized in Dahlheim 1981), pregnancy rate of adult females has been estimated at about 0.13, which may extrapolate to a population birth rate of 4-5%, based on the assumption that adult females comprise 40% of the Pacific Northwest population. The calving interval may be about 4-7 years, with calf dependence lasting at least 2 years (Dahlheim 1981). Age and sex structure of the Bering Sea killer whale population is not known. No estimates of mortality rates are available. Killer whales live at least 25 years and perhaps 35 to 40 years (Dahlheim 1981).

Diet Composition

Killer whales are opportunistic feeders and have one of the most diverse diets of all marine mammals. Among their foods are seals, sea lions, cetaceans, fishes, sharks, seabirds, sea turtles, and squids (Betesheva 1961, Rice 1968, Caldwell and Caldwell 1969, Yukhov et al. 1975). Pods of whales use coordinated feeding behavior when preying on marine mammals (e.g., Smith et al. 1981) and perhaps also on fishes (Steiner et al. 1979).

Available data for the North Pacific and Bering Sea do not allow an assessment of the relative dietary importance of the various prey species. Known marine mammal prey include fur seals (Bychkov 1967), walruses (Tomilin 1957), sea lions, elephant seals, harbor porpoises, Dall's porpoises, and minke whales (Tomilin 1957, Rice 1968). Principal types of fishes eaten are cods, flatfishes, and salmon (Nishiwaki and Handa 1958, Rice 1968, Fiscus 1980). Although in other areas they are known to prey extensively on herring (Tomilin 1957, Dahlheim 1981), this relationship has not been documented in the Bering Sea.

Food Requirements

Sergeant (1969) estimated a daily food intake of 3.6 to 4.4% of the total body weight for four captive killer whales weighing approximately 1,000 to 1,500 kg. Palo (1972, citing Scheffer 1967) reports on three captive whales: a 4.3-m female ate 54 kg/day, a 6-m male ate 200 kg/day, and another 6-m male ate 45-90 kg/day.

New or Unanalyzed Data

We have located no new or unanalyzed data on killer whales in the Bering Sea. Continuing studies of killer whales in British Columbia and Washington State may yield valuable information on behavior and population parameters.

11.15 Dall's Porpoise

Population Status

Dall's porpoises are widely distributed in the North Pacific Ocean. They range from the Bering Sea to the Sea of Japan and northern Baja California (Kasuya 1978). In addition to the closely related True's porpoise (Phocoenoides truei) which has a limited distribution off northern Japan, Kasuya (1978) has suggested the existence of three stocks of Dall's porpoise in the western North Pacific, based on variations in color types. The approximate ranges of those stocks are: 1) the Sea of Japan and Okhotsk Sea, 2) off the Pacific coast of Japan (mixing with P. truei), and 3) the northwestern North Pacific and western Bering Sea. Since distinctions among animals in the eastern and western Bering Sea have not been reported and no geographic barriers exist, it is likely that Bering Sea Dall's porpoises comprise a single stock.

Most of the information available on distribution in the Bering Sea is from sightings made during summer, particularly June and July. Those observations (e.g., Kawamura 1975a, Wahl 1979) indicate that Dall's porpoises are abundant near the Aleutians and along the edge of the continental shelf, particularly from the Pribilof Islands to Unimak Pass. Kawamura (1975) noted an abundance of Dall's porpoises near Amchitka Pass in the Aleutians during June and July 1974. Fewer sightings have occurred over the deep Aleutian Basin or in shallow water over the continental shelf. The pattern of local and seasonal movements is poorly described (see NMML 1981). The distribution shifts southward during winter, with some animals leaving the Bering Sea (Fiscus 1980).

Estimates of the size of the Bering Sea population have recently been presented, based on the analysis of sightings made from research vessels in 1978 and 1979 (Bouchet 1981). Those estimates (Table 11.15-1) vary widely, depending on the type of analysis used and the year during which data were collected. In addition, estimates based on a single year and technique show wide confidence limits, and biases associated with collection of data may have caused substantial overestimation of abundance (Bouchet 1981). The six estimates produced for the Bering Sea range from 46,021 to 173,995; the mean of the estimates is 107,456. Correcting for a possible upward bias of 60% results in a conservative mean estimate for the Bering Sea of about 67,000. The population in the northern North Pacific (including the Bering Sea) is estimated to number between 580,000 and 2.3 million individuals (Bouchet 1981), with the lower estimate considered a conservative minimum. Estimates of the pre-exploitation population size range from 640,000 to 1.7 million, which when compared to the present conservative minimum estimate suggests the population is in the lower portion of the OSP range (NMML 1981).

Dall's porpoises are robust small cetaceans. Individuals are approximately 100 cm long at birth and grow to a maximum length of

Table 11.15-1. Estimates of abundance of Dall's porpoises in the Bering Sea (from Bouchet 1981).

Year	Based on 200-m strip transects		Based on 400-m strip transects		Based on line-transect analysis	
	Mean	95% confidence interval	Mean	95% confidence interval	Mean	95% confidence interval
1978	70,108	35,399-104,887	65,699	39,084-92,314	46,021	24,002-68,040
1979	173,995	108,775-239,215	123,179	76,449-169,858	165,732	134,839-196,625

about 220 cm (NMML 1981). Mature individuals are 170-180 cm long (NMML 1981), at which length they weigh approximately 100 kg (Scheffer 1953, Kajimura et al. 1980). Determination of the relationships between age and weight is complicated by problems with determination of age which are discussed in Kasuya (1978) and NMML (1981). Length and weight measurements are available in Scheffer (1953) and Mizue et al. (1966) and have been collected during recent studies by the NMML.

Studies of the vital parameters of Dall's porpoises have suffered from problems with determination of ages of individuals and probable biases associated with available specimen collections (see discussions in Kasuya (1978) and NMML (1981)). NMML (1981) has estimated that males become sexually mature at age 5, while females first give birth at 3 to 8 years of age (mean 4.5 in 1978 and 5.1 in 1979). Apparent pregnancy rates in mature females were 0.91 in 1978 and 0.96 in 1979, which suggests annual breeding. Age and sex structure of the population cannot be estimated with available samples. Based on the sex ratio of fetuses, females are slightly more common than males (Kasuya 1978). Kasuya (1978) estimated an annual total mortality rate for males older than 3.5 years of 9.7%. A major source of mortality is the incidental catch of porpoises by the Japanese high seas salmon gillnet fishery (NMML 1981).

Diet Composition

Observations of the stomach contents of porpoises caught in the Bering Sea and Aleutian Islands region by the high seas salmon gillnet fishery have provided some information on their foods. Mizue and Yoshida (1965) and Mizue et al. (1966) found mostly squid and small amounts of fish bones and shrimps in stomachs they examined. Specimens were collected between May and August 1964 and 1965; few details concerning the analysis or results were presented. The NMML has collected and examined stomach contents from 457 Dall's porpoises taken during the 1978 and 1979 fishing seasons. The results have been partially described in NMML (1981) and elaborated in Crawford (1981). Squids, mostly belonging to the family Gonatidae, were the major volumetric constituent of the stomachs. Euphausiids occurred in about 4% of the stomachs in insignificant quantities. Fishes were identified and enumerated, based on otoliths: at least 29 species of epi- and meso-pelagic fishes were found. Over 90% of the number of otoliths recovered from each year's sample were from fishes of the family Myctophidae (principally *Protomyctophym thompsoni*) (Table 11.15-2). Sand lance occurred in substantial numbers in 1978. Pollock occurred in small numbers in the 1978 sample, while Atka mackerel were found in low numbers both years. Fishes eaten ranged from 20 to 480 mm, with a modal size of 60-70 mm, based on partially digested whole specimens. No differences in quantities or types of prey were found among porpoises of different sex, maturity, or reproductive state.

Kajimura et al. (1980) reported the items occurring in stomachs of seven animals collected near Unimak Pass and in the Bering Sea from

Table 11.15-2. Summary of information on foods of Dall's porpoises (from NMML 1981). * indicates values less than 1%.

DATES	1978	1979
SAMPLE SIZE	184	87
COMPOSITION OF SAMPLE	% number	% number
Myctophids	91.3	98.0
Bathylagids	3.4	*
Sand lance	3.6	--
Pollock	*	--
Atka mackerel	*	*
Other fishes	1.9	*

June to October 1960-68. One stomach was empty. The number of stomachs in which each prey type occurred was: squid - 3, capelin - 3, and pollock - 1. In the stomachs of two porpoises taken in the Gulf of Alaska in May 1958 and 1960, they found capelin in one and sand lance in the other. Scheffer (1953) found only capelin in the stomachs of two animals collected in the Gulf in June-July 1952.

Commercially important fish species found in stomachs of Dall's porpoises examined from other locations in the eastern Pacific include herring, salmon, northern anchovy, hake (Merluccius productus), and flatfishes (Scheffer 1953; Fiscus 1979, 1980; Stroud et al. 1981). Squids appear to be a major food in all areas.

Available data have not been examined for seasonal and regional feeding patterns. Since almost all samples have been collected during summer months, they are probably not adequate to examine seasonal dietary differences. Mizue et al. (1966) found similar foods in stomachs of males and nonpregnant females. They noted that stomachs of pregnant females were less full and contained more different items. Age-related feeding preferences are unknown.

Food Requirements

Some information on food requirements of Dall's porpoises is available. Ridgway (1966) indicated that a 120-kg male required 15 kg of mackerel per day in order to maintain body weight. Walker (1975) stated that two animals which lost weight after capture failed to return to their original weight in spite of a 10-13 kg/day food intake. A daily food intake in excess of 10% of the body weight per day is therefore likely.

New or Unanalyzed Data

A considerable amount of biological data on Dall's porpoises in the North Pacific and Bering Sea has been collected by the NMFS NMML under terms of the International Convention for the High Seas Fisheries of the North Pacific Ocean. Although a preliminary report of those studies is available (NMML 1981), we are unable to determine the exact nature of unprocessed specimens and unanalyzed data presently in hand. The report states that ovaries collected in 1980 have not been completely analyzed. Results from them will increase the available data on reproductive characteristics of females.

11.16 Harbor Porpoise

Population Status

Harbor porpoises occur in coastal waters of both the North Atlantic and North Pacific. In the North Pacific, they regularly occur from the Chukchi Sea southward to the southern coasts of Japan and California (Tomilin 1957, Leatherwood and Reeves 1978). In southern portions of their range, they are generally seen near the coast in waters less than 20 m deep (Leatherwood and Reeves 1978).

Little information is available on the distribution of harbor porpoises in the Bering Sea. They regularly occur along the mainland coast, including Bristol Bay, the Yukon-Kuskokwim Delta, and Norton Sound (ADF&G, unpubl.) and have been occasionally recorded near the Aleutian Islands (Murie 1959, Alaska Maritime National Wildlife Refuge 1981, Fiscus et al. 1981). Hanna (1923) recorded two incidences of strandings on the Pribilof Islands in 1916 and 1917. Prescott and Fiorelli (1980) suggest an onshore-offshore seasonal migration pattern in the northwest Atlantic. Formation of seasonal sea ice in the Chukchi and Bering seas undoubtedly affects harbor porpoise distribution. No estimates of population size are available for the Bering Sea or North Pacific.

Size and growth of Pacific harbor porpoises are poorly known. They are the smallest oceanic cetacean and rarely grow to more than 180 cm in length (Leatherwood and Reeves 1978). A female caught in a net near Nome on 8 June 1981 was 170 cm long and weighed 52.7 kg (ADF&G, unpubl.). Information on age and growth in Atlantic harbor porpoises is available (see references in Prescott and Fiorelli 1980); however, extrapolation to the Bering Sea may not be justified since there may be differences in growth rates between European and northwest Atlantic populations (Prescott and Fiorelli 1980). Generally speaking, adults average 1.5 to 1.6 m long and weigh 45 to 60 kg (Prescott and Fiorelli 1980).

No information is available on vital parameters of Bering Sea harbor porpoises. Based on studies in the North Atlantic, reported by Fisher and Harrison (1970) and Prescott and Fiorelli (1980), sexual maturity is attained in males at 4 to 5 years of age, while females mature at about age 6. It is unclear whether individual females reproduce annually or at some longer interval. Sex and age structure of populations and mortality rates are not known.

Diet Composition

Stomachs from only three harbor porpoises taken in the Bering Sea have been examined (Frost and Lowry 1981a and unpubl.). All were from animals caught in salmon nets in northern and eastern Norton Sound. Contents of all three consisted principally of bones, flesh, and otoliths of small fishes, and small amounts of benthic crustaceans (Table 11.16-1).

Table 11.16-1. Summary of information on foods of harbor porpoises from Norton Sound. * indicates values less than 1%.

SEX	Unknown		Female		Male	
DATES	22 July 1971		8 June 1981		17 June 1981	
SAMPLE SIZE	1		1		1	
WEIGHT OF CONTENTS	122.4 g		222.8 g		31.6 g	
COMPOSITION OF SAMPLE	% volume	# individuals	% volume	# individuals	% volume	# individuals
Amphipod	--	--	*	1	--	--
Shrimp	1.6	6	1.3	1	--	--
Hermit crab	--	--	*	1	7.9	1
Saffron cod	57.2	16	96.5	10	6.3	5
Herring	32.6	1	--	--	85.4	1
Sculpin	--	--	--	--	*	1
Unidentified fish	8.2	1	--	--	--	--
Pebbles, shells, etc.	*	--	*	--	*	--

Based on identifiable remains (principally otoliths), 31 of 34 fishes eaten were saffron cod.

The diet of harbor porpoises in the North Atlantic has been comparatively well studied. Pelagic and semipelagic fishes, particularly of the familes Gadidae (cod) and Clupeidae (herrings), mostly from 10 to 26 cm long, have been the major prey identified, with a variety of other fishes and benthic invertebrates occurring occasionally (Rae 1973, Smith and Gaskin 1974, Prescott and Fiorelli 1980). Fink (1959) observed a group of harbor porpoises off central California feeding on a school of sardines. At other locations on the Pacific coast, they have been reported feeding on herring (Wilke and Kenyon 1952) and capelin (Scheffer 1953). Tomilin (1957), based on information from the Black Sea, suggested that benthic fishes are the primary food and that pelagic fishes are consumed only when they occur in large, dense schools in the coastal zone.

Food Requirements

Physiological information summarized in Prescott and Fiorelli (1980) indicates that harbor porpoises are poorly insulated for living in cold water and therefore maintain a high metabolic rate. They suggest a feeding rate of captive animals of about 10% of their body weight per day, which is similar to the 8.3-10.8% estimated by Sergeant (1969).

New or Unanalyzed Data

We have located no new or unanalyzed data on harbor porpoises in the Bering Sea.

11.17 Northern Fur Seal

Population Status

Northern fur seals seasonally inhabit a vast area of the North Pacific Ocean. According to Kajimura et al. (1980), they can be found in all parts of their range in any month of the year. The range includes the Bering Sea, the Sea of Japan, and the Sea of Okhotsk, south along the eastern Pacific continental shelf to waters off San Diego, California (32°N), and in the western Pacific to waters off Honshu, Japan (Scheffer 1958, Kajimura et al. 1980, and McAlister 1981).

The current worldwide abundance of northern fur seals is estimated as 1,684,000, which includes 1,219,000 from the Pribilof Islands; 2,000 from San Miguel Island; 265,000 from the Commander Islands; and 198,000 from Robben Island and the Kuril Islands. Tagging studies have shown mixing of these stocks; however, most animals return to their rookeries of birth as adults (Lander and Kajimura 1976, Gentry 1981).

Historically the population from the Bering Sea was exploited and numbers were reduced, particularly after the rookery islands were discovered. Fur seals were given protection by international treaty in 1911. At that time, reproducing colonies existed on the Pribilof Islands, the Commander Islands, Robben Island, and possibly on the Kuril Islands.

Johnson (1976b) states that, since hunting of fur seals has been controlled, the fur seal populations have increased. During the period of most rapid growth on the Pribilof Islands, Commander Islands, and Robben Island, the number of pups born increased at an annual rate of about 8%. By the early 1950's it was concluded that the Pribilof population was near the maximum number. Following an international agreement reached in 1957, the Commander Islands and Robben Island herds increased and by the mid-1960's had leveled off. The limited information on the Kuril population indicates it is still increasing.

The following discussion of seasonal distribution of the Pribilof fur seals is taken from Kajimura et al. (1980), BLM (1981), and McAlister (1981). Most of the Pribilof Islands fur seals spend November through May or June at sea and the rest of the year on and around the Pribilof Islands. Most immature animals (pups to 2-3 years) remain at sea and do not return to the rookeries. Most of the adult fur seals summer on the Pribilof Islands, and, with the exception of many adult males, most remain there through October. At that time, some immature females (less than 4 years old) may still be arriving, while males have abandoned their breeding territories and occupy nearby haulouts. By late October some adult females may begin their migration into the North Pacific through Unimak Pass and some of the smaller eastern Aleutian passes. Most of the remaining fur seals leave the Pribilofs during November, and by the end of the month only about 10% of the population remains. During December seals are traveling to their winter feeding grounds.

Some breeding-age males (10 to 15 years old) remain in the southern Bering Sea, while others move south of the Aleutian Islands or into the Gulf of Alaska. Many of the younger animals of both sexes and most females move into the Gulf of Alaska during late November and December. Some, mostly adult females, move directly across the North Pacific to as far south as central California. The younger animals and females continue to move southward to wintering areas through January and remain there through February and into March. These wintering areas extend from southeastern Alaska to the Mexican border and from the Kurils to Honshu, Japan. Most seals seem to remain between 46 and 93 km offshore, but occasionally they have been sighted as far as 148 km offshore. During mid-March many of the adult females begin their northward migration, while the immature females are still arriving at the more southerly areas. Fur seals continue their northward movements through April and May, concentrating off Washington, British Columbia, and Kodiak Island, with numbers building up along the south side of the Alaska Peninsula. From April to mid-June, large numbers of fur seals of both sexes and all ages (except the older adult males) are found throughout coastal Gulf of Alaska. Breeding-age males that have wintered in the Bering Sea or south of the Aleutian Islands arrive at the Pribilof Islands in late April and May, followed by those from the Gulf of Alaska. Older pregnant females begin entering the Bering Sea in June, arriving at the Pribilofs by late June, and younger pregnant females and nonpregnant females arrive soon after. Younger nonbreeding males (3-5 years old) arrive and occupy bachelor areas adjacent to the rookeries in late June and continue to arrive until September. Most of the adults remain in the vicinity of the Pribilof Islands throughout the summer. The adult males maintaining territories remain ashore until about mid-August, while females with pups make feeding trips, generally within 160 km but occasionally as far as 400 km from the islands.

At birth, female fur seal pups weigh 3.9 kg and males weigh 5.4 kg. They grow rapidly, attaining a mean weight of 10 kg (males) and 8.6 kg (females) in the first year. Rapid growth is characteristic in the first 5 years for females, both pregnant and nonpregnant (Figures 11.17-1 and 2). By the fifth year, nonpregnant females have attained a mean weight of 26.2 kg and a mean length of 114 cm (Kajimura et al. 1979). Nonpregnant females over the age of 5 years attained a mean weight of 37.8 kg and a mean length of 125.8 cm. Pregnant females weigh 30.5 kg at 5 years of age and are 117 cm long. Mean weight and length for pregnant females older than 5 years are 40.8 kg and 126.9 cm. Male fur seals continue to grow at a rapid rate for the first 9 years (Figures 11.17-1 and 2). Mean weight of males under 10 years old is 49.4 kg and mean length is 129.5 cm. By the ninth year, males weigh 102.5 kg and are 171 cm long (average for ninth year class). On the average, males greater than 9 years old (10 to 17 years) weigh 127 kg and are 186 cm long (Kajimura et al. 1979).

The mean age at first reproduction for female fur seals ranges from 5.68 to 6.96 years (Kajimura et al. 1979). Calculation of

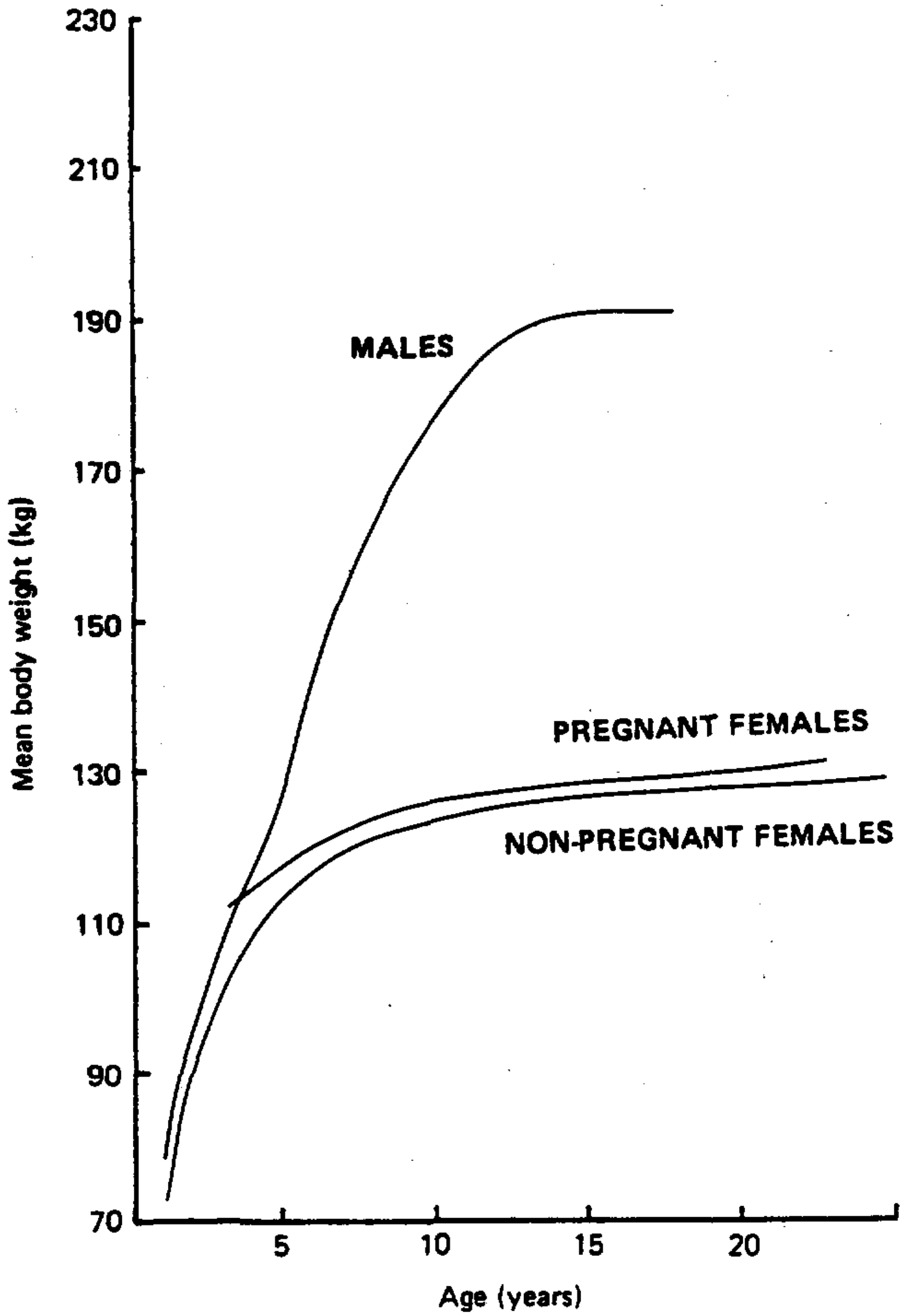

Figure 11.17-1. Mean length, by age, of fur seals collected during 1958-1974 by Canadian and United States research vessels in the North Pacific Ocean and eastern Bering Sea (from Lander 1979).

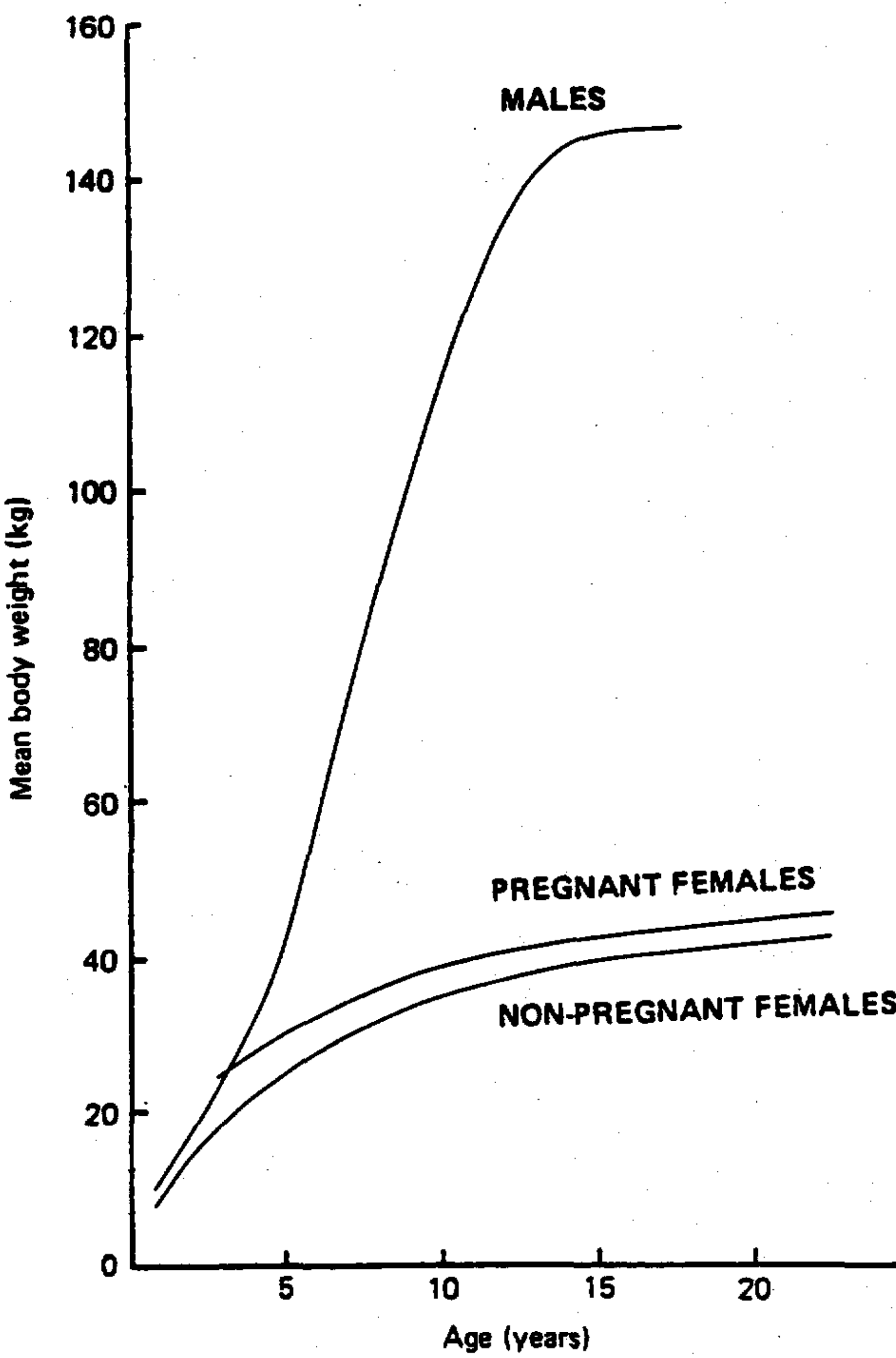

Figure 11.17-2. Mean weight, by age, of fur seals collected during 1958-1974 by Canadian and United States research vessels in the North Pacific Ocean and eastern Bering Sea (from Lander 1979).

age-specific pregnancy rates is complicated by sex and age segregation during migrations and the likelihood that there is differential migration and segregation of pregnant and nonpregnant females. Kajimura et al. (1980) give an overall pregnancy rate of 0.93 for females ages 7-13 in the Bering Sea near the Pribilof Islands. Pregnant females arrive at the Pribilof Islands, give birth, and ovulate 3 to 5 days after parturition (Craig 1964). The female spends 1 to 2 days ashore nursing her pup and 6 to 9 days at sea feeding (Bartholomew and Hoel 1953).

A wide range of factors influences fur seal mortality. Bachelor males (ages 2 to 5) have been harvested on the rookeries; harvests on the Pribilof Islands have recently averaged 30,000 per year. Natural mortality stems from disease, starvation, desertion of pups, old age, and other factors. Kajimura et al. (1980) estimate a mortality rate of 0.50 in the first year for males from St. Paul and Pribilof females, and 0.60 for males from St. George and Sea Lion Rock (Table 11.17-1).

Diet Composition

The diet of fur seals has been extensively studied throughout their range. Scheffer (1950) examined about 1,300 stomachs, most of which were taken between Washington and Alaska. The most frequently encountered food items found in stomachs from animals taken in the Bering Sea were squid, pollock, seal fish (*Bathylagus* sp.), salmon, and lamprey. Kenyon (1956) studied stomach contents from 50,239 fur seals harvested on land in 1954. He found that 27 stomachs contained food; all stomachs contained sand fish (*Trichodon trichodon*), and five stomachs had the sturgeon-like sea-poacher (*Agonus acipenserinus*). Wilke and Kenyon (1957) found that disgorged material on the hauling grounds and rookeries, particulary areas frequented by young males, consisted almost entirely of bones of cods. Pollock was the predominant species, while small cods such as the tom cod (*Microgadus proximus*) and Pacific cod were also important. Spalding (1964) reported on comparative feeding habits of fur seals, sea lions, and harbor seals on the British Columbia coast. Perlov (1968) reported that females of the Commander herd feed mainly on sand lance on Kitolovnaya bank and males feed on salmonids and Atka mackerel on Stelmete bank and southeast of Medny Island. Panina (1971) examined stomachs of fur seals caught for research between February and May 1958-1968 in the Sea of Japan. She found that pollock occurred in 75.3% of the stomachs and was the major food in the northwestern Sea of Japan, while squids occurred in 40.3% of the stomachs and were the most important foods in the central part. Wada (1971) found that, off the Sanriku and Joban coasts of Japan, fur seals fed mainly on migratory fishes and squids associated with the boundary layers between water masses. Kajimura et al. (1980) reported that fur seals collected in the Bering Sea had been feeding primarily on capelin, walleye pollock, Atka mackerel, deep sea smelt, and gonatid squids (*Berryteuthis magister* and *Gonatopsis borealis*). Lander and Kajimura (1976) state that fur seals feeding over the continental shelf tend to feed on fishes, while in areas beyond the

Table 11.17-1. Summary of age-specific and cumulative survival rates for Alaskan fur seals (from Kajimura et al. 1980).

	Males				Females	
	St. Paul Island		St. George Island and Sea Lion Rock			
Age	By age	From age 0	By age	From age 0	By age	From age 0
0	--	1.000	--	1.000	--	1.000
1	0.500	0.500	0.400	0.400	0.500	0.500
2	0.760	0.380	0.750	0.300	0.800	0.400
3	0.778	0.296	0.800	0.240	0.840	0.336
4	0.478	0.141	0.800	0.192	0.920	0.309
5	0.342	0.048	0.750	0.144	0.940	0.290
6	0.682	0.033	0.700	0.101	0.940	0.273
7	0.800	0.026	0.650	0.066	0.945	0.258
8	0.800	0.021	0.600	0.040	0.950	0.245
9	0.800	0.017	0.550	0.022	0.950	0.233
10	0.760	0.013	0.500	0.011	0.938	0.219
11	0.730	0.009	0.450	0.005	0.924	0.202
12	0.700	0.006	0.400	0.002	0.906	0.183
13	0.650	0.004	0.320	0.001	0.884	0.162
14	0.590	0.002	0.220	<0.001	0.858	0.139
15	0.540	0.001	0.100	--	0.876	0.122
16	0.430	<0.001	0.010	--	0.789	0.096
17	--	--	<0.010	--	0.743	0.071
18	--	--	--	--	0.692	0.044
19	--	--	--	--	0.630	0.031
20	--	--	--	--	0.564	0.017
21	--	--	--	--	0.490	0.008
22	--	--	--	--	0.411	0.003
23	--	--	--	--	0.330	0.001
24+	--	--	--	--	<0.330	<0.001

shelf they feed mostly on squids. Kajimura et al. (1980) reported on feeding habits of fur seals off California and Washington.

The most complete analysis of fur seal feeding habits appears in a series of reports which were prepared using the pelagic collections of fur seals made by the US and Canada during 1958 to 1974 as the data base (Perez and Bigg 1981a, b). The following discussion of fur seal feeding habits in the Bering Sea is taken from those reports. Perez and Bigg (1981b) used a method for analysis of stomach contents which they call the modified volume method (Perez and Bigg 1981a). It involves a two-step frequency-volume analysis where squids and fishes are separated initially and combined in the final computations; also, trace remains ($\leq$ 10 cc) were eliminated. Earlier reports generally used the Index of Relative Importance, which combines data on percent by volume, percent by number, and percent frequency of occurrence.

Fishes of the gadid and osmerid families and squids of the gonatid family make up the most important components in the fur seals' diet in the eastern Bering Sea. The primary species in these families taken by fur seals are walleye pollock, capelin, and *Berryteuthis magister*.

In order to facilitate analysis of the data, they were broken down into subregions by Kajimura et al. (1980) and Perez and Bigg (1981b). The data are presented in terms of either the eastern Bering Sea or subregions 17 through 20 (Figure 11.17-3). Subregion 17 is the area near Unimak Pass, subregion 18 is the area within approximately 60 miles of the Pribilof Islands, subregion 19 is the northeast Bering Sea, and subregion 20 is the southeast Bering Sea.

In subregion 17 in all months, the most important species was capelin (Table 11.17-2). The second most important were the squid *Berryteuthis* in June, pollock in July and August, *Berryteuthis* again in September, and Atka mackerel in October.

In subregion 18, walleye pollock was most important in July, August, and September (Table 11.17-3). The squid *Gonatopsis borealis* was second in importance in subregion 18 in July and September, while herring was second in importance in August.

Capelin was most important in subregion 19 for the months of June and October, while walleye pollock was most important from July to September (Table 11.17-4). Capelin was second in importance in subregion 19 for the months of July, August, and September. Atka mackerel was second in importance for the months of June and October.

In subregion 20, capelin was the most important species for June and September, walleye pollock was most important for July, and the squids *Berryteuthis magister* and *Gonatopsis borealis* were most important for August and September, respectively (Table 11.17-5).

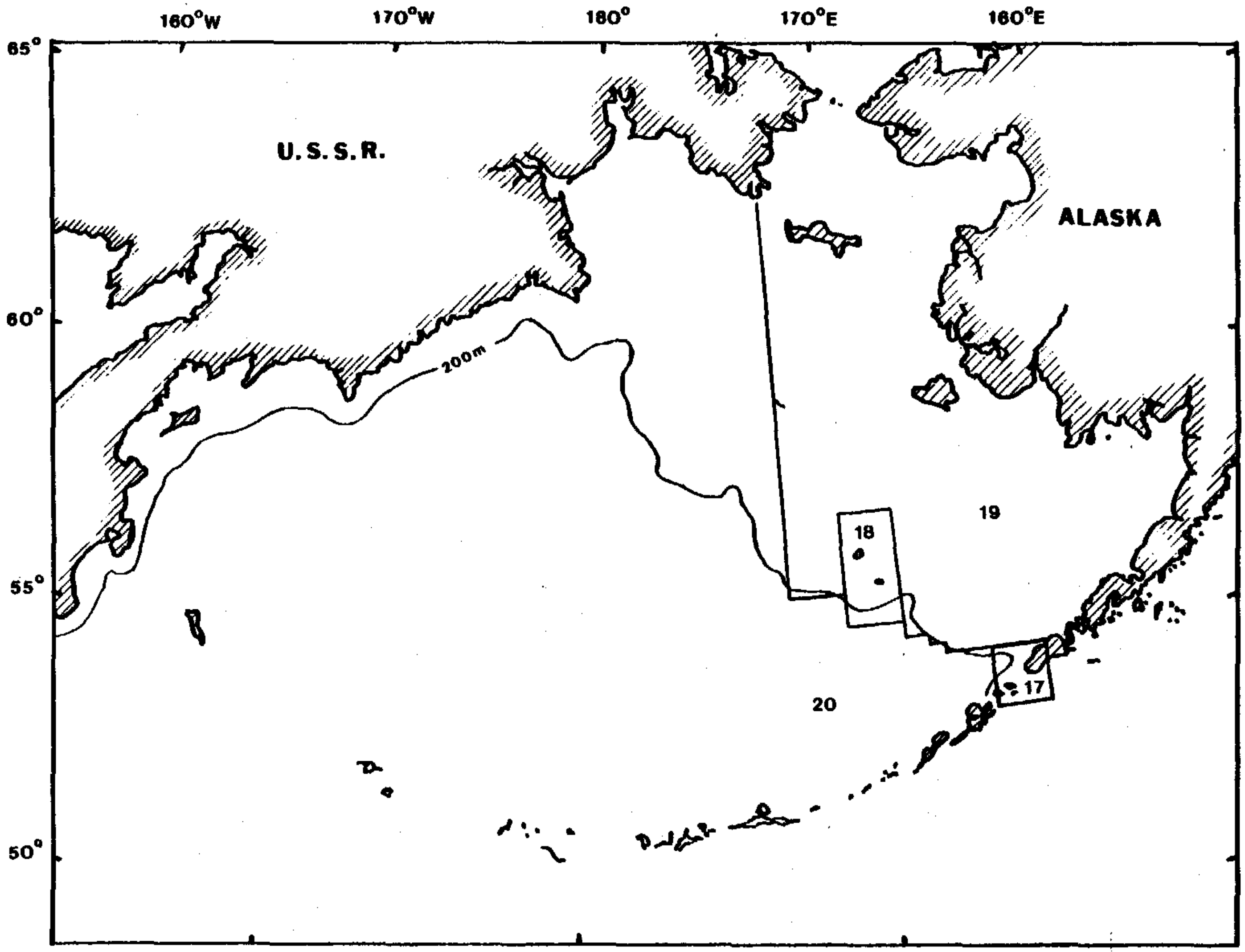

Figure 11.17-3. Boundaries of subregions 17-20 of Bering Sea fur seal feeding habits study (adapted from Kajimura et al. 1980).

Table 11.17-2. Rank order of importance of prey (based on percent modified volume) in the diet of fur seals in subregion 17 of the Bering Sea (from Perez and Bigg 1981b).

Prey rank	June	July	August	September	October
1	Capelin	Capelin	Capelin	Capelin	Capelin
2	*Berryteuthis magister*	Pollock	Pollock	*Berryteuthis magister*	Atka mackerel
3	Sand lance	*Berryteuthis magister*	*Berryteuthis magister*	Atka mackerel	
4	Atka mackerel	Sablefish	Atka mackerel		
5	Salmon	*Gonatopsis borealis*	*Gonatopsis borealis*		
6	Pollock	Herring			
7		Atka mackerel			
8		Salmon			

Table 11.17-3. Rank order of importance of prey (based on percent modified volume) in the diet of fur seals in subregion 18 of the Bering Sea (from Perez and Bigg 1981b).

Prey rank	July	August	September
1	Pollock	Pollock	Pollock
2	*Gonatopsis borealis*	Herring	*Gonatopsis borealis*
3	*Berryteuthis magister*	*Berryteuthis magister*	Bathylagidae
4	Bathylagidae	*Gonatopsis borealis*	*Berryteuthis magister*
5	*Gonatus* sp.	Greenland halibut*	*Gonatus* sp.
6	Salmon	Atka mackerel	Greenland halibut*
7		Bathylagidae	
8		Salmon	
9		Capelin	

* *Reinhardtius hippoglossoides*

Table 11.17-4. Rank order of importance of prey (based on percent modified volume) in the diet of fur seals in subregion 19 of the Bering Sea (from Perez and Bigg 1981b).

Prey rank	June	July	August	September	October
1	Capelin	Pollock	Pollock	Pollock	Capelin
2	Atka mackerel	Capelin	Capelin	Capelin	Atka mackerel
3	*Berryteuthis magister*	*Gonatopsis borealis*	Herring	*Berryteuthis magister*	
4	Pollock	*Berryteuthis magister*	*Berryteuthis magister*	*Gonatopsis borealis*	
5	Salmon	Atka mackerel	Greenland halibut	Bathylagidae	
6	*Gonatopsis borealis*	Sablefish	Atka mackerel	Greenland halibut	
7		Salmon	*Gonatopsis borealis*	*Gonatus* sp.	
8		Bathylagidae	Salmon		
9			*Gonatus* sp.		

Table 11.17-5. Rank order of importance of prey (based on percent modified volume) in the diet of fur seals in subregion 20 of the Bering Sea (from Perez and Bigg 1981b).

Prey rank	June	July	August	September	October
1	Capelin	Pollock	*Berryteuthis magister*	*Gonatopsis borealis*	Capelin
2	*Berryteuthis magister*	*Gonatopsis borealis*	Pollock	Bathylagidae	*Berryteuthis magister*
3	*Gonatopsis borealis*	*Berryteuthis magister*	*Gonatopsis borealis*	*Berryteuthis magister*	Eulachon
4	Pollock	Capelin	Capelin	Capelin	Sand lance
5	Atka mackerel	Bathylagidae	Bathylagidae	Atka mackerel	
6		Salmon	Salmon	Pollock	
7		*Gonatus* sp.	*Gonatus* sp.	*Gonatus* sp.	
8			Sand lance	Salmon	
9			Atka mackerel	Eulachon	

Combining the data into one set for the entire eastern Bering Sea and using the Index of Relative Importance to rank prey shows that capelin was most important for the months of June and October, walleye pollock was most important in July and September, while unidentified gonatid squids were most important in August (Table 11.17-6). Atka mackerel was second in importance for the months of June and October, capelin was second in importance in August, and unidentified gonatid squids were second most important for July and September.

Combining all the data within months for each region and for the eastern Bering Sea as a whole, capelin was most important in subregions 17 and 19 from June to October, walleye pollock was most important from July to September for subregion 18, *Berryteuthis magister* was the most important species in subregion 20, and capelin was the single most important species in the entire eastern Bering Sea from June to October (Table 11.17-7). *Berryteuthis magister* was second in importance in both subregions 17 and 18, walleye pollock was second in importance in subregion 19, *Gonatopsis borealis* was second in importance in subregion 20, and walleye pollock was the second most important species in the entire Bering Sea. Quantitative results for each region are summarized in Table 11.17-8.

Perez and Bigg (1981b) found that the diet for both male and female fur seals, or for females of different reproductive condition, is essentially similar in general pattern of diversity, preference, and importance of prey within the diet. They found that salmonids, herring, capelin, and sand lance were mainly fed on at night, while walleye pollock were primarily taken during the day. Atka mackerel was fed upon either at night or the very early morning hours. The data seem to suggest that *Berryteuthis magister* and *Gonatopsis borealis* were fed upon only in the midmorning hours; however, they felt that their small sample sizes at dawn were misleading and that these squids were fed upon at night also.

Food Requirements

Scheffer (1950) estimated that an "average" fur seal in the wild eats 1/15 (6.7%) of its body weight per day. Nesterov (1971) fed a 2-year-old male fur seal and estimated that it ate an average of one-ninth (11.1%) of its body weight per day. Miller (1978) calculated that maintenance of temperature and basic body functions of seals 3 years old and younger would require 14% of the seal's body weight in pollock per day. Spotte and Adams (1981) found a high correlation between water temperature, body weight, and feeding rates for adult female fur seals. They expressed their findings in the following equation:

Feeding rate as a percent of body mass per day =
(− 0.782) X water temperature in degrees Celsius −
0.096 times body mass in kilograms + 25.77

Table 11.17-6. Rank order of importance of prey (based on Index of Relative Importance) in the diet of fur seals in the eastern Bering Sea (from Perez 1979 and Kajimura et al. 1980).

Prey rank	June	July	August	September	October
1	Capelin	Pollock	Gonatidae	Pollock	Capelin
2	Atka mackerel	Gonatidae	Capelin	Gadidae	Atka mackerel
3	*Berryteuthis magister*	Capelin	Pollock	Gonatidae	*Berryteuthis magister*
4	Gonatidae	*Gonatopsis borealis*	*Berryteuthis magister*	Capelin	Sand lance
5	Pollock	*Berryteuthis magister*	*Gonatopsis borealis*	*Gonatopsis borealis*	Eulachon
6	*Gonatopsis borealis*	Bathylagidae	Bathylagidae	Bathylagidae	
7	Sand lance	*Gonatus* sp.	Gadidae	*Berryteuthis magister*	
8	Unidentified Fish	Unidentified Fish	Herring	Pleuronectidae	
9	Atka mackerel	Atka mackerel	*Gonatus* sp.	*Gonatus* sp.	
10	Salmon	Salmon	Greenland halibut	Atka mackerel	

Table 11.17-7. Rank order of importance of prey (based on percent modified volume) in the diet of fur seals for each subregion and all regions combined for June to October (July to September for subregion 18 only) (from Perez and Bigg 1981b).

Prey rank	Subregion 17 (Jun-Oct)	Subregion 18 (Jul-Sep)	Subregion 19 (Jun-Oct)	Subregion 20 (Jun-Oct)	Eastern Bering Sea (Jun-Oct)
1	Capelin	Pollock	Capelin	*Berryteuthis magister*	Capelin
2	*Berryteuthis magister*	*Berryteuthis magister*	Pollock	*Gonatopsis borealis*	Pollock
3	Pollock	Herring	*Berryteuthis magister*	Capelin	*Berryteuthis magister*
4	Atka mackerel	*Gonatopsis borealis*	Herring	Pollock	*Gonatopsis borealis*
5	*Gonatus* sp.	Bathylagidae	Atka mackerel	Bathylagidae	Atka mackerel
6	Sand lance	Greenland halibut	*Gonatopsis borealis*	Atka mackerel	Herring and Bathylagidae
7	Sable fish	Atka mackerel	Bathylagidae	Salmon	Salmon
8	Herring	*Gonatus* sp.	Greenland halibut	*Gonatus* sp.	*Gonatus* sp.
9	Salmon	Salmon	Sablefish		Greenland halibut
10			*Gonatus* sp.		Sablefish

Table 11.17-8. Summary of information on foods of fur seals for subregions 17-20 and the eastern Bering Sea. Values indicate percent modified volume (from Perez and Bigg 1981b).

SEX/AGE CLASS	All	All	All	All	All
LOCATION	Subregion 17	Subregion 18	Subregion 19	Subregion 20	Eastern Bering Sea
DATES	Jun-Oct	Jul-Sep	Jun-Oct	Jun-Oct	Jun-Oct
SAMPLE SIZE	542	308	1017	732	1749
Herring	1.25	11.53	5.70	--	2.92
Salmon	0.86	0.72	--	1.92	1.06
Capelin	66.79	--	39.98	17.96	30.59
Bathylagidae	--	4.63	1.32	8.22	2.92
Pollock	9.35	59.72	32.83	16.54	25.08
Sablefish	1.60	--	0.41	--	0.22
Atka mackerel	4.24	1.17	3.75	2.34	3.53
Sand lance	1.77	--	--	--	0.17
Greenland halibut	--	1.95	0.98	--	0.59
Gonatus sp.	4.18	1.11	0.30	1.10	0.81
Berryteuthis magister	9.96	12.44	11.12	28.07	18.79
Gonatopsis borealis	--	6.73	3.62	23.87	13.66

New and Unanalyzed Data

New data are collected by the NMML annually in conjunction with the commercial fur seal harvest in the Pribilofs. The North Pacific Fur Seal Commission sponsors an ongoing pelagic program studying feeding habits and age and sex distribution of fur seals at sea. The NMML is continuing studies to assess the feeding habits of northern fur seals and compare them with the species composition and abundance of fishes in the water column. For that project, 17 fur seals were collected between 13 October and 7 November 1981 in the southern Bering Sea; stomach contents, reproductive tracts, body measurements, and age material will be analyzed (Loughlin, pers. commun.). Perez and Mooney of the NMML are investigating energetics and food consumption of lactating northern fur seals.

11.18 Steller Sea Lion

Population Status

Steller sea lions are gregarious, highly mobile pinnipeds and are the largest and most widely distributed otariids in the North Pacific Ocean. Their total range includes the North Pacific rim, from 34°N latitude to 66° latitude. The breeding range is from the Pribilof Islands, along the Aleutian Islands, southward along the west coast of North America to southern California, and westward to the Commander Islands, Kamchatka Peninsula, and Japan (Scheffer 1958, Kenyon and Rice 1961). The southern breeding limit is San Miguel Island, one of southern California's channel islands (Schusterman 1981). In the Bering Sea there appears to be a late summer movement of males toward Bering Strait, although no breeding areas are found that far north. In the Soviet Union sea lions are found in the Kuril Islands, the Okhotsk Sea, the Commander Islands, and the western Bering Sea (Perlov, pers. commun.). Steller sea lions have also been recorded from Hokkaido and northern Honshu Island and from the northern coast of the Korean Peninsula.

Estimates of sea lion numbers have generally been made based on counts at rookeries and haulouts. This type of estimate usually results in minimum population numbers, as it cannot take into account those animals which were at sea at the time counts were made. No other kinds of information are available on sea lion numbers in the Bering Sea; therefore, the following are minimal estimates and do not represent the true total populations. Perlov (pers. commun.) estimated the sea lion population in the Soviet portion of the Bering Sea in 1979 to be approximately 4,600 animals, which includes 1,100 from the east coast of the Kamchatka Peninsula and 3,500 from the Commander Islands. Data from ADF&G files indicate that approximately 1,200 sea lions utilize haulouts on the north side of Bristol Bay from Cape Newenham to the Walrus Islands. Braham et al. (1980a) and Fiscus et al. (1981) estimate a total of 89,113 sea lions in the Aleutian Islands. Braham et al. (1980a) also counted 4,575 sea lions at Amak Island and Sea Lion Rock. G. Antonelis (pers. commun.) counted 1,172 sea lions at Walrus Island in the Pribilof Islands in 1981, and Kenyon and Rice (1961) estimated 1,600 for the rest of the Pribilof Islands. This represents a total of 102,320 sea lions which have been counted in the Bering Sea at rookeries and haulouts over several years. It is not possible to call this a population estimate, although it does approximate a minimum number of sea lions in the Bering Sea.

Fluctuations in sea lion numbers at certain locations have occurred recently. The best documented case is that of the eastern Aleutian Islands where Braham et al. (1980a) reported at least a 50% reduction from the 50,000 noted by Mathisen and Lopp (1963) in 1957 to less than 25,000 in 1975 to 1977. Another decline in abundance which has been noted but not well or recently documented appears to have occurred at the Pribilof Islands (Kenyon 1962a). No specific causes are apparent for these declines, and no studies have been initiated to directly address them. A reduction in carrying capacity through reduced food supply due to increased fishing in the Bering Sea may have the most merit among several theories, although it is likely that several factors may be involved.

Steller sea lions move long distances and have been sighted 1,500 km from rookeries where they were born (Calkins and Pitcher, unpubl. ms.). Seasonal movements are known to occur in California, but movements in the Bering Sea have not been well documented. It is likely that a seasonal winter movement of males takes place from the Aleutian Islands to the ice edge in the central Bering Sea.

Very little information on vital parameters of sea lions in the Bering Sea is available. Information on size, reproductive parameters, mortality, and sex ratio is available from the Gulf of Alaska (Pitcher and Calkins 1981; Calkins and Pitcher, unpubl. ms.), and information is available on reproduction from the Kuril Islands (Perlov 1971). The following discussion of vital parameters is taken from those sources; however, it is important to note that these parameters could be substantially different for sea lion populations in the Bering Sea.

Steller sea lions show a pronounced sexual dimorphism. At birth pups weigh about 23 kg and and are about 120 cm in curvilinear length. cm. Although there is great variability between year classes, most females probably reach adult size and maximum skeletal growth by their 6th year, and males reach adult size as indicated by maximum skeletal growth in their 11th year. The average weight of adult males sampled was 566 kg, with length averaging 282 cm. Adult females weighed 263 kg average, and their average length was 228 cm. Although adult males were only about 20% longer than females, they weighed more than twice as much.

In the Gulf of Alaska, age-specific ovulation rates were as follows: age 3, 26%; age 4, 81%; age 5, 80%; and age 6 and older, 100%. Pregnancy rates were approximately 20% at 3 years of age, 53% at 4, 57% at 5, 83% at 6, and 84% for all females 7 years old and older. Males were physiologically capable of breeding, as indicated by presence of sperm in epididymides, between 3 and 6 years old. However, they are probably unable to hold territories on the breeding rookeries until they reach physical maturity at about age 11. Females produce a single pup annually and breed shortly after parturition, which occurs from late May to early July. Implantation is delayed until about October. Twinning has occurred but is rare. Most young are weaned by the end of their first year of life but some continue to nurse until 3 years old.

For females in the Gulf of Alaska, combined mortality from birth to 3 years was estimated to be 53%, while for age classes 3 through 11 the average annual mortality was 11%. In males, mortality from birth to 3 years was 73%, and the average annual mortality for ages 3 through 5 years was 13%. Approximately 30% of the females born survived to reproductive maturity. In the Gulf of Alaska, the sex ratio at birth appears to slightly favor males; in a sample of over 7,000 pups, 51% were males and 49% females.

Diet Composition

The diet of Steller sea lions has been studied extensively in areas other than the Bering Sea. Only two works have been published dealing with food habits of sea lions in the Bering Sea, and only a total of 12 stomachs with food was examined in these two studies. Table 11.18-1 shows the major food species found in the 12 sea lion stomachs taken in the Bering Sea by Wilke and Kenyon (1952) and Fiscus and Baines (1966).

Stomachs of four sea lions collected on the sea ice near the Pribilofs on 20 March 1976 have been examined (Lowry and Pitcher, unpubl.). Pollock comprised the majority of the stomach contents (Table 11.18-2). Based on sizes of otoliths in stomachs, pollock consumed ranged from 34 to 57 cm in length.

One of the co-investigators on this project (Calkins) participated in a joint US-USSR research cruise in the central and western Bering Sea during March and April 1981 on which stomach contents from 111 Steller sea lions were collected. Although much of the stomach contents remains unanalyzed, a preliminary examination of the material indicated that these sea lions were eating pollock, cod, gonatid squids, herring, octopus, and sculpins.

Other studies of food habits have been conducted in the Gulf of Alaska and off the coast of British Columbia, Washington, and Oregon by Pike (1958), Mathisen et al. (1962), Thorsteinson and Lensink (1962), Spalding (1964), Fiscus and Baines (1966), Jameson and Kenyon (1977), and Pitcher (1981). Studies of sea lion feeding habits and diet composition from areas other than the Bering Sea can be useful for comparisons and may also give some indication of the types of species important to sea lions in the Bering Sea; however, specific percentages of diet composition are not applicable and cannot be used to quantify feeding in the Bering Sea. Table 11.18-3 shows the food species of importance to sea lions off the coast of Oregon, Washington, and British Columbia, and Table 11.18-4 shows the species of importance in the Gulf of Alaska.

Food Requirements

Very little information is available on Steller sea lion food requirements. Fiscus and Baines (1966) reported that one sea lion stomach contained food remains which amounted to 9.4% of the total body weight. Keyes (1968) reviewed the literature on food habits and concluded that adult, nonpregnant, nonlactating sea lions require 6-10% of their body weight in food per day.

Table 11.18-1. Rank order of importance of prey in the diet of Steller sea lions in the Bering Sea.

Prey rank	Pribilof Islands July 1951 Wilke and Kenyon 1952	Unimak Pass and Bering Sea June-September 1962 Fiscus and Baines 1966
1	Sand lance	Capelin
2	Halibut	Sand lance
3	Cod	Sculpins
4	Pollock	Pollock
5	Flatfishes	Flatfishes
6	Sculpin	Atka mackerel

Table 11.18-2. Composition of the stomach contents of four Steller sea lions collected 20 March-19 April 1976 near the Pribilof Islands. * indicates less than 1%.

Prey item	Percent volume	Percent number	Number of occurrences
Pollock	97	95	4
Squids	2	3	2
Octopus	*	*	1
Flatfishes	*	*	1
Lamprey	*	*	1
Prickleback	*	*	1

Table 11.18-3. Summary of information on foods of Steller sea lions off the coast of Washington and British Columbia.

SOURCE	Spalding 1964	Fiscus and Baines 1966	Jameson 1977
LOCATION	British Columbia	California/Oregon	Oregon
SAMPLE SIZE	393	4	84 observations
	Octopus	Flatfishes	Lamprey
	Rockfishes	Rockfishes	Salmon
	Herring		
	Cod		
	Squids		
	Salmon		
	Hake		

Table 11.18-4. Summary of information on foods of Steller sea lions in the Gulf of Alaska.

SOURCE	Mathisen et al. 1962	Thorsteinson and Lensink 1962	Fiscus and Baines 1966	Pitcher 1981
LOCATION	Gulf of Alaska	Gulf of Alaska	Gulf of Alaska	Gulf of Alaska
SAMPLE SIZE	114	251	5	250
	Squids	Squids or octopus	Sand lance	Walleye pollock
	Octopus	Clam, mussel, or snail	Capelin	Squids
	Shrimps and crabs	Sand lance	Salmon	Pacific herring
	Greenling	Rockfishes	Rockfishes	Capelin
	Smelts	Flatfishes	Flatfishes	Pacific cod
	Rockfishes	Greenling		Salmon
	Sculpins	Crabs		Octopus
		Halibut		Sculpins
		Lumpfishes		Flatfishes
				Rockfishes

New or Unanalyzed Data

Stomach contents from 111 sea lions collected in the Bering Sea in March and April 1981 are in the possession of ADF&G. This collection is presently being analyzed. The NMML plans to initiate a sea lion research program in the Bering Sea to assess status, determine vital rates, and examine feeding habits. Primary emphasis will be on the Pribilof Islands and eastern Aleutian Islands.

11.19 Pacific Walrus

Population Status

Walruses can at present be considered circumpolar in distribution. Fay (1982) recognizes six geographically isolated populations in the northern hemisphere: the Hudson Bay - Davis Strait region, eastern Greenland, Svalband and Franz Josef Land, Kara Sea - Novaya Zemlya, Laptev Sea, and Bering and Chukchi seas. The population which inhabits primarily the Bering and Chukchi seas is considered a distinct subspecies, the Pacific walrus, Odobenus rosmarus divergens. The overall distribution of Pacific walruses appears to be limited by water depth, with only occasional sightings in water deeper than 100 m (Fay 1982). Although they have been recorded from the Gulf of Alaska, Sea of Okhotsk, East Siberian Sea, and Beaufort Sea, the primary range is the broad, continental shelf area which comprises the Bering-Chukchi platform (Fig. 11.19-1).

Walruses migrate seasonally from wintering areas in the Bering Sea to summering grounds on the coast of the Bering and Chukchi seas and the Chukchi Sea ice edge. Based on observations conducted from 1960 to 1976, two areas of concentration usually occur in late winter and early spring, one south and west of St. Lawrence Island and the other in Bristol Bay (Fay 1982)(Fig. 11.19-2). The actual location of these concentrations is somewhat dependent on the extent of ice in the Bering Sea, which the animals use as a resting platform when not engaged in other activities such as feeding and breeding. In at least 1967 and 1979, the ice front did not extend south of Nunivak Island (Burns et al. 1981), and it seems highly probable that the Bristol Bay concentration occurred farther to the north and overlapped the St. Lawrence Island concentration. The degree of fidelity to these concentration areas and the normal rate of interchange between them have not been documented. Walruses in each of these concentration areas are predominantly adult females and their young and a few mature males, while adjacent to them groups of immature and subadult animals have sometimes been observed (Fay 1982).

Much of the population migrates northward through Bering Strait in April and May. It appears that animals from the Bristol Bay concentration move north along the Alaskan coast and pass east of St. Lawrence Island, while those wintering southwest of St. Lawrence pass mostly around the west end (Fay 1982). During the northward migration, adult males become largely segregated from the rest of the population. Subadults and females with young follow the retreating ice edge northward and summer primarily in the northern Chukchi Sea (Estes and Gilbert 1978). Adult males form large herds on hauling grounds in Bristol Bay, Bering Strait, and along the Chukchi Peninsula (Fig. 11.19-3).

The pattern of southward migration is presently unclear. Walruses that summered along the Chukchi Sea ice edge migrate southward in October and are seen in large numbers in Bering Strait and near St.

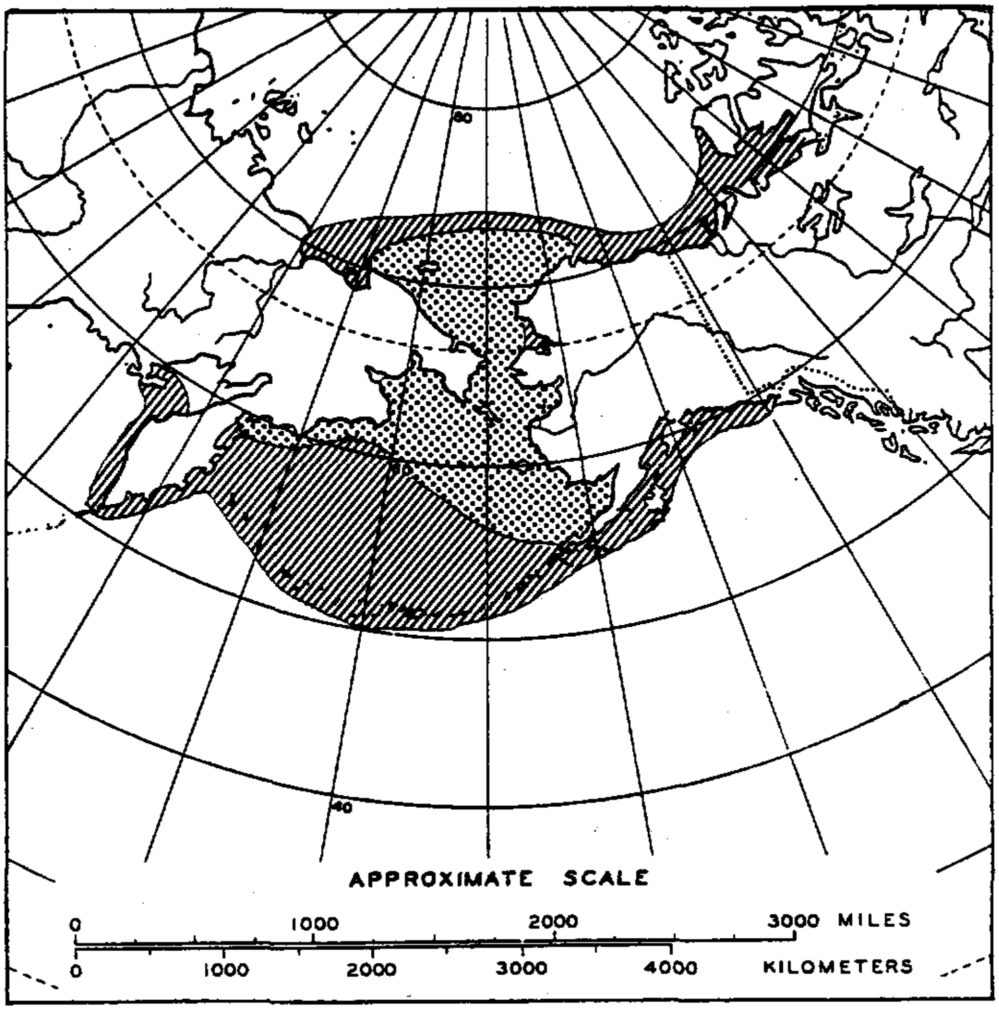

Figure 11.19-1. General distribution of Pacific walruses. Stippled area is primary range; crosshatched area indicates limits of recent sightings. (From Fay and Lowry 1981).

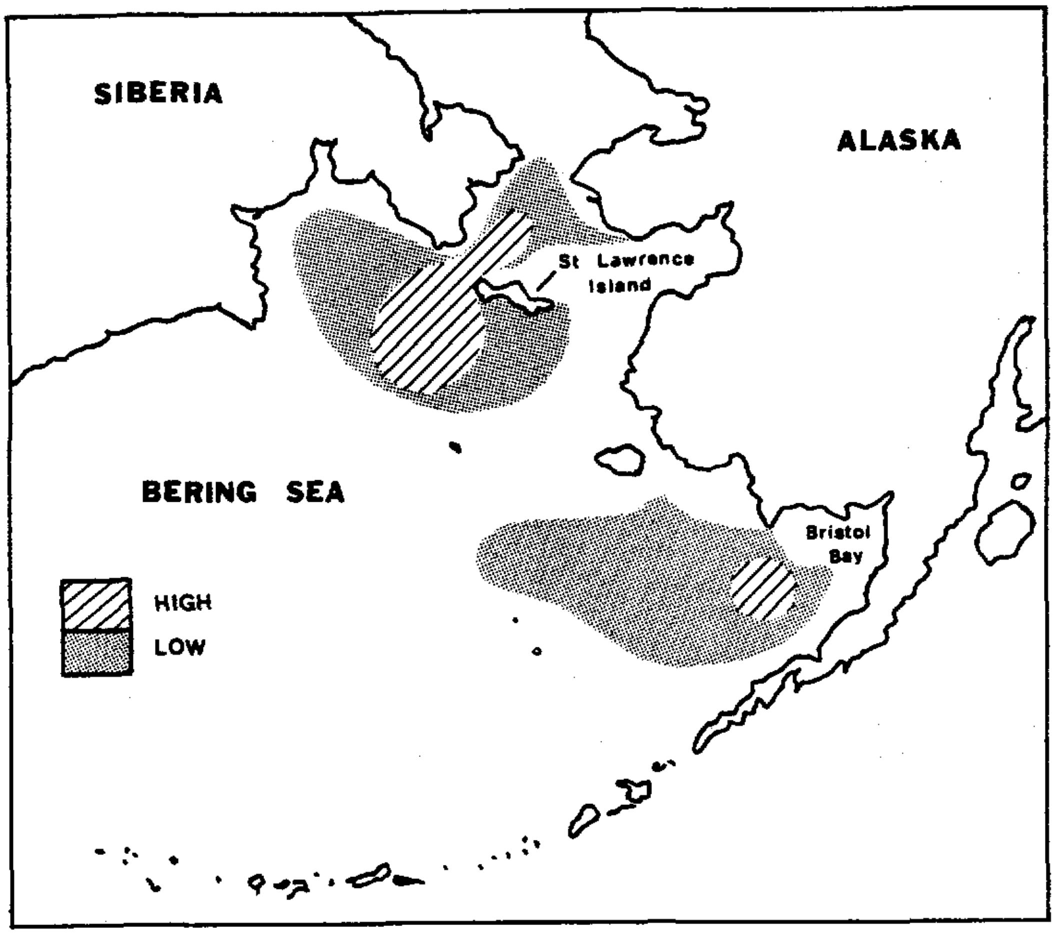

Figure 11.19-2. High- and low-density zones of walrus distribution in the Bering Sea, April 1982 (from Fay 1982).

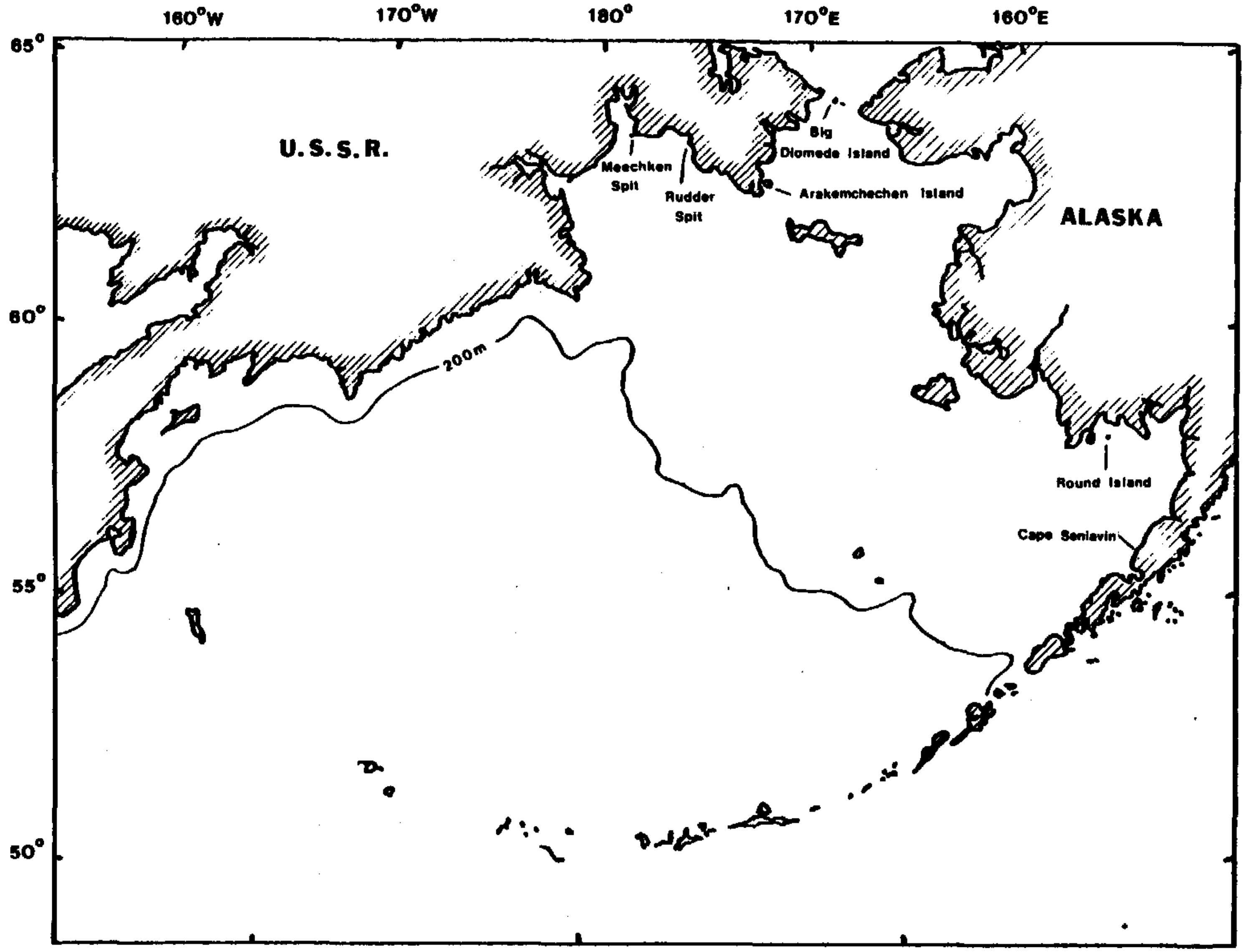

Figure 11.19-3. Locations of Bering Sea haulouts used in summer by adult male walruses.

Lawrence Island. Herds that summered in coastal areas of the Siberian coast usually leave the hauling grounds in late September (Fay 1982). Animals are abundant on Round Island at least into November (Fay and Lowry 1981).

The distribution of walruses just described represents present conditions. In the mid-20th century, the normal range was considerably smaller due to a reduced population (Fedoseev 1962). For example, Kleinenberg (1957) noted that of 33 former coastal concentration areas on the Chukchi Peninsula only three remained in 1954. In the 1970's, an increase in range has accompanied a population increase. Gol'tsev (1976) discovered two new haulouts in 1975, and extralimital occurrences have become common in Alaska (ADF&G, unpubl.).

The abundance of Pacific walruses has fluctuated greatly in the past 2 centuries, largely as a result of human harvesting. The size of the population prior to the arrival of commercial hunters in the Bering Sea is unknown; however, Fay (1957) has estimated that it must have numbered at least 200,000 individuals. Excessive harvests greatly reduced the population in the 19th and first half of the 20th centuries (Fedoseev 1962, Fay 1982). Based on harvest levels, the population may have reached its lowest historical levels in the mid-1950's.

Since 1958, regular attempts at censusing the walrus population have been made by both Soviet and American scientists. These attempts have all been aerial surveys, generally with photographs taken of concentrations at rookeries, and visual counts on strip transects of walruses on the ice and in the water. In spring, surveys were flown over major concentrations in the Bering Sea, while in late summer-early autumn they have covered the Chukchi ice edge and coastal rookeries along the Chukchi Peninsula. Surveys have varied considerably in their completeness of coverage and in the methodology used to estimate the total population size from sample counts. Nonetheless, the surveys indicate a major increase in the size of the walrus population (Table 11.19-1). A survey similar to that done in 1975 was conducted in autumn 1980. Preliminary analysis of data from the US sector of the Chukchi Sea indicates 101,000 walruses there, while the Soviets' preliminary estimate for their zone was "more than 180,000" (USFWS, in litt.). Considering that at least 10,000 animals were in Bristol Bay at that time (Fay and Lowry 1981), the 1980 walrus population may have numbered approximately 300,000.

Surveys conducted in the Bering Sea allow the delineation of zones of high and low abundance during years of average ice conditions (Kenyon 1972, Fig. 11.19-2). However, since the walrus population at the time of the last extensive Bering Sea survey was probably less than half as large as it is at present, it seems a very real possibility that this pattern of abundance has changed. Such a distributional shift was suggested by Krogman et al. (1979), who provide information on distribution and density of walruses in portions of the Bering Sea in spring 1976 (see also Burns and Harbo 1977). Fay and Lowry (1981) conducted

Table 11.19-1. Estimates of size of the Pacific walrus population.

Date	Estimated population (1000's) Mean	Range	Comments	Source
August-September 1958	40	--	Aerial survey in East Siberian and Chukchi seas	Nikulin, cited in Fedoseev 1962
23 February - 2 March 1960	--	78-117[a]	Aerial strip transects in Bering Sea, 1 mi wide at 500-700 ft altitude, 125 knots. 1,240 mi traveled; 3,914 walruses counted on transects.	Kenyon 1960b
25-28 April 1960	--	73-110[a]	Similar to above. 2,472 mi traveled; 3,323 walruses counted on transects.	Kenyon 1960b
25 September - 20 October 1960	50	--	Aerial photographic survey of drifting ice in East Siberian and Chukchi seas and coastal haulouts on Chukchi Peninsula--85% of Soviet sector censused, number in American sector estimated.	Fedoseev 1962
20-30 March 1961	--	73-110[b]	Aerial survey in Bering Sea. 61.3 flight hr, 4,929 walruses counted in 1-mi-wide transects.	Kenyon 1972
16-23 April 1968	--	73-110[b]	Aerial survey in Bering Sea. 37.5 flight hr, 4,666 walruses counted in 1-mi-wide transects.	Kenyon 1972
13 September - 19 October 1970	101[c]	--	Aerial survey (photographic and visual) of animals hauled out on ice and land. 62% counted on photographs.	Gol'tsev 1972
7-16 April 1972	136[d]	85-162[d]	Aerial strip transects in Bering Sea, 1 mi wide, at 500 ft altitude, 145 mph. 4,279 mi traveled; 9,299 walruses counted on transects.	Kenyon 1972
8 September - 16 October 1975	209	168-250	Joint US-USSR aerial survey of Chukchi Sea ice edge and coastal haulouts on Chukchi Peninsula (photographed).	Krogman et al. 1979[e]

[a] 25-50% correction factor for animals not seen.
[b] Details of data analysis not published.
[c] Unclear whether this includes animals in American sector.
[d] 10% correction factor for animals not seen.
[e] Total estimate derived from Gol'tsev (1976) and Estes and Gilbert (1978). Does not include animals in Bristol Bay (Walrus Islands).

aerial surveys of walruses in Bristol Bay from April 1980 to May 1981 and provide information on seasonal distribution and abundance in that area (Fig. 11.19-4, Table 11.19-2).

Vital rates and population parameters of walruses have been described by Fay (1982), based on all available data collected from 1952 to 1979. In most instances it was necessary to treat these data in aggregate in order to arrive at an adequate description, which is unfortunate since trends or changes in parameters which might be indicative of population status are obscured.

Newborn walrus calves are about 100-120 cm in standard length and weigh 45-75 kg. Subsequent growth is quite rapid, with the weight of 1-year-olds two to three times that of newborns. Males grow faster than females and are longer at physical maturity (10 years old in females, 15 in males). Females attain their maximum average weight (880 kg) at 12-14 years of age, while males reach a maximum (1200 kg) after their 16th year (Fay 1982, Fig. 11.19-5). Weight varies with time of year and reproductive status: animals are generally heavier in the winter and when carrying a near-term fetus. This variation is due in large part to variation in thickness of the blubber layer. Fay and Kelly (1980) present data indicating that blubber thickness was less on animals which died on the Punuk Islands in autumn 1978 than on animals of comparable age and sex harvested in the same general area from 1958 to 1973.

Some male walruses are sexually potent at 7 years of age; however, most probably do not attain that condition until a year or two later. Fay (1982) suggests that males do not actually participate in breeding until about 15 years old when they have reached full reproductive and physical development.

A small percentage of female walruses ovulates first at 4 years of age; the percentage increases until 100% are fertile at 10 years old (Fay 1982). Not all ovulations result in successful pregnancies, especially in the younger and older age classes. Fay (1982) estimates that about 68% of all potentially estrus females are successfully impregnated each year. In the most productive age classes (8-15 years of age), conception rates are over 80%. About 95% of conceptions result in successful births. Since walruses mate during winter and give birth about 15 months later in spring, the usual interval between pregnancies is 2 years, although for various reasons longer and shorter intervals sometimes occur. According to Fay, the most probable annual calf production, based on available samples, ranges from 32 to 41% (mean 36.7%) of the adult female segment of the population.

Human harvesting is probably the major cause of mortality for walruses (Table 11.19-3). Other sources of mortality have been extensively reviewed by Fay (1982), who estimates the overall rate of recruitment of animals to breeding age at 40-50% for females and

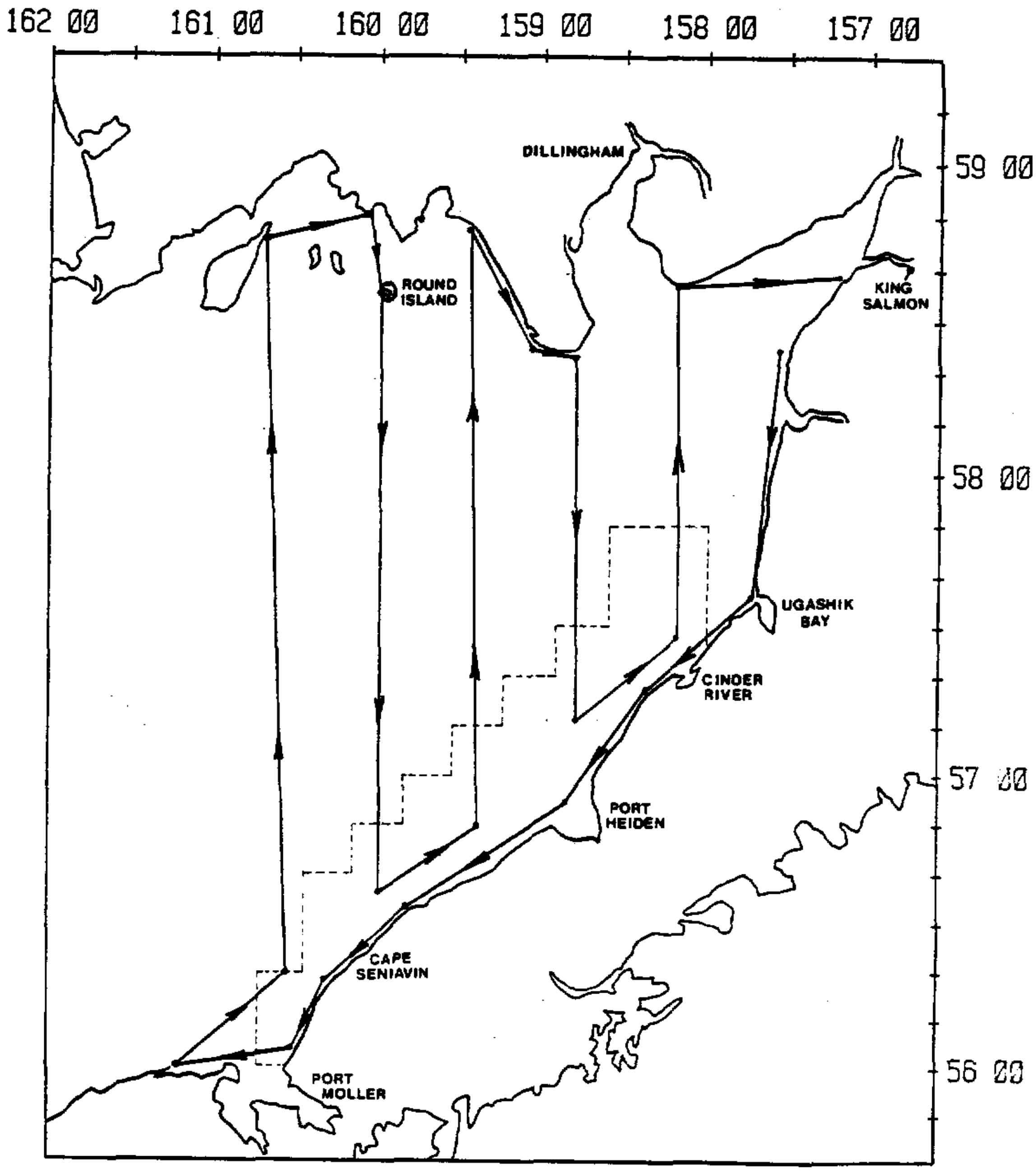

Figure 11.19-4. Map of Bristol Bay showing flight lines for aerial surveys of walruses, April 1980 to May 1981. Clam fishery zone is indicated by dashed line. (From Fay and Lowry 1981).

Table 11.19-2. Estimated total numbers of walruses in and out of the proposed clam fishery zone at the time of each aerial survey (from Fay and Lowry 1981).

Date	Estimated no. of walruses in the water[a]		No. walruses hauled out on land		Estimated total no. of walruses		Percent total walruses in clam zone
	In clam zone	Out of clam zone	In	Out	In	Out	
16 April 1980	12,962	3,988	1,000	3,000	13,962	6,988	66.6
27 May 1980	2,752	56,296	0	7,500	2,752	63,796	4.1
23 June 1980	0	3,297	0	1,100[b]	0	4,397	0.0
22 August 1980	0	14,851	0	9,700[b]	0	24,551	0.0
18 September 1980	0	8,163	0	2,100[b]	0	10,263	0.0
17 October 1980	0	565	0	450	0	1,015	0.0
15 November 1980	0	816	0	7,500	0	8,316	0.0
22 January 1981	0	283	0	0	0	283	0.0
10 February 1981	0	283	0	40	0	323	0.0
10 March 1981	148	556	0	0	148	556	21.0
7 April 1981	3,285	879	1,750	2,500	5,035	3,379	59.8
7 May 1981	289	21,382	0	5,000	289	26,382	1.0

[a] Areas estimated as 9,185 km^2 in the clam fishery zone and 44,854 km^2 in the remainder of the survey area.

[b] Based on ground counts made at Round Island (J. Taggart and C. Zabel, pers. commun.).

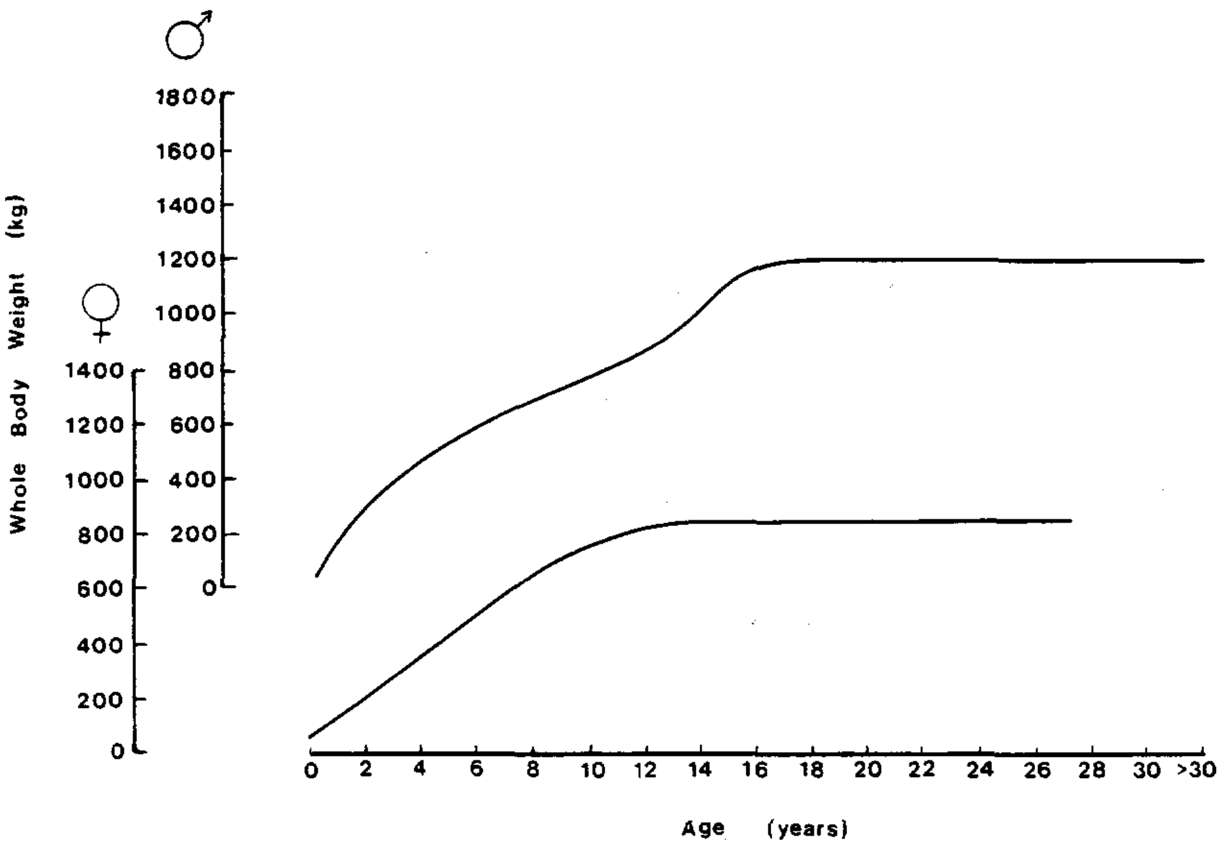

Figure 11.19-5. Whole body weight of male (upper) and female (lower) Pacific walruses in relation to age (from Fay, in press).

Table 11.19-3. Retrieved harvests and estimated total kills of Pacific walruses for the period 1958 to 1977[a] (from Fay 1982).

Calendar year	Retrieved harvests: Soviet Union Total	Retrieved harvests: United States Males[b]	Females[b]	Calves	Total	Estimated total kill[c]
1958	4,038	--	--	--	1,500	9,230
1959	3,183	--	--	--	1,400	7,638
1960	2,866	--	--	--	2,300	8,610
1961	2,573	--	--	--	1,860	7,388
1962	1,818	--	--	--	1,690	5,847
1963	1,249	--	--	--	1,725	4,957
1964	1,500	649	255	71	975	4,125
1965	891	1,010	503	254	1,767	4,430
1966	909	1,741	789	278	2,808	6,195
1967	940	1,192	132	23	1,347	3,812
1968	939	933	330	174	1,437	3,960
1969	965	620	186	76	882	3,078
1970	988	881	427	114	1,422	4,017
1971	897	1,592	254	69	1,915	4,687
1972	1,518	847	344	134	1,325	4,738
1973	1,291	1,240	231	110	1,581	4,787
1974	1,205	1,097	263	50	1,410	4,358
1975	1,265	1,488	650	240	2,378	6,072
1976	1,271	1,820	867	302	2,989	7,100
1977	1,461	1,338	650	325	2,450[d]	6,518

[a] Soviet data 1958-1964 from Krylov (1968), 1965-1977 from unpublished records, Ministry of Fisheries; US data all years from unpublished records, Alaska Department of Fish and Game.

[b] "Males" and "Females" 1 year old and older.

[c] Assuming sum of retrieved harvests = 60% of kill.

[d] Includes 137 adults for which sex was not determined.

10-20% for males. Fay and Kelly (1980) documented a case of mass natural mortality at St. Lawrence Island in 1978.

The sex ratio of walruses at birth is 1:1. Due to protection afforded to females by State of Alaska hunting regulations from 1960-1972 and perhaps also due to higher natural mortality among adult males, females predominate in the current population. Fay (1982) estimates that, in 1972, females 6 years old and older comprised 46% of the total population as opposed to 38% in 1960.

Diet Composition

Most walrus calves nurse for approximately 1 year. Some feeding on benthic organisms occurs prior to that time, and some animals may continue to nurse during their 3rd year of life. Most are probably fully weaned at about 2 years of age (Fay 1982).

Based on the compilation by Fay (1982), more than 60 genera of marine organisms, belonging to 10 phyla, have been identified as prey of the Pacific walrus. Most of those are bottom-living invertebrates. In virtually all areas from which quantitative data are available, meats from bivalve molluscs have comprised over 80% of the stomach contents. A notable exception in some individual walruses is the presence of meat, organs, skin, and blubber from seals in the ingesta (Lowry et al. 1981a; Fay 1982; Lowry and Fay, in prep.).

Data are available on foods of walruses from approximately 15 locations in the Bering Sea and Bering Strait (Fig. 11.19-6). In addition to non-quantitative observations (Table 11.19-4), quantitative data have been collected on the composition of the stomach contents of 179 animals taken in subsistence harvests and during research efforts (Tables 11.19-5 through 11.19-9); 90 of which were taken at Diomede (location 15, Fig. 11.19-6). Of the animals in these collections for which sex is known, 124 were males and 41 were females.

By far the majority (144/179) of the stomachs which have been quantitatively examined were collected from Eskimo subsistence harvests in Bering Strait during the spring migration period. The exact locations where these animals were taken are not known. In one collection (Lowry et al. 1981a), only subsamples of contents were examined, which possibly introduces biases, as well as precluding the determination of stomach contents volumes. From these samples (Tables 11.19-6 through 11.19-9), a general assessment of the relative importance of prey species in the diet of walruses near St. Lawrence Island, Bering Strait, and Norton Sound can be made (Table 11.19-10). For *Serripes* sp., a decline in the frequency of occurrence and proportion of the ingesta was seen between 1975 and 1979 at Gambell, Savoonga, and Diomede. The decline was particularly evident at Diomede, where *Serripes* was virtually absent from the 1979 samples. A parallel decline in the importance of *Serripes* in the diet of bearded seals at Diomede has been documented over the same period of time (Lowry et al. 1980a).

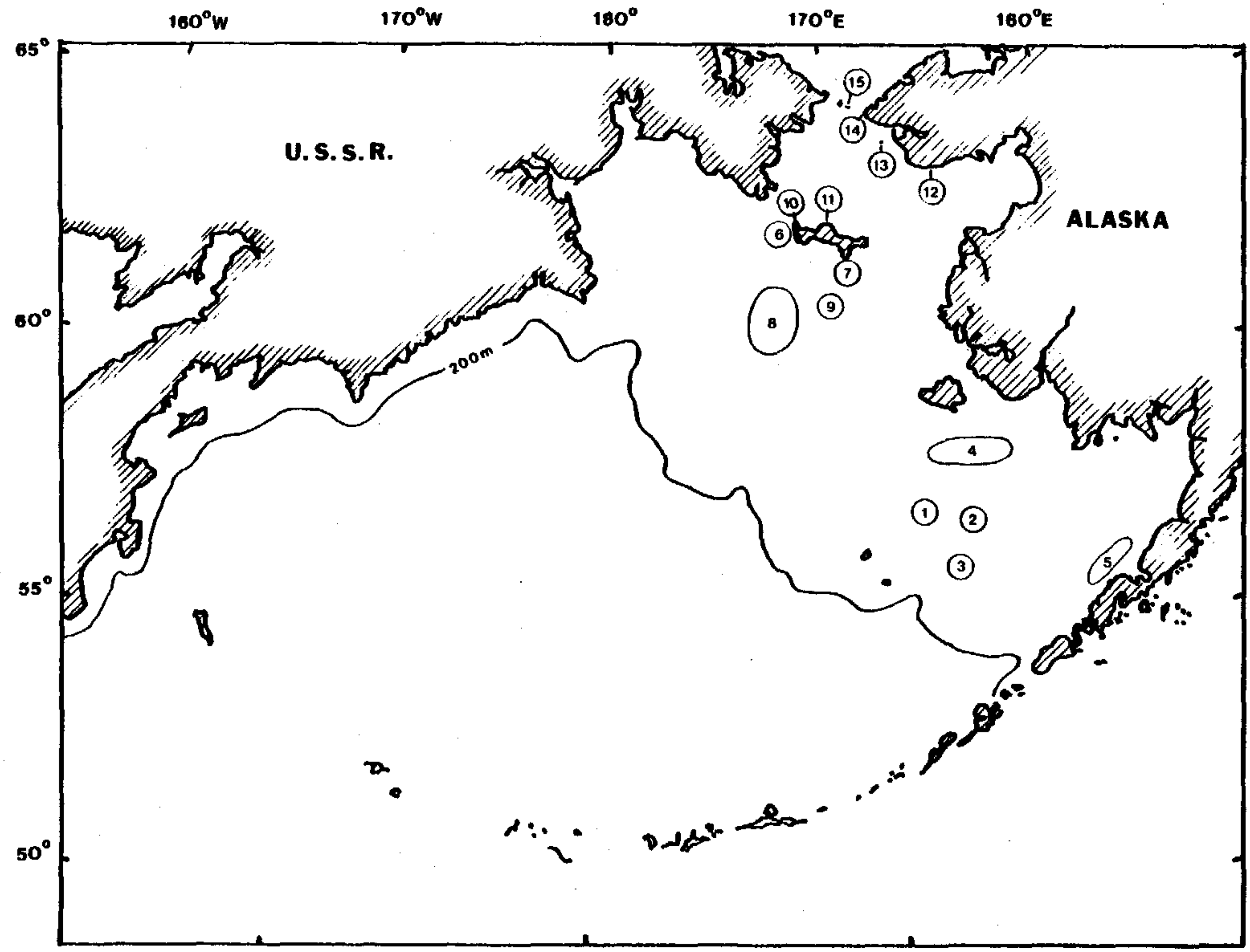

Figure 11.19-6. Locations where data have been collected on foods of Pacific walruses. Numbers correspond to locations in Tables 11.19-4 through 11.19-9.

Table 11.19-4. Summary of non-quantitative information of foods of Pacific walruses. All samples are from stomach contents unless noted otherwise. Numbers in parentheses refer to locations in Figure 11.19-6.

SOURCE	Tikhomirov 1964	Fay et al. 1977	Fay et al., in prep.	Fay et al., in prep.	Brooks 1954
LOCATION	240 nm southwest of Nunivak Is. (1)	West end St. Lawrence Is. (6)	61°52'N, 171°45'W (9)	61°26'-63°00'N 172°12'-174°27'W (8)	Bering Strait (15)
DATES	March 1962	January 1957	March-April 1971	February-March 1972	June 1952 and 1953
SAMPLE SIZE	50	1	Unknown	Unknown	Unknown
	Principal foods were "shrimps, crabs (including a few king crabs), and lesser amounts of molluscs."	Mainly siphons of *Spisula* sp. with fewer cockle and gastropod feet.	Food items found near breathing holes and hard parts identified from feces--shells of bivalves (*Musculus* and *Nucula*) and gastropods, fragments of tanner crabs, shrimps, amphipods, tunicates, and priapulids, and one intact hermit crab.	Hard parts identified from walrus feces collected on the ice. Dominant by number were snails, tanner crabs, priapulids, and bivalves. Also identified were shrimp, amphipods, tunicates, and echiurid worms.	Males fed mainly on *Mya* and *Clinocardium* and to a lesser extent on *Molpadia arctica* (sea cucumber). Females and immatures tended toward smaller bivalves (*Astarte* and *Macoma*), polychaete worms, and sipunculids.

Table 11.19-5. Summary of information on foods of Pacific walruses from southern Bering Sea. * indicates values less than 1%.

SOURCE	Fay et al., in prep.		Fay et al., in prep.		Fay and Lowry 1981		Fay and Lowry 1981	
SEX/AGE CLASS	Adult male	Subadult male	Unknown		3 male, 12 female		Mature males	
LOCATION	58°58'N, 164°45'W (2)		56°43'-57°30'N 165°10'-166°31'W (3)		Southern Kuskokwim Bay (4)		Southern Bristol Bay (5)	
DATES	January 1970		March - April 1976		March 1981		April 1981	
SAMPLE SIZE	1	1	21		15		4	
MEAN VOL./WT. OF CONTENTS	10.9 kg	3.7 kg			2.2 kg		5.1 kg	
COMPOSITION OF SAMPLE	% volume	% volume	% frequency	Maximal no. per stomach	% frequency	% weight	% frequency	% weight
Cockles[a]	100	25	33	2,881	--	--	--	--
Mya truncata	--	--	24	79	--	--	50	1.8
Serripes sp.	--	--	--	--	80	6.7	50	*
Spisula sp.	--	--	--	--	100	16.1	100	61.4
Tellina sp.	--	--	--	--	100	60.9	75	14.2
Siliqua sp.	--	--	--	--	87	3.0	25	1.1
Other bivalves[b]	--	--	24	1,360	100	9.6	100	10.8
Gastropods	--	60	62	342	73	*	75	*
Sea cucumbers	--	--	--	--	--	--	25	*
Polychaetes	--	--	--	--	60	*	75	*
Echiuroids	--	--	--	--	47	2.4	25	*
Crustaceans	--	--	--	--	53	*	50	*
Tunicates	--	5	5	7	--	--	--	--
Hydrozoans	--	--	--	--	33	*	25	8.8
Non-food	--	10	--	--	--	--	--	--

[a] *Serripes* and *Clinocardium*.
[b] Includes bivalve fragments.

Table 11.19-6. Summary of information on foods of Pacific walruses from northern Bering Sea. * indicates values less than 1%.

SOURCE	Fay et al., in prep.	Fay et al., in prep.[a]		Fay et al., in prep.[a]		Lowry et al. 1981a	
SEX/AGE CLASS	Adult female	All males		1 male, 1 female		Female	
LOCATION	62°25'N, 169°40'W (7)	Nome/Norton Sound (12)		King Island (13)		Wales (14)	
DATES	February 1970	May-June 1975		June 1976		June 1979	
SAMPLE SIZE	1	7		2		1	
MEAN VOL./WT. OF CONTENTS	2.0 kg	2.7 kg		8.2 kg		3.1 kg	
COMPOSITION OF SAMPLE	% by volume	% frequency	% volume	% frequency	% volume	% frequency	% weight
Hiatella sp.	--	--	--	50	*	--	--
Mya sp.	25	--	--	100	87.1	--	--
Serripes sp.	--	86	97.0	50	*	--	--
Spisula sp.	--	28	*	100	11.7	100	3.3
Tellina/Macoma	--	86	1.0	50	*	100	92.6
Other bivalves[b]	--	--	*	--	--	100	*
Gastropods	10	71[c]	1.0	50	*	100	*
Sea cucumbers	--	--	--	100	*	--	--
Priapulids	--	71	*	--	--	--	--
Polychaetes	--	14	*	50	*	--	--
Echiuroids	--	--	--	100	*	--	--
Crustaceans	--	14[c]	*	50	*	--	--
Tunicates	53	--	--	--	--	--	--
Other food	3	--	--	--	--	--	--
Non-food	9	14	*	--	--	100	3.6

[a] Particulate digesta not included.
[b] Includes unidentified molluscan fragments.
[c] Minimum values.

Table 11.19-7. Summary of information on foods of Pacific walruses from Gambell. * indicates values less than 1%.

SOURCE	Fay et al., in prep.[a]		Lowry et al. 1981a	
SEX/AGE CLASS	10 male, 3 female		10 male, 4 female	
LOCATION	Gambell (10)		Gambell (10)	
DATES	April - May 1975		May - June 1979	
SAMPLE SIZE	13		14	
MEAN VOL./WT. OF CONTENTS	4.5 kg		2.2 kg[d]	
COMPOSITION OF SAMPLE	% frequency	% volume	% frequency	% volume
Hiatella sp.	23	12.7	7	2.2
Mya sp.	100	50.4	79	34.7
Serripes sp.	54	11.9	71	7.1
Spisula sp.	92	6.8	71	8.1
Tellina/Macoma	--	--	29	1.5
Other bivalves[b]	46[c]	3.7	43	2.3
Gastropods	77[c]	1.4	79	4.1
Sea cucumbers	77	3.4	36	*
Priapulids	77	1.0	36	*
Echiuroids	54	*	21	2.5
Polychaetes	23[c]	1.3	15	17.6
Crustaceans	77[c]	4.2	71	1.2
Others	31[c]	*	--	--
Non-food	100	28.4	86	16.6

[a] Particulate digesta not included.
[b] Includes unidentified molluscan fragments.
[c] Minimum values.
[d] Mean weight of subsamples.

Table 11.19-8. Summary of information on foods of Pacific walruses from Savoonga. * indicates values less than 1%.

SOURCE	Fay et al., in prep.[a]		Lowry et al. 1981a	
SEX/AGE CLASS	13 male, 1 female		12 male, 2 female	
LOCATION	Savoonga (11)		Savoonga (11)	
DATES	May - June 1974 and 1975		May - June 1979	
SAMPLE SIZE	14		14	
MEAN VOL./WT. OF CONTENTS	7.0 kg		1.5 kg[d]	
COMPOSITION OF SAMPLE	% frequency	% volume	% frequency	% volume
<u>Hiatella</u> sp.	7	*	--	--
<u>Mya</u> sp.	86	51.8	86	54.0
<u>Serripes</u> sp.	79	34.0	57	16.3
<u>Spisula</u> sp.	71	8.2	50	2.0
<u>Tellina/Macoma</u>	14	*	21	1.5
Other bivalves[b]	21[c]	2.6	21	4.6
Gastropods	71[c]	*	93	1.2
Sea cucumbers	57[c]	*	43	1.3
Priapulids	57	*	50	1.4
Echiuroids	57	*	15	4.3
Polychaetes	36[c]	*	29	*
Crustaceans	64[c]	*	29	*
Others	21[c]	*	--	--
Non-food	93[e]	*	64	16.7

a Particulate digesta not included.
b Includes unidentified molluscan fragments.
c Minimum values.
d Mean weight of subsamples.
e Includes bivalve shell fragments.

Table 11.19-9. Summary of information on foods of Pacific walruses from Diomede. * indicates values less than 1%.

SOURCE	Fay et al., in prep.[a]		Lowry et al. 1981a	
SEX/AGE CLASS	55 male, 15 female		7 male, 1 female, 12 unknown	
LOCATION	Diomede (15)		Diomede (15)	
DATES	May - June 1975		May - June 1979	
SAMPLE SIZE	70[d]		20	
MEAN VOL./WT. OF CONTENTS	7.3 kg		3.1 kg[e]	
COMPOSITION OF SAMPLE	% frequency	% volume	% frequency	% volume
<u>Hiatella</u> sp.	72	11.3	5	3.9
<u>Mya</u> sp.	90	54.2	100	78.2
<u>Serripes</u> sp.	87	9.4	10	*
<u>Spisula</u> sp.	89	19.1	85	4.9
<u>Tellina/Macoma</u>	15	*	10	5.0
Other bivalves[b]	3	*	--	--
Gastropods	66[c]	1.3	20	*
Sea cucumbers	13[c]	*	65	2.1
Priapulids	37	*	21	*
Echiuroids	8	*	10	*
Polychaetes	37[c]	*	14	*
Crustaceans	18[c]	*	--	--
Others	39[c]	*	--	--
Non-food	97[f]	2.3	95	2.8

a Particulate digesta not included.
b Includes unidentified molluscan fragments.
c Minimum values.
d Excluding one stomach containing mostly <u>Erignathus</u>.
e Mean weight of subsamples.
f Includes bivalve shell fragments.

Table 11.19-10. Estimated rank order of importance of prey in the diet of Pacific walruses.

	Area/season				
Prey rank	Pribilof Is.-Kuskokwim Bay winter - spring	Southern Bristol Bay spring	St. Lawrence Is. spring	Norton Sound spring	Bering Strait spring
1	Serripes/Clinocardium	Spisula	Mya	Serripes	Mya
2	Tellina	Tellina	Serripes	Tellina/ Macoma	Spisula
3	Spisula	Hydrozoans	Spisula	Gastropods	Hiatella
4	Siliqua	Mya	Hiatella		Tellina/ Macoma
5	Gastropods	Siliqua	Echiuroid worms		Serripes
6	Echiuroids		Polychaete worms		Sea cucumbers
7	Mya		Gastropods		
8			Tellina/Macoma		

The relative importance of prey at areas and seasons for which some data are available are estimated in Table 11.19-10. The ranking for southern Bristol Bay is based on a research collection of four animals for which exact collection locations and quantitative analysis of the contents are available (Fay and Lowry 1981). For the Pribilof Islands - Kuskokwim Bay region, rankings are based on a comparatively large number (86) of stomachs examined (Tables 11.19-4 and 11.19-5). However, complete quantitative data are available for only 15 of those specimens, and for one collection (Tikhomirov 1964b) the results are so unlike all others that they are highly questionable. Data on winter foods of walruses in the St. Lawrence Island concentration are available from only two stomachs (Tables 11.19-4 and 11.19-6). Additional observations are available on items found near breathing holes and in feces (Table 11.19-4); however, it is not known how such items relate to what was actually consumed. We do not consider the data from that area adequate to rank the importance of prey.

Examination of stomach contents of walruses poses some particular problems. The bivalve molluscs eaten are poorly represented in available museum collections and, in many instances, consist only of shells. Since whole shells almost never occur in walrus stomachs, identifications must be based on soft parts for which there is little comparative material available. For this reason, identification of prey to species is usually not possible, and in some instances (e.g., Tellina and Macoma) closely related genera cannot be distinguished. Due to inadequate comparative material, errors in identification of ingesta have occurred. In collections made in the northern Bering Sea in 1975 and 1979 (Lowry et al. 1981a; Fay et al, in prep.), siphons of what are now thought to be a species of Mya were sometimes identified as Spisula (Fay, pers. commun.). Additional error results from digestion, which causes small prey to be underrepresented in analyses of partially digested stomach contents (Fay and Lowry 1981).

Food Requirements

Fay (1982) has compiled and analyzed all available data on food requirements of walruses. Based on daily food intakes of captive animals and caloric values of foods, he estimated daily gross energy intake (GEI) as 280 to 530 (mean 380) kcal/kg$^{3/4}$ per day. Using the mean value for GEI and a diet of 95.8% molluscs (caloric value 1,200 kcal/kg) and 4.2% other invertebrates (caloric value 850 kcal/kg), walruses would consume 5-7% of their total body weight (TBW) per day. With an average weight of 720 kg (based on the 1972 population), the average net daily rate of food intake was 6.2% of the TBW or about 16,300 kg consumed annually by the average individual.

New or Unanalyzed Data

A considerable amount of the material collected from walruses in recent years has not yet been processed or has been incompletely analyzed and reported. Fay and ADF&G have records of ages of approximately

7,000 walruses harvested in Alaska from 1952 to 1975. These records are now being analyzed for their utility in determining population age structure (Fay and Sease, pers. commun.). Ages have been determined for 521 walruses harvested in 1979 (ADF&G, unpubl.). In 1980 and 1981, teeth were collected from 963 and 721 harvested animals by the USFWS (Schliebe, pers. commun.). Those teeth will be processed within a year.

During July and September 1979, age composition data were gathered for approximately 3,000 walruses in the northeastern Chukchi Sea (Fay and Hoover, pers. commun.).

Female reproductive tracts have been collected from 1975 to 1981, summarized as follows: 1975, 161 mature animals, analyzed and partially reported in Lowry et al. (1980a); 1979, about 100 collected by ADF&G, presently being analyzed; 1980, 184 collected by USFWS, presently being analyzed by F. H. Fay (Schliebe, pers. commun.); 1981, 73 mature animals collected and analyzed during a joint US-USSR research cruise (Fay, pers. commun.).

Blubber thickness measurements have been taken by USFWS from 189 walruses taken in 1980 and 237 taken in 1981 (Schliebe, pers. commun.). An additional 172 blubber thickness measurements were taken during the joint US-USSR research collection (Fay, pers. commun.).

Stomach contents from approximately 100 walruses taken in Alaska in 1980 were collected by USFWS. Those samples have been processed, but the data are not yet analyzed (Fay, pers. commun.).

11.20 Harbor Seal

Population Status

The North Pacific harbor seal is found in coastal waters from northwestern Mexico along the North American coast as far north in the Bering Sea as Kuskokwim Bay, along the Aleutian Island chain, in the Pribilof Islands, the Commander Islands, the Kuril Islands, eastern Kamchatka, the Okhotsk Sea, and northern Japan (Burns and Gol'tsev, in press). Shaughnessy and Fay (1977) separated the land-breeding harbor seals into two taxa: the insular seal of eastern Asia and the western Pacific (*P. v. stejnegeri*) and the coastal harbor seal of western North America (*P. v. richardsi*). Burns and Gol'tsev (in press) could not substantiate the physical characteristics which separated the two groups so they rejoined the subspecies as *P. v. richardsi*. The ice-breeding spotted seal (*P. largha*) is closely related and has only recently been widely recognized as a separate species (Shaughnessy and Fay 1977). The harbor seal and the spotted seal are sympatric in several parts of their range, and in fact there is some evidence of intergradation. They occur together along the north side of the Alaska Peninsula, in Bristol Bay, and as far north as Kuskokwim Bay, on the Pribilof Islands, Kuril Islands, and Commander Islands, and possibly the Aleutian Islands, the southern Okhotsk Sea, and eastern Hokkaido (Shaughnessy and Fay 1977; Burns and Gol'tsev, in press).

Harbor seals have long been considered sedentary; however, recent studies by Pitcher and McAlister (1981) have shown movements up to 194 km across 74 km of open ocean. Also, Spalding (1964) reported sightings of harbor seals 50-65 km offshore in the Gulf of Alaska, and Wahl (1977, cited in Pitcher 1980) observed a seal 80 km off the coast of Washington State.

Abundance of harbor seals is extremely difficult to assess. No serviceable, reliable technique exists to census harbor seals over areas as broad as the Bering Sea. Only relatively crude estimates exist for certain areas within the Bering Sea. Surveys conducted by Everitt and Braham (1980) and unpublished material from ADF&G files indicate harbor seals concentrate at specific locations along the north side of the Alaska Peninsula (Figure 11.20-1); the largest concentrations are in the area of Cinder River, Port Heiden, Port Moller, and Izembek Lagoon (Table 11.20-1). The total number of harbor seals in Bristol Bay and the Alaska Peninsula is estimated at 30,000 (NOAA 1979). Burns and Gol'tsev (in press) found the lowest abundance of harbor seals in the Aleutian Islands to be seven seals along 7.2 km of beach on the north side of Yunaska Island and 57 seals along 22.5 km of beach of Chuginadak Island. Fiscus (pers. commun. in McAlister 1981) estimated 20,000-25,000 harbor seals in the Aleutian Islands. No estimate was found for harbor seals in the western Bering Sea.

Near-term harbor seal fetuses were weighed and measured by Pitcher and Calkins (1979) in the Gulf of Alaska near Kodiak. Mean standard

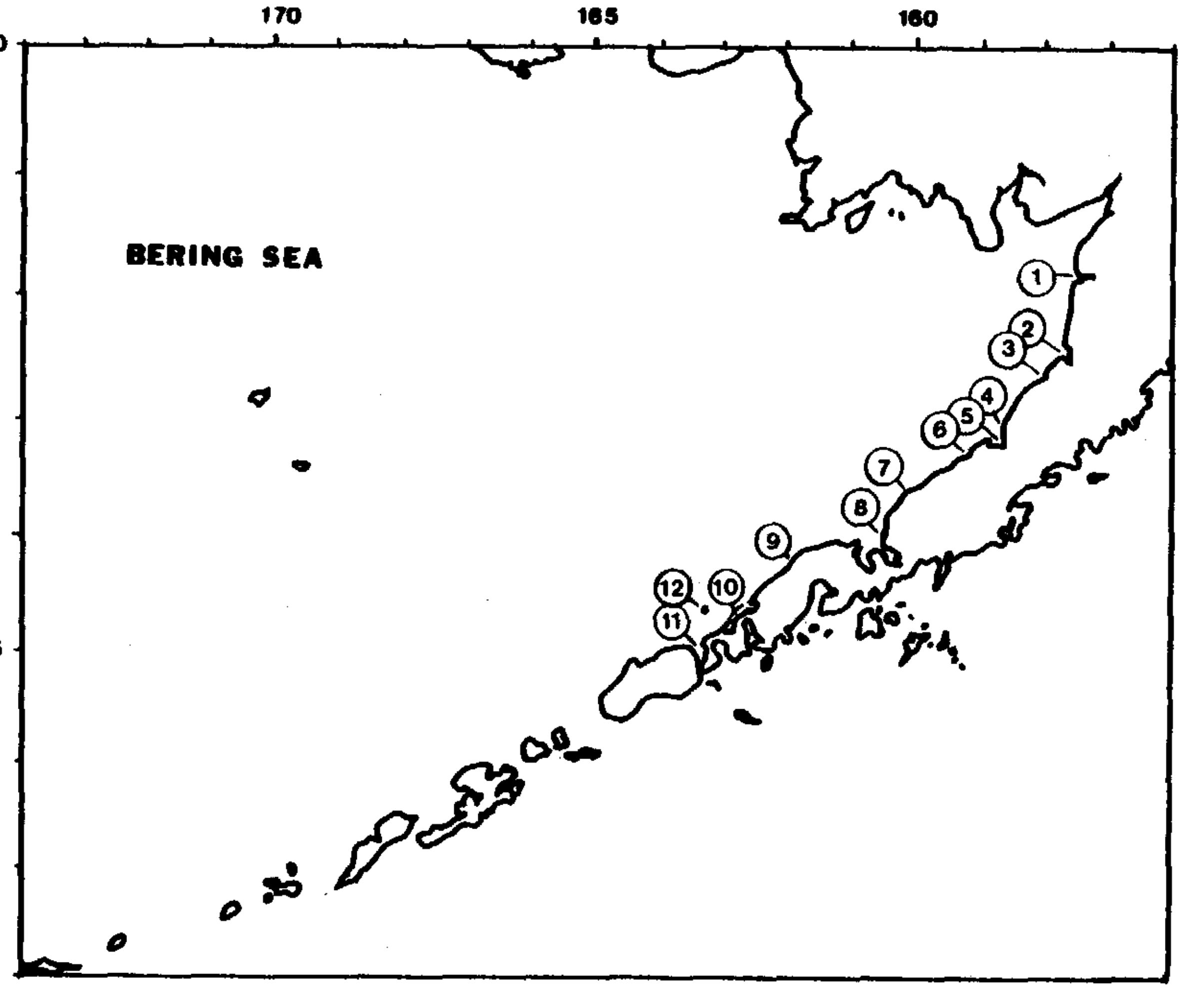

Figure 11.20-1. Locations of harbor seal concentration areas on the north side of the Alaska Peninsula. Names of locations are listed in Table 11.20-1.

Table 11.20-1. Concentration areas of harbor seals on the north side of the Alaska Peninsula, with highest total sighted at each location by Everitt and Braham (1981) from 1975-77. See Figure 11.20-1 for location of reference number.

Reference no.	Location name	Highest count
1	Egegik Bay	70
2	Ugashik Bay	438
3	Cinder River	4,503
4	North Port Heiden	48
5	Port Heiden	10,548
6	Seal Islands	1,137
7	Cape Seniavin	71
8	Port Moller	7,968
9	Cape Leiskof	199
10	Izembek Lagoon	2,034
11	Izanotski Islands	511
12	Amak Island	61

lengths were 78.6 ± 2.7 cm for males and 76.5 ± 1.9 cm for females. Mean weights were 12.0 ± 1.0 kg for males and 11.5 ± 0.6 kg for females. No significant differences were apparent between sexes for either standard length or weight. With both sexes combined, mean standard length was 77.7 ± 1.7 cm, and mean weight was 11.7 ± 0.61 kg. The pups grow rapidly, more than doubling their weight during the suckling period (Bigg 1969). The suckling period usually lasts 3 to 6 weeks.

Harbor seals continue to grow rapidly, although at a reduced rate, until approximately the 10th year. Burns and Gol'tsev (in press) suggest that most growth is achieved by age 6 or 7; the average length of adult male seals (11 years and older) was 176.2 cm, while the average adult female was 161.8 cm. Harbor seal weights vary seasonally due to changes in fat reserves. Weights are highest in the winter and spring, low in summer (associated with lactation, breeding, and molt), and increasing in autumn (Pitcher and Calkins 1979). Pitcher (unpubl.) gives the average weight of adult males as 85 kg and the average weight of adult females as about 76 kg.

Age at first ovulation for harbor seals in the Bering Sea was from 3-5 years (Burns and Gol'tsev, in press). No information on age-specific or overall reproductive rates is available for the Bering Sea; however, Pitcher and Calkins (1979) reported that in the Gulf of Alaska pregnancy rates increased from 17% at 4 years to 100% at 8 years old. The pregnancy rate for females 8 years old and older was 92%. Delay of implantation lasts approximately 11 weeks, and pups are born in June or July. Reproductive failures were noted in 10.6% of the reproductively mature females collected between implantation and birth in the Gulf of Alaska (Pitcher and Calkins 1979).

Pitcher and Calkins (1979) found that in the Gulf of Alaska mortality rates for both sexes were high from birth to 4 years, estimated at 74.2% for females and 79.2% for males. The mean annual mortality rate for females between 4 and 19 years was 11.4% and for males between 4 and 17 years, 12.7%.

Sex ratios appear to be even in the younger age classes and weighted toward females in older age classes. Pitcher and Calkins (1979) show 78% females at ages 21-31. This agrees with Bigg (1969) who found 53% of postnatal seals were females, with few males over 20 years old.

Diet Composition

As with most other aspects of harbor seal biology in the Bering Sea, information on diet composition is lacking. Some animals have been taken in the Aleutian, Pribilof, and Kuril Islands, and one animal from drifting ice in Bristol Bay. No detailed systematic studies of harbor seal feeding habits have been undertaken. Wilke (1957) found that at Amchitka Island seven harbor seal stomachs contained remains of octopus (*Paroctopus apollyon*), crab, pollock, other Gadidae, and the fringed greenling (*Hexagrammus superciliosis*). Kenyon (1965) examined 11 harbor seal stomachs with food from the same location and found only octopus and Atka mackerel. Lowry et al. (1979) reported that seals collected in three different locations in the Aleutian Islands had different food items in their stomachs. Pollock and cod were found in three stomachs from Unalaska Island; pandalid shrimps, mysids, Pacific cod, sculpins, and crangonid shrimps were found in six stomachs from Adak Island; and octopus was found in two stomachs from Atka Island. Capelin were found in one harbor seal stomach taken on drifting ice in southwestern Bristol Bay. Lowry and Frost (1981) examined stomach contents from eight seals with food taken from Otter Island in the Pribilof Islands and found the composition of the diet to be 63.5% fishes, 28.7% octopus, 4.6% other invertebrates, and 2.9% algae. Fishes eaten were mostly pollock and Pacific cod, and small numbers of flatfishes, eelpout (Lycodes sp.), and sculpins. A mixture of fishes, cephalopods, and shrimps in the diet of harbor seals has been reported from the Commander (Marakov 1968) and Kuril Islands (Panina 1966). Burns and Gol'tsev (in press) reported on 16 stomachs with food remains from the Commander Islands. Fourteen contained only octopus beaks, 1 contained octopus and unidentified fishes, and 1 contained squid beaks. They felt the presence of beaks in their sample did not accurately represent the proportion in the diet because the beaks probably persist for long periods in the stomach and may represent several meals. Table 11.20-2 summarizes published information on diet of harbor seals in the Bering Sea.

Thirty harbor seals were collected during a recent (October 1981) research cruise in the southeastern Bering Sea. Stomachs of the 19 animals which contained food remains were analyzed for this report (Table 11.20-3). Fishes were the major prey at all locations with major geographical differences in species consumed.

Much information is available on harbor seal feeding habits outside the Bering Sea in the eastern Pacific. Pitcher (1977, 1980) found that in the Gulf of Alaska the five top-ranked prey overall were pollock, octopus, capelin, eulachon, and herring. In Prince William Sound, the most important food items were pollock, herring, and cephalopods, while on the Copper River Delta the major prey was eulachon. Spalding (1964) reported that in British Columbia harbor seals ate mainly octopus, squids, herring, and salmon in the summer and autumn. Imler and Sarber (1947) found that gadids, herring, flatfishes, salmon, and shrimps were major foods in southeast Alaska.

Food Requirements

Ashwell-Erickson et al. (1978) estimated that the food intake of spotted seals ranged from 13% of body weight during the first year to a mean of 3% at 9 years. Ashwell-Erickson and Elsner (1981) estimated the energy requirements of the Bering Sea harbor seal population using two different models (Table 11.20-4). The mean daily net energy requirement predicted by the two models shows close agreement after age class 2. They felt that the large differences between the two

Table 11.20-2. Summary of information of foods of harbor seals in the Bering Sea. Sample size indicates number of stomachs that contained food.

SOURCE	Wilke 1957	Kenyon 1965	Lowry et al. 1979	Lowry et al. 1979
LOCATION	Amchitka Island	Amchitka Island	Unalaska Island	Adak Island
DATES	March 1954	April 1959, January, March 1962	10-13 April 1972	25 July-1 August 1973
SAMPLE SIZE	7	11	3	6
	Octopus Crab Pollock Fringed greenling Unidentified fish	Atka mackerel Octopus	Pollock Pacific cod	Pandalid shrimps Mysids Pacific cod Sculpins Crangonid shrimps

SOURCE	Lowry et al. 1979	Lowry et al. 1979	Lowry and Frost 1981	Burns and Gol'tsev, in press	Panina 1966
LOCATION	Adak Island	SW Bristol Bay	Otter Island	Commander Islands	Kuril Islands
DATES	2-3 August 1973	27 March 1976	13 April 1979	15-30 August	1963 and 1964
SAMPLE SIZE	2	1	8	15	34
	Octopus	Capelin	Pollock Pacific cod Flatfishes Eelpout Sculpins Octopus Invertebrates	Octopus Unidentified fishes Squid	Fishes Octopus Cephalopods Crustaceans

Table 11.20-3. Rank order of importance of major items in stomachs of harbor seals collected in the southeastern Bering Sea, 4-12 October 1981. Numbers in parentheses indicate the estimated total number of fishes of each group consumed. Sample sizes include only stomachs containing food.

Rank	Nunivak Island N = 2	Cape Peirce N =3	Port Heiden N = 5	Port Moller N = 4	Akun Island N = 5
1	Greenling (12)	Rainbow smelt (42)	Sculpins (87)	Sand lance (250)	Pacific cod (5)
2	Sculpins (1)	Greenling (2)	Sand lance (63)	Pollock (10)	Octopus
3		Lamprey (1)	Flatfishes (9)		Pollock (3)
4			Pollock (8)		Pacific halibut (2)
5			Pacific cod (4)		Rockfishes (1)
6			Rainbow smelt (4)		Sculpins (1)

Table 11.20-4. Energy requirements for a population of 1,000 Bering Sea harbor seals (from Ashwell-Erickson and Elsner 1981).

Age (yrs)	Wt (kg)	Age-freq.	Biomass (kg)	Mort. rate	Biomass dead (kg)	Preg. rate	Freq. preg.	Mean daily energy requirement (kcal X 10^5)		Annual net energy requirement (kcal X 10^7)	
								Model I	Model II	Model I	Model II
0	24.5	149.1	3653.0	.23	840.2	0	0	7.65	3.10	25.81	10.48
1	38.7	114.8	4523.1	.20	904.6	0	0	5.50	3.22	20.08	11.78
2	44.9	91.8	4121.8	.17	700.7	0	0	3.67	2.99	13.43	10.94
3	52.2	76.2	3893.8	.17	661.9	0	0	2.87	2.89	10.48	10.56
4	60.7	63.2	3678.2	.11	404.6	.17	5.4	2.34	2.36	8.56	8.65
5	66.6	56.2	3726.1	.10	372.6	.63	17.7	2.11	2.30	7.71	8.40
6	75.2	50.6	3820.3	.10	382.0	.88	22.3	1.91	2.25	6.99	8.23
7	82.3	45.5	3744.7	.09	337.0	.89	20.2	1.74	2.08	6.36	7.61
8	88.3	41.4	3655.6	.09	329.0	1.00	20.7	1.52	1.93	5.55	7.06
9	93.2	37.7	3513.6	.09	316.2	.88	16.6	1.38	1.73	5.05	6.35
10	97.4	34.3	3340.8	.09	300.7	.79	13.5	1.18	1.53	4.31	5.62
11	100.9	31.2	3148.1	.09	283.3	.97	15.1	1.07	1.37	3.92	5.03
12	103.8	28.4	2947.9	.09	265.3	.97	13.8	0.95	1.20	3.48	4.39
13	106.2	25.8	2740.0	.08	219.2	.97	12.5	0.83	1.03	3.05	3.79
14	108.2	23.7	2564.3	.09	230.8	.97	11.5	0.73	0.89	2.69	3.28
15	109.9	21.6	2373.8	.10	237.4	.97	10.5	0.64	0.76	2.34	2.80
16	111.3	19.4	2159.2	.10	215.9	.94	9.1	0.58	0.65	2.12	2.38
17	112.5	17.5	1968.8	.11	216.6	.94	8.2	0.52	0.57	1.93	2.11
18	113.5	15.6	1770.6	.10	177.1	.94	7.3	0.47	0.51	1.73	1.89
19	114.3	14.0	1600.2	.13	208.0	.94	6.6	0.42	0.46	1.56	1.71
20	115.0	12.2	1403.0	.12	168.4	.94	5.7	0.37	0.40	1.37	1.49
21	115.6	10.7	1236.9	.15	185.5	1.00	5.4	0.33	0.36	1.23	1.33
22	116.1	9.1	1056.5	.14	147.9	1.00	4.6	0.28	0.30	1.03	1.13
23	116.5	7.8	908.7	.82	745.1	1.00	3.9	0.24	0.26	0.89	0.97
>23	118.5	1.4	165.9	1.00	165.9	1.00	0.7	0.04	0.49	0.16	0.18
Totals		1000.0	67714.9		9015.9		231.3	39.34	35.63	141.83	128.16

models for age classes 0 and 1 may have been caused by greater activity and consumption of food by young captive seals than by animals in the wild, as a result of adjustment to captivity.

New or Unanalyzed Data

The ADF&G has recently collected and examined 30 harbor seals from the eastern Bering Sea. They were collected from 4-12 October 1981 at Nunivak Island, Cape Pierce, Cinder River, Port Heiden, Port Moller, and Akun Island. All animals were weighed, measured, and necropsied. Skulls, reproductive organs, and stomachs were collected and will be examined to determine ages, reproductive condition, and foods. Results of stomach content analysis have been briefly summarized in this report. Examination of reproductive and age material should be completed within a year.

James Estes of the University of California, Santa Cruz, has an unanalyzed collection of 50-100 harbor seal scats collected in summer 1973 from Attu Island.

11.21 Spotted Seal

Population Status

Spotted seals occur only in the northern extremes of the North Pacific Ocean and adjacent arctic waters. They occur in the Sea of Okhotsk and in the Bering, Chukchi, and Beaufort seas (Shaughnessy and Fay 1977, Burns 1978). Although the degree of interchange between animals in the Okhotsk and adjacent Bering Sea has not been determined, they are generally considered to be separate populations.

In late winter and spring, the entire Bering-Chukchi spotted seal population is concentrated in or near the ice front (Figure 11.21-1) (Burns and Harbo 1977; Burns 1978). At least three major pupping and breeding concentrations usually occur: 1) the Bristol Bay-Pribilof Islands region, 2) Karaginskiy Bay, and 3) the Gulf of Anadyr (Shaughnessy and Fay 1977). Fidelity to breeding areas and interchange among animals in these regions are not known. As the sea ice disintegrates and recedes in spring, spotted seals move generally northward and toward the coast. They are common along the eastern Bering and Chukchi coasts during summer, and a few animals move eastward into the Beaufort Sea (Burns 1978).

The population of spotted seals in the Bering-Chukchi region has been estimated at 280-330,000, of which 80,000 are of the Karaginskiy Bay stock (Burns 1978). No recent changes or trends in abundance have been reported.

At birth spotted seal pups are about 84 cm long and weigh 9.5 to 11.8 kg (Burns 1970). Physically mature animals are 142 to 170 cm in standard length and usually weigh 82 to 109 kg, of which 33-38% is hide and blubber (Burns 1978). Age-specific weight data have not been published.

Burns (1978) reports a maximum longevity of 35 years, with sexual maturity attained at 3-4 years of age in females and 4-5 years in males. Pregnancy rates of adult females are 85-95% (Burns 1978). Sex ratio is thought to be 1:1. Age structure and mortality data are available only for the Okhotsk Sea population (Fedoseev 1976). Based on those data, mature animals (4 years old and older) comprise about 69% of the population, excluding pups. Mortality during the first year of life was estimated as 45%; average annual mortality for subsequent years was 13.7%.

Diet Composition

Foods of spotted seals in the Bering Sea in spring are presented in two papers by Golt'sev (1971) and Bukhtiyarov et al. (in press). Golt'sev examined stomachs of 319 seals taken in Karaginskiy Bay and the Gulf of Anadyr (Figure 11.21-2) in April-June 1966-68, of which only 45 contained food. Unfortunately, the results are presented in a

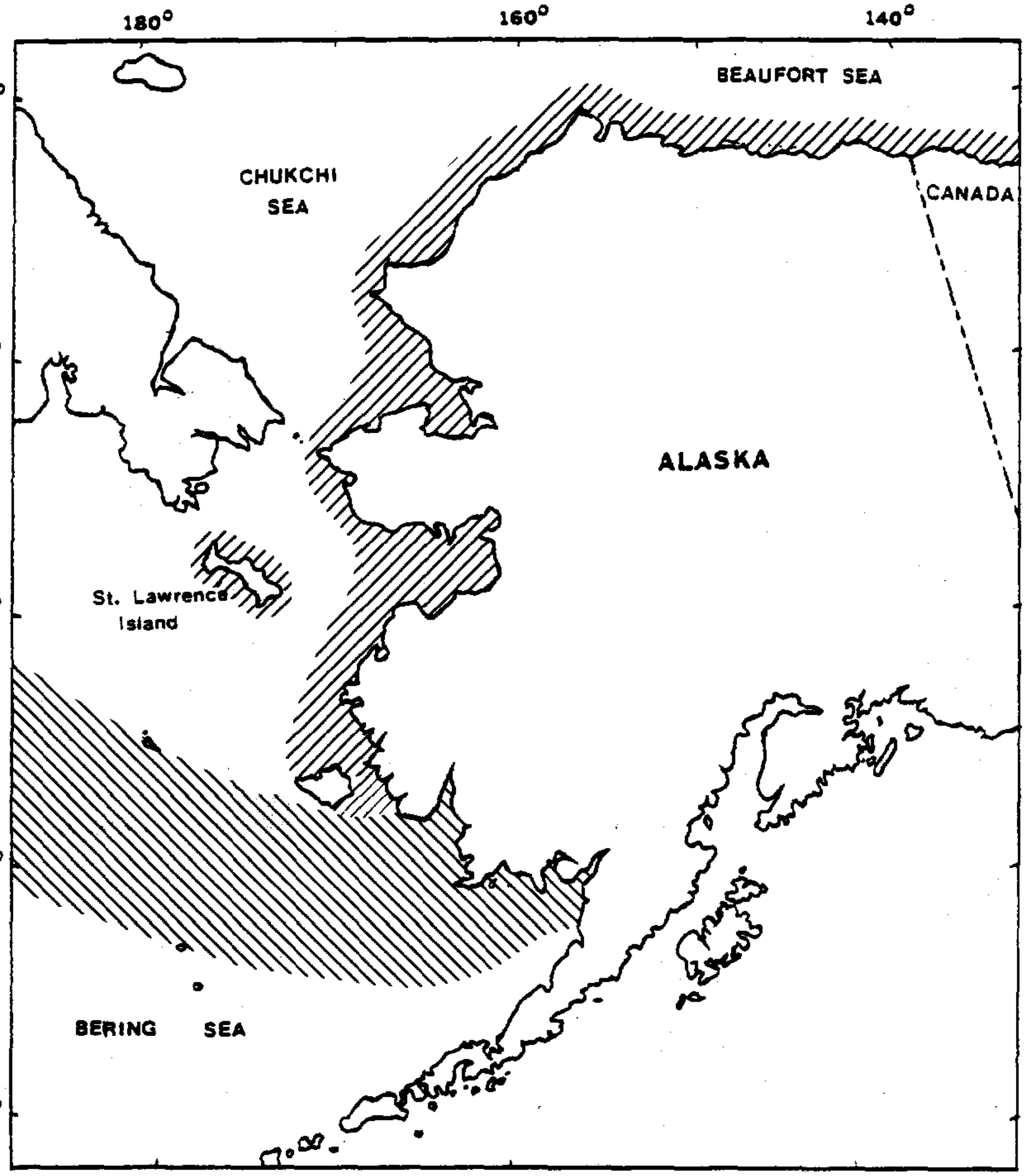

Figure 11.21-1. Approximate winter \\\ and summer /// distributions of spotted seals.

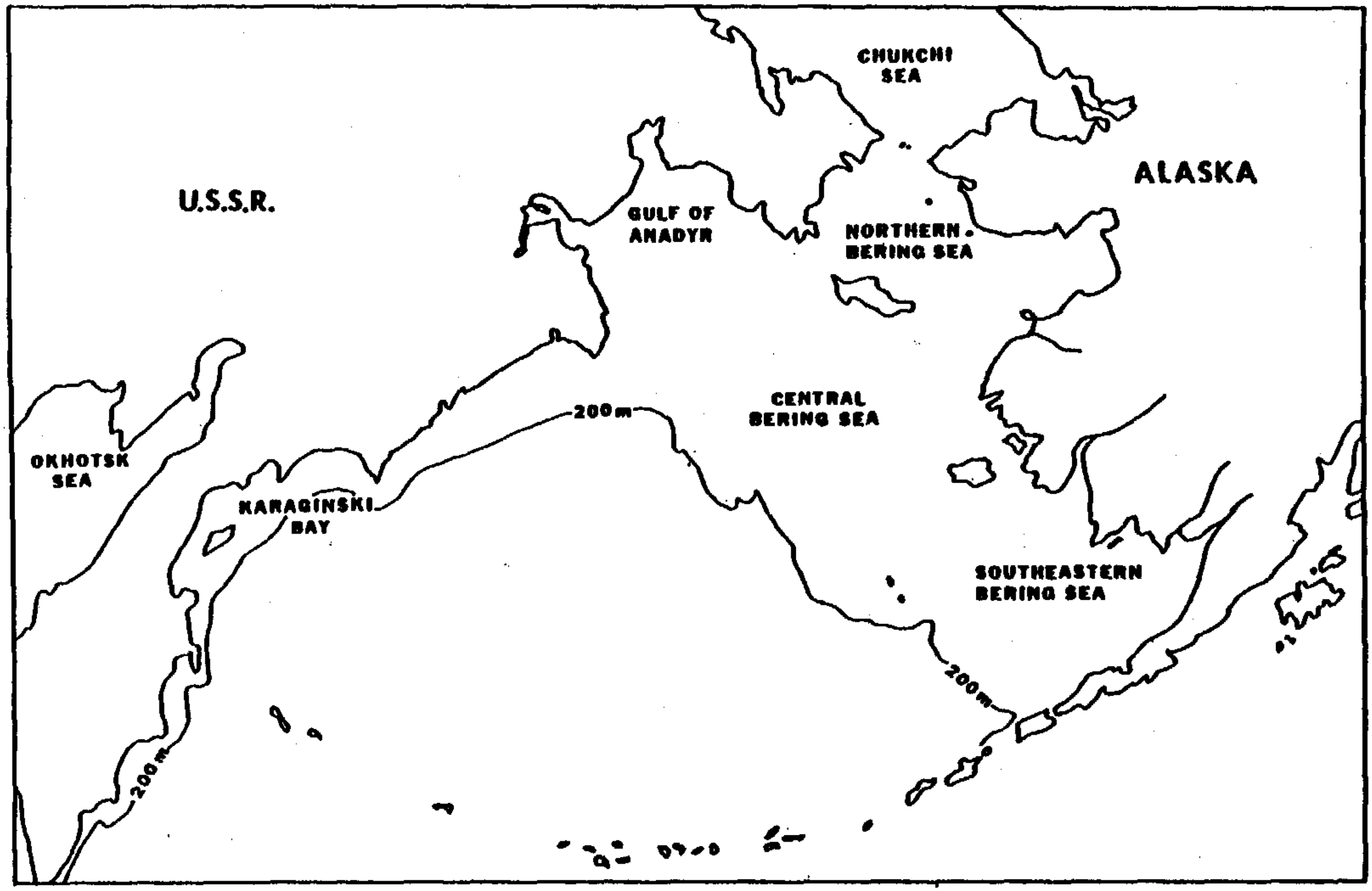

Figure 11.21-2. Map of the Bering Sea showing areas in which spotted seals were collected.

rather confusing manner, and the quantification of prey is done primarily by frequency of occurrence and maximum numbers and weights. He found that recently weaned pups fed primarily on gammarid amphipods, with stones and algae also occurring in the stomachs. Slightly older pups ate shrimps and fishes (primarily sand lance). Seals 1-4 years old ate fishes (principally arctic cod, saffron cod, and sand lance), octopus, and shrimps. Adult animals (5 or more years old) fed on fishes, cephalopods, shrimps, and crabs, and included more benthic forms in the diet. Based on frequency of occurrence in the entire sample, the following is a list (in descending order of importance) of principal prey: octopus, arctic cod, Pandalus goniurus, sand lance, sculpins, and walleye pollock.

Bukhtiyarov et al. (in press) present quantitative data on foods of spotted seals collected in Karaginskiy Bay and the Gulf of Anadyr in spring 1972 and 1973 and in the southeastern, central, and northern Bering Sea in 1976-78 (Figure 11.21-2). The following items were major foods in 68 seals from Karaginskiy Bay: sand lance - 32.4% of total stomach contents weight; herring - 13.2%; octopus - 10.3%; unidentifiable fish - 14.7%; and shrimps - less than 5%. In 42 seals from the Gulf of Anadyr major prey were: arctic cod - 29.5%; pollock - 13.6%; and sand lance - 9.1%. Octopus were also a major prey, occurring in 40% of stomachs with food. Pups ate primarily sand lance and shrimps; seals 1-4 years old ate shrimps, fishes (mostly sand lance and herring), and occasionally octopus; older animals ate shrimps, crabs, octopus, and fishes. Based on frequency of occurrence in adult animals in both areas, major prey (ranked in descending order) were: octopus, sand lance, unidentified fish, Pandalus sp., arctic cod, and tanner crab. Results were very similar to those presented by Gol'tsev (1971). In the American sector of the Bering Sea, results were presented for three regions. Since many of the stomachs were empty, counts of otoliths from stomachs and intestines were combined and resulted in data on fishes consumed by 31 seals out of a total of 51 examined (Table 11.21-1). Major prey were pollock and eelpout in the central Bering; capelin, pollock, and herring in the southeastern Bering; and arctic cod, capelin, and saffron cod in the northern Bering. Fishes comprised over 95% of the volume of stomach contents in all three areas. Other foods in the stomachs included octopus (2% of volume in central and 3% in northern) and shrimps (less than 1% in northern). A comparison of catches in trawls and components of seal foods indicated selection for capelin in the southeastern Bering Sea. A comparison of sizes of arctic cod eaten by seals and caught by trawls in the northern Bering indicated selection by the seals for larger fishes (Figure 11.21-3).

Additional data on foods of spotted seals are presented in Lowry et al. (1981a). In addition to the samples analyzed and presented in Bukhtiyarov et al. (in press), stomachs containing food from 37 seals taken in spring by coastal hunters were examined. Results (Table 11.21-2) were similar to those from research collections in the same general areas, with the exception that more shrimps were found in the stomachs. Lowry et al. (1981a) also present data on autumn foods of

Table 11.21-1. Summary of information on foods of spotted seals collected at sea in spring (from Bukhtiyarov et al., in press). * indicates values less than 1%.

LOCATION	Central Bering		Southeastern Bering		Northern Bering	
DATES	March-May 1976-77		March-May 1976-77		May-June 1978	
SAMPLE SIZE	5		14		12	
COMPOSITION OF SAMPLE	% no. of fishes	% frequency	% no. of fishes	% frequency	% no. of fishes	% frequency
Walleye pollock	88	80	5	43	2	8
Arctic cod	--	--	*	7	51	92
Saffron cod	--	--	*	7	15	42
Herring	--	--	5	14	4	25
Capelin	--	--	89	86	19	42
Sand lance	--	--	--	--	4	25
Eelpout	11	80	--	--	*	8
Prickleback	*	20	--	--	--	--
Sculpins	*	20	*	21	5	42
Flatfishes	--	--	*	7	*	25

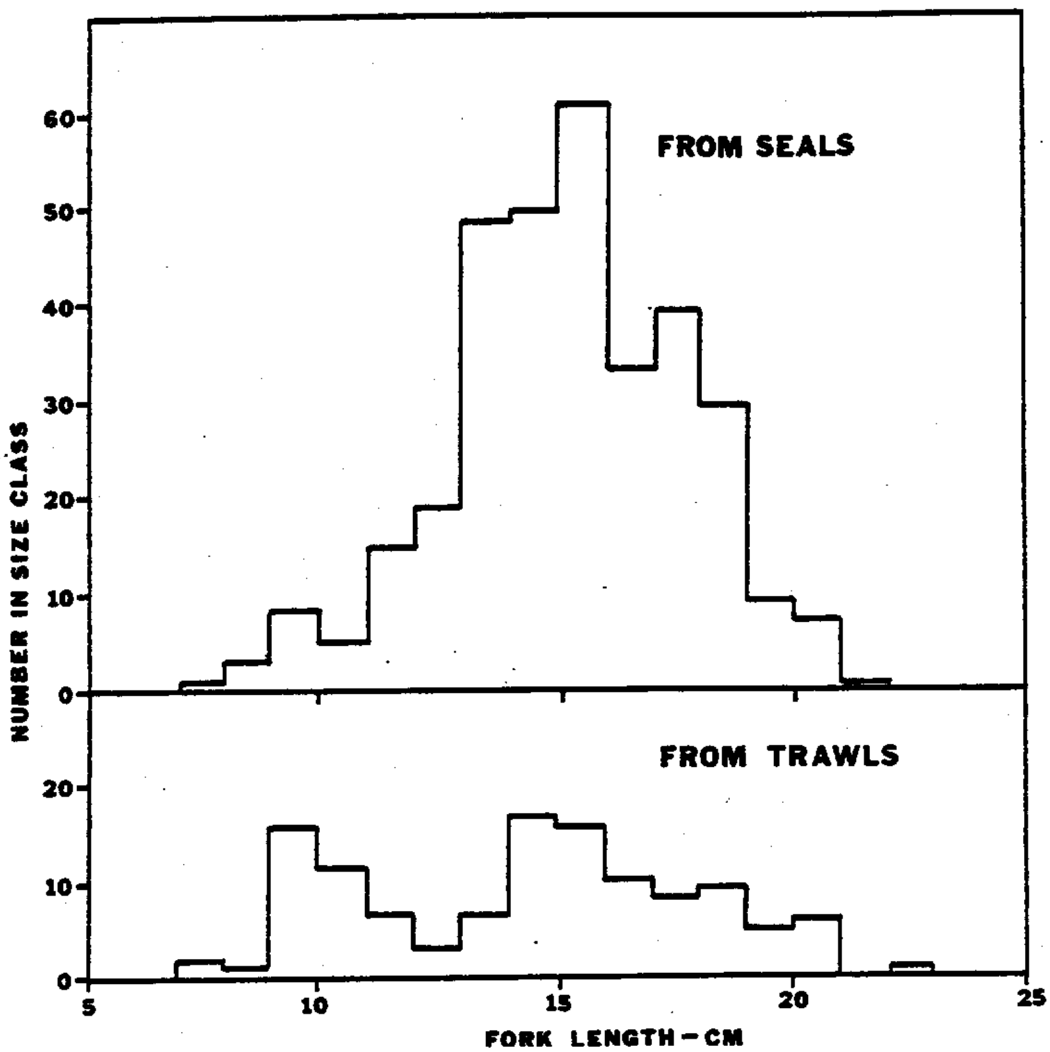

Figure 11.21-3. Length-frequency distribution of arctic cod, Boreogadus saida, obtained from trawl samples and from stomachs of spotted seals in the same areas of the northern Bering Sea. Fork lengths of fishes from seal stomachs were calculated from otolith lengths (from Bukhtiyarov et al., in press).

Table 11.21-2. Summary of information on foods of spotted seals collected at coastal villages in spring (from Lowry et al. 1981a).

LOCATION	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 OF CONTENTS (ml)	97.7	253.3		178.2		76.9	
COMPOSITION OF SAMPLE	% volume	% volume	% no. of fishes	% volume	% no. of fishes	% volume	% no. of fishes
Fish Total	87	96		75		70	
Arctic cod			34		57		--
Saffron cod			--		--		62
Sand lance			33		--		6
Smelt			--		--		12
Herring			--		--		10
Sculpins			32		39		--
Shrimp	13	3		23		29	
Euphausiids	--	--		1		--	
Hyperiid amphipods	--	--		1		--	

seals taken at three locations along the south side of the Seward Peninsula. Those seals ate almost entirely fishes, including primarily saffron cod, smelt, sand lance, and herring (Table 11.21-3).

Foods of spotted seals in the Okhotsk Sea have been reported by several investigators (Wilke 1954, Fedoseev and Bukhtiyarov 1972, Nikolaev and Skalkin 1975). Foods eaten were generally similar to those found in the Bering Sea, particularly Karaginskiy Bay and the central Bering; pollock were overall the major prey.

Food Requirements

The energetic requirements of spotted seals have been studied in detail by Ashwell-Erickson and Elsner (1981). They estimated the annual net energy requirement of a model population of 1,000 spotted seals to be 126-135 X 10^7 kcal. Assuming a diet of pollock, capelin, herring, and invertebrates, and summer and winter populations of 125,000 and 250,000, they calculated total annual consumption of 216,700 metric tons of food.

New or Unanalyzed Data

The only unanalyzed data on spotted seals we are aware of are with ADF&G. Included are the stomachs of approximately 10 spotted seals taken in inner Norton Sound in October 1981 and information on size, age, and reproductive status of several hundred spotted seals examined from 1960 through 1981. The ADF&G data base for seals collected since 1975 includes information from 479 animals, with physical measurements from 258, age data from 425, and male and female reproductive data from 47 and 25 animals, respectively. This does not include approximately 50 animals for which reproductive tracts have not been analyzed. Most of the specimens are from animals taken in coastal areas of the northern Bering Sea. It is expected that results of analysis of all specimens will be presented in a monograph to be prepared by the end of 1983.

Table 11.21-3. Summary of information on foods of spotted seals collected in autumn (from Lowry et al. 1981a).

LOCATION	Cape Woolley		Teller		Teller		Nome	
DATES	14 August-20 September 1971 and 1972		12 September-15 October 1970 and 1972		8-21 November 1972		21 November 1976	
SAMPLE SIZE	2		5		2		1	
MEAN VOLUME OF CONTENTS (ml)	50.1		1,480.0		965.0		867.0	
COMPOSITION OF SAMPLE	% volume	% no. of fishes	% volume	% no. of fishes	% volume	% no. of fishes	% volume	% no. of fishes
Fish Total	97		100		100		100	
Saffron cod		97		--		24		1
Sand lance		2		--		--		99
Smelt		--		20		76		--
Herring		--		70		--		--
Capelin		--		10		--		--
Gammarid amphipods	2		--		--		--	

11.22 Ribbon Seal

Population Status

The normal range of ribbon seals includes the seasonally ice-covered waters of the Okhotsk, Bering, and Chukchi seas (Burns 1981a). Because their range is restricted by the partial geographical barrier formed by the Kuril Islands and the Kamchatka Peninsula, Okhotsk and Bering Sea ribbon seals are treated as separate stocks. The normal southern boundary for Bering Sea seals is approximately 1,600 km northeast of the Okhotsk population (Shustov 1965e). However, the two populations are considered to be taxonomically the same (Burns and Fay 1970, Fedoseev 1973b) and probably interchange to some extent since geographic barriers are not complete and suitable habitat is continuous between the two regions.

In the Bering Sea, ribbon seals are associated with the ice fringe and pack during winter and spring (Burns 1970, Fay 1974, Burns 1981a). From February to late April or mid-May they are found throughout the ice front to 150 km north of the southern periphery of ice and are most numerous in the inner (northernmost) part of the front from the Pribilof Islands to the Soviet coast (Burns 1970; Fay 1974; Burns et al. 1981; Braham et al., unpubl. ms.). Densities are very low in outer Bristol Bay (Braham et al., unpubl. ms.). They are especially numerous west of the Pribilof Islands, west of St. Matthew Island, and southwest of St. Lawrence Island (Tikhomirov 1964b; Burns et al. 1981; Braham et al., unpubl. ms.). As the ice melts and recedes north in May and June, ribbon seals concentrate on ice remnants and migrate northward passively (Fay 1974) while they are hauled out on the ice to molt. Major areas of concentration then include the Gulf of Anadyr and southwest of St. Lawrence Island, south of St. Matthew Island, and southeast of King Island (Shustov 1965e, Fedoseev and Shmakova 1976).

Most ribbon seals apparently do not move north through Bering Strait with the receding ice, nor do they move toward the coast; very few are sighted by coastal hunters from villages in Bering Strait or the Chukchi Sea. Burns (1970, 1981a) has speculated that they become pelagic, spending the summer and autumn feeding near the shelf break. Summer records of ribbon seals include one sighting made 84 miles west of St. Paul Island and three sightings made 50-70 miles northeast of St. Paul Island (Burns 1981a).

Recent estimates indicate a population of 90-100,000 ribbon seals in the Bering Sea (Littlefield 1977, Burns 1981a).

In the early 1960's, the Bering Sea population of ribbon seals numbered 80-90,000. By 1969 numbers had been reduced to about 60,000 due to intensive commercial sealing by the Soviet Union (Fedoseev 1973b). In 1969 the Soviets imposed a quota on the annual harvest of ribbon seals, and subsequent survey information indicated that the population increased 20% between 1972 and 1974 (Burns 1981a, citing Gol'tsev, pers. commun.). In the mid-1970's, Burns estimated a population of 90-100,000 ribbon seals in the Bering Sea (Littlefield 1977, Burns 1981a). The population is probably near or only slightly below pre-exploitation levels. The Okhotsk Sea population of ribbon seals is estimated at about 133,000 (Fedoseev 1973b).

Vital parameters of ribbon seals have been determined from sampling of Soviet commercial and Alaskan subsistence harvests and from taking for research purposes. By far the majority of samples are from commercial harvests since the take of ribbon seals by Alaskan Eskimos is very limited and research opportunities have been few. There have been some problems with interpretation of data; in particular, determination of the age structure of the population (and dependent parameters such as population productivity) has been complicated by disagreement over whether samples are representative of the population or are biased by hunting practices. Furthermore, since most samples were collected during a period of heavy exploitation, it is probable that density-dependent functions were changing and were not representative of an unharvested or lightly harvested population.

The rate of growth in ribbon seals is rapid. At birth, which usually occurs in April, pups weigh approximately 10.5 kg and are about 86 cm in length. In late May and early June, weaned pups average 22 kg and 92 cm (Burns 1981a). Based on samples from the Alaskan harvest, average standard length and weight at age 1 are 106 cm and 33 kg; age 2, 131 cm and 50 kg; age 3, 139 cm and 59 kg; age 4, 139 cm and 61 kg; age 5, 148 cm and 65 kg; and age 6, 148 cm and 67 kg. Physical maturity is reached at about 7 years, after which the average length is about 151 cm and average weight is 71 kg, with no apparent difference between males and females. Length-at-age data from Soviet commercial harvests in the Bering and Okhotsk seas are similar (Table 11.22-1). There is great variation in length and weight within age classes.

There is also marked seasonal variation in the weight of ribbon seals. They weigh most in autumn and winter and least in late spring and early summer following lactation and reduced feeding associated with the molt. Burns (1981a) found the mean weight of adults in late winter to be 96 kg and 73 kg in June. Shustov (1965b) reported a decrease in blubber thickness from late March to July of 5.3 cm to 2.6 cm.

Ribbon seal males become sexually mature at the age of 3-5 years (Shustov 1965c, Burns 1981). About 22% of 3-yr-old males, 75% of 4-year-olds, and 90% of 5-year-olds have attained sexual maturity (Burns 1981a). Females mature slightly earlier at 2-4 years of age (Shustov 1965c, Fedoseev 1976, Burns 1981a). Shustov (1965c) found that over 50% of 2-year-old females had ovulated. Burns (1969) reported that 38% of the 2-year-olds, 50% of the 3-year-olds, and 100% of the 4-year-olds he examined had successfully conceived. Reproductive senility apparently

Table 11.22-1. Mean length* at age of ribbon seals in the Bering and Okhotsk seas.

	Tikhomirov 1971		Fedoseev 1973b		Burns 1981a and ADF&G, unpubl.	
	n = 440		n = 758		n = 160	
Age	range	mean	range	mean	range	mean
pup	83–118		96–125	110	74–128	92
1	115–151	130	115–139	128	92–136	106
2	129–166	145	130–153	140	109–143	131
3	131–178	154	131–163	149	128–147	139
4	145–182	161	144–167	155	132–145	139
5	140–187	164	147–181	159	130–166	148
6	152–190	165	140–176	161	140–158	148
7	150–196	169	146–173	159	134–151	143
8	148–189	169	149–177	161	146–152	148
9	153–186	170	147–180**	161**	133–171	150
10	152–185	163	147–180	161	162	162
11–23	153–198	169	147–180	161	130–180	155

* Measurements by Burns are standard lengths (straight-line distance between nose and tip of tail with the seal lying on its back). Measurements by Tikhomirov and Fedoseev are probably zoological lengths taken over the dorsal curvature of the body. If so, this would account for the relatively close agreement between the Soviet values and the considerably shorter lengths reported by Burns.

** Range and mean are same for seals $\geq$ 9 years of age.

does not occur; the oldest animal examined by Shustov (1965c, 1969) was a 26-year-old female carrying a fetus. Similarly, the oldest ribbon seal found by Burns (1981a) was a 23-year-old pregnant female.

Most breeding occurs in late April to mid-May, shortly after pups are weaned (Shustov 1965c, Tikhomirov 1966a, Burns 1981a). Implantation is delayed approximately 2-1/2 to 3-1/2 months, and most pups are born from late March to mid-May, with a peak in early to mid-April (Shustov 1965c; Tikhomirov 1961, 1964b; Burns 1981a). A single pup is born to a female. The sex ratio at birth, as in adulthood, is 1:1 (Shustov 1965c, 1969; Burns 1981a).

Annual pregnancy rate in females older than 5 years was found to be 76-83% (Shustov 1965c, 1969). Based on 1970 harvest data compiled by Fedoseev (1973b), seals 5 years or older comprise 57% of all seals older than pups. Since the sex ratio is 1:1, mature females would make up about 28-29% of the population, for a gross productivity of 22-24%. This figure agrees quite closely with the 25 or 26% proposed by Shustov (1969).

The magnitude of predation on ribbon seals is unknown. Major predators include polar sharks, killer whales, and humans (Shustov 1969). Less significant predators are polar bears, large gulls, and eagles.

The harvest of ribbon seals by humans has fluctuated markedly over the last 20 years. Relatively few ribbon seals were or are taken by coastal subsistence hunters of Siberia and Alaska. However, in 1961 intensive Soviet commercial hunting was initiated in the Bering Sea. From 1961-68, the average annual Soviet harvest of ribbon seals, which comprised about 90% of the total commercial harvest of ice seals, was around 10,000, with a peak in 1966 of 14,500 (Fedoseev 1973b). In response to a noticeable reduction in the population and a change in the age structure of the harvest (mean age of 10 years in 1961, 7 in 1962, and 5 in 1963), the harvest was reduced to about 6,000 in 1968 and further reduced in 1969 to a maximum of 3,000. The annual harvest since then has remained at about that level, with subsequent recovery of the population (Shustov 1965a, Fedoseev 1973b, Burns 1981a). The harvest of ribbon seals in Alaska since 1968 has been less than 100 animals per year. The maximum recorded harvest in Alaska was 1,200-1,500 in 1967-68, a year of minimal ice cover when the seals were abundant near St. Lawrence Island (Burns 1981a; ADF&G, unpubl.).

Based on life tables derived from harvest data (Table 11.22-2), mortality in ribbon seals during the first year is about 45%, decreasing to 30% in yearlings, and 8-12% annually in seals 3-15 years old. Mortality increases rapidly after age 20.

Table 11.22-2. Age structure and mortality rates of ribbon seals based on Soviet harvest data from 1970 (Fedoseev 1973b).

Age	Number of seals	Percent of total seals	Smoothed number of seals	Percent age-specific mortality*
pup			61	45
1	30	14.7	33	30
2	26	12.7	22	17
3	18	8.8	18	12
4	13	6.4	16	12
5	12	5.9	14	10
6	8	3.9	13	10
7	12	5.9	11	9
8	12	5.9	10	8
9	11	5.4	10	8
10	9	4.4	9	10
11	8	3.9	8	10
12	6	2.9	7	10
13	6	2.9	7	11
14	5	2.4	6	11
15	8	3.9	5	12
16	2	1.0	5	13
17	6	2.9	4	13
18	2	1.0	4	14
19	4	2.0	3	14
≥20	6	2.9	9	>20
Total	204		275	

* Mortality rates are based on smoothed age-frequency data.

Diet Composition

Ribbon seal pups nurse for a period of 3-4 weeks during which time their weight more than doubles (Tikhomirov 1966a, Burns 1981a). Weaning is abrupt, when the pup is abandoned by its mother. Pups spend the next several weeks learning to feed and living off blubber reserves accumulated during the nursing period. During that time they lose considerable weight, dropping from approximately 27-30 kg at weaning to an average of 22 kg in early June (Burns 1981a).

There are few published accounts of the foods of ribbon seals. Arsen'ev (1941) and Wilke (1954) reported on the stomach contents of 56 seals taken in the Okhotsk Sea in spring. By far the most common food items were pollock, squids, and octopus. Shrimps (mostly *Pandalus goniurus*) and Pacific cod were fairly common in stomachs examined by Arsen'ev, who suggested that crustaceans are more commonly eaten by young seals that are just learning to feed than by adults. He found that cephalopods were eaten more frequently and in greater quantity in April and May than in June. In the Shantar region of the Okhotsk Sea, Fedoseev and Bukhtiyarov (1972) also found the main prey in spring to be pollock. They stated that cephalopods were a major food in some areas.

Shustov (1965b) reported the results of examination of 1,207 stomachs from ribbon seals taken in the central Bering Sea in March to July. Of this sample only 32 contained food remains, the majority of which was shrimps, mysids, crabs, cephalopods, and several species of fishes, including arctic cod, pricklebacks (*Lumpenus medius*), sand lance, herring, and saffron cod. No sex-related differences in diet were noted.

Burns (1981a) reported stomach contents of six seals taken at St. Lawrence Island. Of four seals taken in April and May, two contained shrimps (*Pandalus* sp. and *Sclerocrangon* sp.), one contained a single large fish (*Pholis* sp.), and one, a pup, had only milk in its stomach. In two seals taken in February, Burns found pollock in one and arctic cod in the other.

Frost and Lowry (1980) examined the digestive tracts of 61 ribbon seals collected in the ice front of the Bering Sea in March through June 1976-79. They found only small quantities ($\leq$ 40 ml) of food remains in 28 individuals, and based on the condition of the contents judged that none had been actively feeding at the time of collection. Seven of those had food remains in both the stomach and intestine, the other 21 only in the intestine. Small amounts of invertebrates (octopus, crustaceans, crabs) were present in 11 seals. Most of the identifiable food remains were from fishes (Table 11.22-3). Based on number and back-calculated weight of fishes, pollock were the major prey in southcentral Bering Sea, followed by eelpout and capelin. In central Bering Sea, pollock and eelpout were the major prey, followed

Table 11.22-3. Fish remains in stomachs and intestines of ribbon seals collected in the Bering Sea during March-June 1976-79 (Frost and Lowry 1980).

	Southcentral Bering March-April 1976, 1977 N = 9			Central Bering April-May 1978, 1979 N = 12			Northern Bering May-June 1978 N = 7		
Species	% total no. fishes	% total wt. fishes	No. occurrences	% total no. fishes	% total wt. fishes	No. occurrences	% total no. fishes	% total wt. fishes	No. occurrences
Pollock	89.4	49.7	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	--	--	--	--	--	--

by Greenland halibut, pricklebacks, and capelin. In northern Bering Sea, the major prey were arctic cod.

Frost and Lowry (1980) found that ribbon seals were nonselective with regard to size of pollock consumed but appeared to select for large arctic cod. The seals were also apparently selecting for gadids (pollock, saffron cod, and arctic cod), eelpout, and Greenland halibut. The data suggest that feeding conditions may be more favorable for ribbon seals in southcentral Bering Sea than in more northern areas. Their passive migration north into the less optimal northern areas coincides with a period of reduced feeding when the seals are hauled out on the ice to bask and molt.

Three ribbon seals were collected west of St. Matthew Island on the ZRS Zvyagino cruise in spring 1981. The stomachs of two of those contained identifiable food remains; both had eaten fishes (Antonelis, pers. commun.).

It is important to note that, with the exceptions of the two winter stomachs reported by Burns (1981a), there are no data on the foods of ribbon seals at any time of year except spring, which is a time of reduced feeding.

Food Requirements

We know of no data on the food requirements of ribbon seals. Frost and Lowry (1980) presumed a maintenance requirement of 6% of body weight per day, based on other species of pinnipeds, and from that estimated that 100,000 ribbon seals feeding in the southern and central Bering Sea for 8 months of the year would consume 110,000 tons of food.

New or Unanalyzed Data

The Alaska Department of Fish and Game has partially analyzed specimen data on 79 ribbon seals collected from 1976 through 1979. Those data include physical measurements, analyses of reproductive tracts, and ages. Food habits information has been analyzed and published (Frost and Lowry 1980).

We know of no other unanalyzed data on ribbon seals.

11.23 Ringed Seal

Population Status

Ringed seals are the most abundant and widely distributed marine mammals in ice-covered regions of the northern hemisphere. Their distribution is circumpolar and includes the contiguous northern seas of the arctic basin as well as subarctic waters in association with seasonal sea ice. They are found along the arctic coasts of North America and Eurasia, including Greenland, Spitsbergen, and Novaya Zemlya, and range seasonally into the North Atlantic, Hudson and James bays, and the Bering Sea (Frost and Lowry 1981b). There are several subspecies of ringed seals. The subspecies *P. h. hispida* inhabits the polar basin and the seas immediately adjacent to it, including the Beaufort and Chukchi seas. Ringed seals of the Sea of Okhotsk comprise a separate subspecies, *P. h. ochotensis* (Frost and Lowry 1981b). The proposed subspecific separation between ringed seals of the Bering and Chukchi seas, for which intergradation is indicated as occurring in the vicinity of Bering Strait (e.g., Scheffer 1958), is an artificial one. Ringed seals of the Beaufort and Chukchi seas are most certainly of the same population as those in the Bering Sea, since regular seasonal movements of seals between these seas occur, and no barriers to these movements exist (Frost and Lowry 1981b; Burns et al., in prep.).

The distribution of ringed seals in Alaskan waters is strongly correlated to that of sea ice (Burns 1970, Fay 1974). In the Bering, Chukchi, and Beaufort seas, these seals are most abundant in association with seasonal ice, although they range north in multi-year ice as least as far as 85°N latitude (Burns and Eley 1978). The seasonal expansion and contraction of their range requires that a significant proportion of the population is "migratory" while, during the same annual cycle, other animals may be relatively sedentary or undertake only short seasonal movements. Such movement patterns are corroborated by the results of marking studies undertaken in the eastern Beaufort Sea (Smith and Stirling 1978; T. G. Smith, pers. commun.).

During summer and early autumn, ringed seals are abundant in nearshore ice remnants in the Beaufort Sea (Burns et al. 1981; Frost and Lowry, pers. observation), at the pack ice fringe, and probably well inside (north of) the ice fringe of the Chukchi and Beaufort seas (Burns et al., in prep.). They also occur in ice-free waters of the Beaufort Sea and in open water close to the ice edge in the Chukchi Sea. With the onset of freeze-up, many ringed seals migrate southward and are abundant in grease and slush ice in areas south of the advancing pack. They become increasingly common in the ice-free coastal zone near Bering Strait and in Norton Sound throughout autumn and early winter. During late January and February, they are abundant in the southern Chukchi Sea, Bering Strait, and northern Bering Sea, exhibiting strong sustained directional movement southward through Bering Strait, past St. Lawrence Island, and eastward along the south shore of the Seward Peninsula. They occur as far south as Nunivak Island and Bristol

Bay, depending on ice conditions in a particular year, but are generally not abundant south of Norton Sound except in nearshore areas (Burns et al., in prep.). Braham et al. (unpubl. ms.) saw very low densities of ringed seals in outer Bristol Bay ($0.02/nm^2$) and north of the Pribilof Islands in April 1976. By about mid-March, the directional movements are no longer apparent. During March and April, adult seals are occupied with establishing and maintaining territories, bearing and nurturing pups, and breeding. Partitioning of habitat based on age, sex, reproductive status, or a combination thereof apparently occurs during late winter and spring, with adults predominating in and near the fast ice, subadults in the flaw zone, and both occurring in drifting pack ice (McLaren 1958, Fedoseev 1965a, Burns 1981). Few ringed seals are found in the ice front and fringe zones at the southern extent of seasonal sea ice in the Bering Sea (Burns et al. 1981).

Northward movement, mainly by subadults, begins in April and is well underway by May. Adults migrate as the fast ice breaks up, pups remain in the ice remnants or move into the adjacent pack, and immatures are most numerous in the pack. Many ringed seals pass through Bering Strait in May and June. A small proportion of the population, mainly juveniles, may remain in ice-free areas of the Bering and southern Chukchi seas during summer, but most move farther north with the receding ice.

Population estimates of ringed seals are imprecise; they are complicated by seasonal movements, seasonal and diurnal haulout patterns, and the effects of ice conditions on the distribution of seals (McLaren 1958, Burns and Harbo 1972, Finley 1979, Burns et al. 1981). Results of aerial surveys flown in the Beaufort and Chukchi seas in June (Burns and Harbo 1972, Stirling et al. 1977, Burns and Eley 1978) suggest average densities of hauled-out seals in the fast ice ranging from 0.4 $seals/nm^2$ in the Beaufort Sea to 6.2 $seals/nm^2$ in the Chukchi Sea between Wainwright and Barrow. The average densities of hauled-out ringed seals in the pack ice in 1976 were 0.2 and $0.1/nm^2$ in the Chukchi and Beaufort seas. When applied to estimates of available habitat of various types, these densities produce estimates of at least 250,000 ringed seals in the shorefast ice and a total population in Alaska of 1-1.5 million (Littlefield 1977; Burns 1978; NOAA 1979). Based on the number of seals thought to be killed by polar bears, these estimates are probably conservative. It is unknown what proportion of the total population lives in the Bering Sea. Popov (1976) estimated Bering Sea ringed seals to number 70-80,000.

The biology of ringed seals has been studied in conjunction with US and Canadian subsistence and Soviet commercial/research harvests for over 25 years. Consequently, the vital parameters of ringed seals are relatively well known.

Ringed seals are the smallest of the northern phocid seals. Pups at birth weigh about 4.5 kg and average 65 cm in length (McLaren 1958, Fedoseev 1965b, Burns 1970). By June, pups in Alaska grow to approximately

13 kg and 72-74 cm (ADF&G, unpubl.). Mean standard length for 1-year-old seals is about 65-75% of mature adult size (Fedoseev 1965b; Burns et al., in prep.). Growth continues throughout the first 8-10 years of life, although approximately 90 to 98% of the final body length is attained by sexual maturity at 6-8 years (Fedoseev and Nazarenko 1970; Burns et al., in prep.). The size attained by adult ringed seals varies geographically, and in all age classes there is great individual variation in lengths and weights (Frost and Lowry 1981b). On the average, adult males tend to be slightly larger than females; however, there is considerable overlap. In Alaska, average standard length and weight of animals 8 years and older were 112.9 cm and 48.1 kg in females (n = 216) and 116.3 cm and 51.6 kg in males (n = 212). Burns et al. (in prep.) found maximum values of 137.2 cm and 111.4 kg for females and 141.2 cm and 87.2 kg for males. Fedoseev and Nazarenko (1970) report the maximum length for males in the Bering Sea as 153 cm. The average weight of a seal in the Bering-Chukchi population (n = 929) was about 34 kg (Frost and Lowry 1981b).

Body weight and blubber thickness fluctuate markedly throughout the year. Physical condition, as measured by weight and blubber thickness, is best during winter (average blubber thickness 5.0 cm) and poorest in July-August (average blubber thickness 2.6 cm) after a prolonged period of reduced feeding associated with breeding and molting (Johnson et al. 1966, Frost and Lowry 1981b).

Sexual maturity occurs at about 5 to 7 years of age in both males and females. In males, sexual maturity is marked by a rapid increase in testes and baculum size and by the onset of spermatogenetic activity (McLaren 1958, Frost and Lowry 1981b). Males are territorial, but it is unknown whether they breed one female or many.

Female ringed seals may ovulate for the first time at 3 years of age. However, successful pregnancy does not occur until the 4th to 7th year of life. The majority of females become sexually mature in their 7th year (McLaren 1958; Mansfield 1967; Frost and Lowry 1981b; ADF&G, unpubl.). Reproductive rates appear constant from age 10 to maximum life expectancy. The maximum life span is about 40 years, although normal life expectancy is between 15 and 20 years (McLaren 1958, Frost and Lowry 1981b).

Most breeding occurs in late April and early May within 1 month after parturition (McLaren 1958; Johnson et al. 1966; Burns et al., in prep.). Implantation of the fetus, which is delayed for about 3-1/2 months after fertilization, occurs in late August (Burns, unpubl.). Most pups are born from March to early April, for a total gestation period (including delayed implantation) of 10-1/2 months. Although twinning has been reported, a single pup is by far the most common. At birth, as in adulthood, the sex ratio is 1:1.

Since breeding occurs shortly after pupping, the normal interval between production of pups is 1 year. However, for various reasons some mature females do not produce young each year. The observed pregnancy rate for Alaskan seals in 1975-77 was 72% for females 7 years or older, or 84% for females 10 years or older, for a birth interval of one pup every 1.2-1.4 years (ADF&G, unpubl.). Based on harvest data, seals 7 years or older comprise 44% of all seals older than pups, and therefore mature females make up 22% of the population, resulting in a gross productivity of 16-18%. Since some females younger than 7 produce young, gross productivity is actually somewhat higher.

Ringed seals have a variety of predators, but only polar bears, arctic foxes, and humans are significant (Burns 1970; Smith 1976; Frost and Lowry 1981b; Eley, unpubl. ms.; Burns et al., in prep.). Polar bears are the major cause of mortality in seals older than pups. It is estimated that each bear may kill and eat one ringed seal or the equivalent every 6-7 days (Best 1977; Eley, unpubl. ms.). At that rate, the Alaska population of 5,700-9,500 bears could kill up to 530,000 seals annually.

Human hunting of ringed seals is a relatively small source of mortality and has decreased steadily in the past 20 years. Between 1962 and 1972, the estimated combined Soviet and American harvest of ringed seals was 11-22,000 annually (Table 11.23-1). In 1973-77, the estimated combined annual harvest was 6-10,000 (ADF&G, unpubl.). Data are not available for Alaskan harvests prior to 1960. Soviet harvests in the Bering and Chukchi seas were considerably greater then, averaging 26,500 from 1940 through 1949 and 14,700 from 1950 through 1959. Fedoseev (1965b) found that harvests of that magnitude did not have an apparent detrimental effect on the stock size and age structure of the population.

Based on life tables derived from harvest data (Table 11.23-2), pup mortality in ringed seals may be as low as 30% (Popov 1976; Burns et al., in prep.). Mortality for age classes 5-15 is about 10% per year, increasing gradually after that (Burns et al., in prep.).

Diet Composition

Ringed seal pups nurse for about 5-7 weeks (Frost and Lowry 1981b). At the end of that period, weaning is abrupt; the pups depend on blubber reserves for the next few months while they learn to feed.

Prior to 1975, only three accounts of the food habits of ringed seals in the Bering and Chukchi seas had been published.

Kenyon (1962b) reported on the stomach contents of 14 ringed seals taken in Bering Strait near Little Diomede Island, 11 May - 14 June 1958. The volume of contents ranged from 10 to 300 ml and averaged 86 ml. Shrimp of the genus *Pandalus* accounted for 96% of the individual food items. Mysids, amphipods, and fishes were present in very low numbers.

Table 11.23-1. Retrieved harvest of ringed seals in the US and USSR from 1962 through 1977 (ADF&G, unpubl.).

Year	US	USSR	Total
1962	11,623	--	--
1963	13,418	--	--
1965	14,710	--	--
1966	8,569	5,614	14,183
1967	7,788 - 9,100	12,662	20,450 - 21,762
1968	4,366 - 7,350	6,673	11,139 - 14,123
1969	12,404	3,147	15,551
1970	12,313	3,165	15,478
1971	12,278	3,471	15,749
1972	9,468	4,095	13,563
1973	4,550 - 6,500	3,644	8,194 - 10,144
1974	3,900 - 5,200	2,828	6,728 - 8,028
1975	3,250 - 3,900	2,799	6,049 - 6,699
1976	4,550 - 5,525	2,669	7,219 - 8,194
1977	6,713	1,539	8,252

Table 11.23-2. Age, sex, and mean weight at age of 3,025 ringed seals harvested in the Bering, Chukchi, and Beaufort seas, 1975-79 (ADF&G, unpubl.).

Age	Number of seals: Unknown	Males	Females	Total	Percent of total seals	Mean weight (kg)	Age-specific mortality* (percent)
0	47	296	249	592	19.6	14	32
1	12	185	154	351	11.6	25	18
2	5	104	85	194	6.4	30	14
3	6	87	82	175	5.8	34	12
4	10	110	87	207	6.8	35	10
5	8	107	107	222	7.3	35	10
6	9	122	89	220	7.3	41	11
7	6	92	75	173	5.7	46	9
8	3	95	63	161	5.3	48	10
9	3	76	66	145	4.8	48	9
10	4	55	48	107	3.5	49	12
11	3	70	47	120	4.0	52	11
12	2	32	34	67	2.2	52	9
13	4	35	31	70	2.3	55	10
14	2	24	24	49	1.6	51	11
15	2	31	16	49	1.6	46	12
16	1	15	9	24	0.8	44	14
17	0	9	13	23	0.8	51	16
18	1	9	9	19	0.6	61	13
19	0	10	7	17	0.6	47	21
20	0	3	5	8	0.3	46	18
>20	1	18	11	32	1.0	45	>20

* Age distribution data were smoothed prior to calculation of mortality rates.

Johnson et al. (1966) examined 1,923 stomachs from seals taken at Point Hope and Kivalina between November 1960 and June 1961. From November through February, fishes (mostly sculpins, arctic cod, and saffron cod) made up 90% or more of the contents. From March to June, invertebrates, mostly shrimps and amphipods, comprised more than half and occasionally more than 80% of the total stomach contents.

Fedoseev (1965b) discussed the foods of ringed seals from the coastal waters of the Chukchi Peninsula. Of 151 seals collected 7 May-22 June 1965 in Senyavin Sound on the south side of the Chukchi Peninsula, the stomachs of only 51 contained food. Sixteen seals had eaten only fishes, 13 had eaten crustaceans, and the remainder had eaten a mixture of fishes and crustaceans. Most of the fish were arctic cod, which were present in 75% of the stomachs with food. The crustaceans included shrimps of the genera Pandalus, Eualus, and Spirontocaris; pelagic amphipods Themisto (Parathemisto) libellula; and euphausiids Thysanoessa inermis. Fedoseev found food in 21 of 60 stomachs from seals collected in June along the Chukchi coast north of Bering Strait. Crustaceans, particularly gammarid amphipods and hippolytid shrimps, were present in all stomachs containing food. Saffron cod, rather than arctic cod, was the most common fish and was found in nine stomachs. Two seals had eaten flounder.

Lowry et al. (1981a) report on the examination of 199 ringed seal stomachs containing food from the Bering Sea. Fishes (mostly saffron and arctic cods and sculpins) and crustaceans made up most of the food in spring and early summer (Table 11.23-3). Shrimps (mostly Eualus gaimardi and Pandalus goniurus) were eaten in variable amounts at all locations. The dietary importance of other small crustaceans (amphipods, mysids, and euphausiids) varied considerably among locations. Data were available on the spring diet of ringed seals from Diomede for 7 years since 1958 (Table 11.23-4). Although arctic cod, shrimps, and gammarid amphipods were eaten in almost every year, the relative importance of the three varied from year to year. The highest volumes of stomach contents were generally found in years when arctic cod were the primary foods.

Lowry et al. (1980b, 1981a) also noted marked seasonality in the diet of ringed seals (Table 11.23-5). Near Nome, saffron cod were the main food in November and May-June, arctic cod were the primary food in January-March, and shrimps were particularly important in the diet in March and April. Near Savoonga and Gambell, mysids and amphipods made up a greater proportion of the diet in February and March than in May-June. More fishes, particularly arctic and saffron cods, were eaten in May-June, and quantities of food consumed were larger. Similar seasonal differences were noted by Lowry et al. (1980b) in the Chukchi and Beaufort seas.

No sex-related differences were obvious in the samples of ringed seals examined by Lowry et al. (1981a). However, age-related differences were marked (Table 11.23-6). The proportion of fish in

Table 11.23-3. Summary of information on foods of ringed seals from the Bering Sea in spring (Lowry et al. 1981a).

LOCATION	Mekoryuk		Hooper Bay		Diomede		Savoonga		Gambell		Nome		Wales		St. Lawrence Island	
DATES	22 April- 12 June 1975		March-May 1978-79		May-June 1975-78		May-June 1975-79		May-June 1979		May-June 1975-79		May-July 1977-78		June 1978	
SAMPLE SIZE	6		11		23		13		35		19		30		5	
MEAN VOLUME	67.0		18.0		63.5		110.4		85.5		312.4		122.5		125.9	
COMPOSITION OF SAMPLE	% volume	% number	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.
Fishes	58		10		18		62		35		96		67		20	
Arctic cod		--		--		81		95		40		--		--		72
Saffron cod		65		87		11		--		33		96		100		17
Sculpins		32		--		5		3		17		--		--		6
Sticklebacks		--		6		--		--		--		3		--		--
Sand lance		--		--		--		--		2		--		--		--
Herring		--		--		--		--		--		--		--		6
Shrimps	4		2		38		20		41		3		27		78	
Mysids	18		87		--		13		13		--		5		--	
Gammarid Amphipods	1		--		34		1		4		--		--		2	
Hyperiid Amphipods	13		--		--		--		6		--		--		--	
Euphausiids	--		--		--		2		--		--		--		--	

Table 11.23-4. Information on the foods of ringed seals from Diomede for 7 years between 1958 and 1978 (Lowry et al. 1981a).

DATES	14 May-14 June 1958*		20 May-3 June 1970		23 May-11 June 1971		15 May-1 June 1974		28 May-1 June 1975		27 May-3 June 1977		21-28 May 1978	
SAMPLE SIZE	14		12		14		15		12		7		3	
MEAN VOLUME	86.0		118.3		255.7		138.1		54.9		50.8		136.1	
COMPOSITION OF SAMPLE	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.
Fishes		1	99		99		88		14		40		--	
Arctic cod				81		100		69		43		86		--
Saffron cod				--				23		--		12		--
Sculpins				--				8		54		--		--
Shrimps		96	--		1		2		18		44		83	
Gammarid Amphipods		2	--		--		10		58		15		17	

* Data from Kenyon 1962.

Table 11.23-5. Seasonal variation in foods of ringed seals at three locations in the Bering Sea. Numbers in parentheses indicate percent of total volume made up by a taxon, except for fish taxa, where numbers indicate percent of the total number of fishes identified (from Lowry et al. 1980b).

Time period	Location		
	Nome	Savoonga	Gambell
November	Fishes (96) saffron cod (78) boreal smelt (13) arctic cod (4) Shrimps (3) n = 7; mean vol = 246 ml		
January-February	Fishes (100) arctic cod (85) saffron cod (15) n = 8; mean vol = 64 ml		
March	Fishes (63) arctic cod (83) saffron cod (12) sculpins (3) Shrimps (36) n = 26; mean vol = 228 ml	Mysids (79) Hyperiid amphipods (11) Shrimps (8) Gammarid amphipods (2) n = 4; mean vol = 72 ml	Gammarid amphipods (54) Fishes(32) sculpins (81) saffron cod (12) Shrimps (12) n = 9; mean vol = 58 ml
April	Shrimps (99) Fishes (1) sculpins (50) n = 3; mean vol = 182		
May-June	Fishes (96) saffron cod (96) Shrimps (3) n = 17; mean vol = 312 ml	Fishes (62) arctic cod (95) Shrimps (20) Mysids (13) n = 13; mean vol = 110 ml	Fishes (55) saffron cod (54) sculpins (29) arctic cod (17) Shrimps (37) Mysids (16) n = 7; mean vol = 267 ml

Table 11.23-6. Major food items of ringed seals by sex and age class. Seals were collected in the Bering Sea, April-June 1975-79. Numbers indicate percent of total volume for invertebrates and total fish, and percent of total number for species of fishes (Lowry et al. 1981a).

	Sexes Combined				Seals ≥ 5 yrs old	
	pups n=46	yrlgs n=24	2-4 yrs n=17	≥ 5 yrs n=32	males n=14	females n=18
Shrimps	59	46	28	14	20	10
Hyperiid amphipod	8	2	<1	<1	<1	<1
Gammarid amphipod	4	4	6	4	7	2
Mysid	23	24	6	<1	<1	<1
Euphausiid	2	--	--	--	--	--
Total Fishes	1	23	60	80	70	85
saffron cod	33	92	99	97	97	97
arctic cod	43	<1	<1	2	2	3
sand lance	5	2	--	<1	--	<1
sculpin	5	--	<1	<1	1	<1
Mean volume of contents (ml)	39.4	65.8	155.0	288.3	221.9	340.0

the diet increased with age from 1% in pups to 80% in seals 5 or more years old. The proportion of food which was comprised of shrimps, hyperiid amphipods, and mysids showed a corresponding decrease with age.

Feeding patterns similar to those reported for Bering Sea ringed seals are evident in seals from waters of northern Alaska, the northern USSR, Greenland, and the Canadian arctic islands (Table 11.23-7). Arctic cod are by far the major food during the months of November to April. Benthic crustaceans become important in late spring and summer. In late summer and early autumn, pelagic crustaceans (hyperiid amphipods and euphausiids) are the major food in offshore waters, while mysids are commonly eaten in some nearshore areas. Ringed seals in the Sea of Okhotsk live under somewhat different environmental conditions than ringed seals in other regions. Euphausiids are their major food in spring and summer. In autumn and winter they utilize a variety of nearshore boreal-subarctic fishes (Fedoseev 1965b).

Food Requirements

The energetic requirements of ringed seals were studied by Parsons (1977) and discussed by Lowry et al. (1980b). Parsons found that captive ringed seals weighing 30-80 kg required 35-55 kcal/kg/day or 1,750-2,750 kcal/day, with larger seals requiring fewer calories per unit of body weight. Based on seasonal changes in ringed seal weights, Lowry et al. (1980b) estimated the daily intake of a 46.1-kg seal requiring an average of 1,613 kcal/day (35 kcal/kg) to range from 1,328 kcal in the spring-summer period to approximately 2,500 kcal in autumn. Expressed as percent of body weight per day, food intake on a seasonal basis could range from 2 to 9.5% per day, depending on caloric value of the prey. Frost and Lowry (1981d) assumed daily intake rates (expressed as a percent of total body weight) by ringed seals in the Beaufort Sea of 8.4% in November-March, 1.9% in April-June, 4.1% in July, 5.6% in August and September, and 7.4% in October.

Using life table data from Alaskan ringed seals (Table 11.23-2) and Parson's estimates of age-specific caloric intake, it is possible to calculate annual population energy requirements (Table 11.23-8). The caloric requirement of 1,000 ringed seals for 1 year would be 578 x 10^6 kcal. Translated into tonnages of prey by using caloric values presented in Lowry et al. (1980b), that energy requirement would amount to approximately 410 mt of arctic or saffron cod, or 480-869 mt of euphausiids.

New or Unanalyzed Data

We know of two sources of new or unanalyzed data on ringed seals. The National Marine Mammal Laboratory has six ringed seal stomachs collected on the joint Soviet-American marine mammal research cruise (ZRS Zvyagino) from 18 March-18 April 1981. Preliminary results of stomach contents analysis were presented in the cruise report.

Table 11.23-7. Summary of the major prey of ringed seals in regions other than the Bering Sea (from Lowry et al. 1980b).

Region	Winter	Spring	Summer	Autumn	Source
Sea of Okhotsk	Saffron cod, smelt, herring, and other fishes	Primarily euphausiids, also gammarid and hyperiid amphipods and shrimps		Saffron cod, smelt, herring, and other fishes	Fedoseev (1965), Fedoseev and Bukhtiyarov (1972), Nikolaev and Skalkin (1975)
Bathurst Island			Mysids, hyperiid and gammarid amphipods		Finley (1978)
Southwest Baffin Island, northern Foxe Basin	Hyperiid amphipods offshore; mysids, arctic cod, and shrimps nearshore--no seasonality was found				McLaren (1958)
Ungava Bay and northern Labrador	Mysids, euphausiids, and fishes, including sand lance, pricklebacks, sculpins, and arctic cod--no seasonality was found				McLaren (1958)
Baffin Island			Hyperiid amphipods and mysids		Dunbar (1941)
Northwest Greenland	Arctic cod, amphipods, and shrimps--seasonality not indicated				Vibe (1950)
Kara Sea, Novaya Zemlya	Arctic cod	Hyperiid and gammarid amphipods, and mysids		Arctic cod	Chapskii (1940)
Chukchi Sea	Arctic and saffron cod, sculpins	Shrimp, gammarid amphipods, mysids, and saffron cod		Sculpins, arctic and saffron cod	Johnson et al. (1966), Lowry et al. (1980b)
Beaufort Sea	Arctic cod	Gammarid amphipods, shrimps, and arctic cod	Hyperiid amphipods, euphausiids, and arctic cod	Arctic cod, hyperiid amphipods, and mysids	Lowry et al. (1978, 1980b, 1981a)

Table 11.23-8. Estimated caloric intake for a population of 1,000 ringed seals from Alaska (1975-79).

Age* (yrs)	Weight* (kg)	Age frequency*	Biomass (kg)	Age-specific caloric intake** (kcal/kg/day)	Yearly caloric intake (kcal x 10^3)
0	14	196	2,744	110	110,170
1	25	116	2,900	50	52,920
2	30	64	1,920	50	35,040
3	34	58	1,972	50	35,990
4	35	68	2,380	50	43,440
5	35	73	2,555	45	41,970
6	41	73	2,993	35	38,240
7	46	57	2,622	35	33,500
8	48	53	2,544	35	32,500
9	48	48	2,304	35	29,430
10	49	35	1,715	35	21,910
11	52	40	2,080	35	26,570
12	52	22	1,114	35	14,230
13	55	23	1,265	35	16,160
14	51	16	816	35	10,420
15	46	16	736	35	9,400
16	44	8	352	35	4,500
17	51	8	408	35	5,210
18	61	6	366	35	4,680
19	47	6	282	35	4,680
20	46	3	138	35	3,600
>20	45	11	495	35	6,320
		1,000	34,701	35	577,960

* Data from Table 11.23-2.
** Data from Parsons 1977.

The ADF&G is preparing a final report on ringed seal studies for the period 1975-1981 (Burns et al., in prep.). That report will cover the analysis of specimen data from 2,134 ringed seals, including physical measurements from approximately 1,207; reproductive data from 933 (437 males and 496 females); stomach contents data from 1,238; and age data from 1,979. Stomach contents have already been analyzed and reported by Lowry et al. (1980b; 1981a,b). Age and reproductive data are partially discussed in Frost and Lowry (1981b).

11.24 Bearded Seal

Population Status

Bearded seals are circumpolar in distribution and are found in regions where seasonal ice occurs over relatively shallow water (Burns 1967, 1981b). They regularly inhabit the coastal waters of Greenland and the arctic and subarctic waters of North America; the Bering Sea and North Pacific south to the Amur River on the Asiatic side and to the Aleutian Islands on the American side; Hudson Bay, Hudson Strait, Ungava Bay, the waters off Labrador and occasionally Newfoundland; and the waters over the Siberian shelf (Dunbar 1949). Two subspecies have been recognized in the literature, although discreteness of the two is questionable (Scheffer 1958; King 1964; Burns 1967, 1981b). The North Pacific subspecies, *Erignathus barbatus nauticus*, is considered to occur in the western Arctic and Subarctic from the central Canadian arctic archipelago westward to the Laptev Sea.

Bearded seals can and do make and maintain breathing holes in relatively thin ice; however, they avoid regions of continuous, thick shorefast ice and of unbroken, heavy drifting ice. They prefer ice that is in motion, producing polynyas, leads, and open water through which to breathe (Burns 1967, 1970, 1981b). They are most abundant in areas where pack ice occurs over the shallow waters of the continental shelf.

In Alaskan waters, most bearded seals migrate long distances during the year in response to the seasonal advance and retreat of ice cover. During winter and spring, the combination of favorable ice conditions and shallow water occurs over much of the Bering Sea but is much more limited in the Chukchi and Beaufort seas. Consequently, most of the population moves south through Bering Strait in late autumn-early winter and spends the winter and early spring widely distributed throughout the drifting ice of the Bering Sea (Burns 1967, 1981b; Burns and Frost 1979). The northward spring migration begins in April as the ice begins to melt and recede, and continues until the ice is gone in about mid-June. Most bearded seals spend the summer near the wide fragmented margin of multi-year ice in the Chukchi Sea, although some, perhaps a significant proportion of the juveniles, occur in open water, small bays, or even rivers during summer. The southward migration occurs in autumn and early winter in conjunction with freeze-up but is more diffuse than the spring migration.

Multiple aerial surveys undertaken in the Bering Sea in spring (Kosygin 1966; Burns and Frost 1979; Braham et al., unpubl. ms.) have confirmed that bearded seals are the most widely distributed pinniped occurring in the drifting seasonal ice. These surveys also provide information on the relative regional abundance of bearded seals. In April the highest numbers were consistently seen in the northern Bering Sea near St. Lawrence Island; in ice 60-100 km north of the front zone; west of St. Matthew Island; and in the southern Gulf of

Anadyr. In May and June, as the ice retreated northward so did the seals (Burns and Frost 1979). The abundance of bearded seals in Bristol Bay and the St. George Basin south and east of the Pribilofs is directly related to annual ice conditions; when ice is present, so are bearded seals.

The Bering-Chukchi population of bearded seals has been estimated at 300,000 (NOAA 1979, Burns 1981b). The Soviets estimate that same population at approximately 250,000 (Popov 1976). Bychkov (1971), citing Chapskii (1966), presents an estimate of 450,000 for the entire North Pacific, including the Sea of Okhotsk population which was thought to number about 180,000 in 1969 (Fedoseev 1973).

The life history parameters of bearded seals in Alaska are quite well known (Burns 1967, 1981b; Burns and Frost 1979). Average length at birth is 131 cm, with a weight of about 34 kg. Following a nursing period of 12-18 days, pups increase in length to about 147 cm and weigh approximately 85 kg (Burns 1967). Seals 9 years and older average 220 cm ($n = 41$) and 248 kg ($n = 7$). Females average 2-4% longer than males of the same age. Using 220 cm as the length of physically mature adults, the proportional lengths of younger year classes were as follows: pups, 66% of adult length; 1-year-olds, 73%; 2-year-olds, 83%; 3-year-olds, 88%; 4-year-olds, 94%; and 5-year-olds, 96% (Burns and Frost 1979). Fedoseev (1973) reports similar values for bearded seals in the Sea of Okhotsk. Maximum recorded standard lengths and weights of bearded seals from the Bering-Chukchi region are 243 cm and 361 kg for a female and 233 cm and 318 kg for a male (Johnson et al. 1966, Burns 1967, Burns and Frost 1979). The weight of bearded seals changes on a seasonal basis; they are heaviest in autumn through spring and lightest in summer, following lactation in females and reduced feeding activity associated with the molt in both sexes. Burns and Frost (1979) reported an average blubber layer thickness in late autumn through early spring of 7.2 cm and in summer of 4.4 cm. Mean weights vary accordingly.

Males become sexually mature, as indicated by testes and baculum size and by the onset of spermatogenetic activity, mainly at ages 6-7. Most females do not become pregnant until the age of 6 years (17% at age 4; 50% at age 5; 80% at age 6; 100% at age 8) (Burns and Frost 1979). Most breeding coincides with the end of lactation and occurs from April to early June with the peak in May. Implantation of the fetus occurs mainly from mid-July to early August, after a delay of approximately 2 months. Pups are born from mid-March through early May. Most births occur in April, making a total gestation period of 11 months. A single pup per female is usual; twinning is rare. Females apparently bear young throughout their lives (Burns and Frost 1979). The maximum life span is about 30 years, although normal life expectancy is considerably less. Only 2% of the bearded seals sampled by Burns (1981b) were older than age 20.

Sex ratio at birth is close to 1:1. In harvested animals older than pups, females predominate (Johnson et al. 1966, Burns and Frost

1979, Burns 1981a). Burns and Frost found 53% females in 1962-66 (n = 205) and 55% females in 1975-78 (n = 727).

In the Bering-Chukchi region, breeding is annual. The observed pregnancy rate from 1962 through 1978 remained approximately constant at 83-85% of sexually mature females, or 77% of all females 4 years and older (Burns and Frost 1979). Based on harvest data, female bearded seals 7 years or older comprise approximately 29% of all seals older than pups. This would result in an annual gross productivity of about 24%. Since some females ages 4-6 produce young, gross productivity may be somewhat higher. Soviet investigators studying bearded seals in the Barents, Kara, and Okhotsk seas have reported similar values of 15-20% (Chapskii 1938), 20-22% (Tikhomirov 1969, cited in Fedoseev 1973), and 19% (Fedoseev 1973).

Major predators of bearded seals in the Bering-Chukchi region are polar bears and humans (Burns 1981b). The extent of predation by polar bears is unknown. Human harvest is of two types: coastal-based subsistence hunting in Alaska and Siberia, and pelagic commercial sealing by the Soviets. Between 1966 and 1977, the estimated retrieved Soviet and American harvest of bearded seals averaged 4,400 and ranged from 2,400 to 8,300 (Table 11.24-1) (Burns 1981b).

Based on life tables derived from harvest data, Burns and Frost (1979) estimated that bearded seals 3 years or younger (including pups) comprised 40-45% of the population. Mortality of pups may be as high as 60%, decreasing to 19% by age 1. Mortality for age classes 6-20 was about 8% per year, after which it increased gradually (Table 11.24-2).

Diet Composition

The nursing period in bearded seals is comparatively short, lasting 12-18 days (Burns 1981b). During this time the weight of pups increases approximately 250%, mostly in the form of an accumulated blubber layer (Burns 1967). Weaning occurs when the female abruptly deserts the pup. Some independent feeding apparently occurs during the latter part of the nursing period; newly weaned pups are active feeders (Burns 1981b; Lowry, Frost, and Burns, unpubl. observations).

The results of investigations on foods of bearded seals in the Bering and Chukchi seas have been reported by Kenyon (1962b), Burns (1967), Johnson et al. (1966), Kosygin (1966), and Lowry et al. (1979, 1980a; 1981a,b).

Kenyon (1962b) reported on the stomach contents of 17 bearded seals taken near Little Diomede Island, 11 May-6 June 1958. Shrimps (*Pandalus* sp. and *Sclerocrangon* sp.), crabs (*Hyas coarctatus* and *Pagurus* spp.), and clams (probably *Serripes groenlandicus*) comprised most of the contents. Other benthic invertebrates (sponges, annelids, and snails) and fishes (including sculpins, smelt, and saffron cod) were occasionally

Table 11.24-1. Retrieved harvest of bearded seals in the Bering Sea from 1966 through 1977 (Burns 1981b).

Year	American harvest	Soviet harvest	Total annual harvest
1966	1,242	6,230	7,472
1967	1,300	7,009	8,309
1968	1,050	4,577	5,627
1969	1,772	1,986	3,758
1970	1,759	2,533	4,292
1971	1,754	1,490	3,244
1972	1,353	1,428	2,781
1973	1,500	1,293	2,793
1974	1,600	1,256	2,856
1975	1,200	1,220	2,420
1976	2,125	1,644	3,769
1977	4,750	1,204	5,954

Table 11.24-2. Age, sex, mean weight at age, and age-specific mortality of 1,311 bearded seals harvested in the Bering and Chukchi seas, 1975-78 (Burns and Frost 1979).

	Number of seals						
Age	Males	Females	Unknown	Total	Fitted-age frequency	Mean weight (kg)	Percent age-specific mortality
0	237	197	50	484	225	68	60
1	49	56	10	115	90	112	19
2	32	33	10	75	73	156	14
3	25	24	5	54	63	197	12
4	21	24	12	57	56	210	10
5	17	28	2	47	50	230	9
6	17	20	3	40	46	242	9
7	7	17	5	30	42	242	8
8	6	16	6	28	38	242	8
9	10	21	2	33	35	242	8
10	12	21	6	40	32	242	8
11	18	30	10	58	30	242	7
12	20	34	6	60	28	242	8
13	7	33	7	48	26	242	7
14	13	19	1	33	24	242	8
15	11	14	3	28	22	242	8
16	2	12	1	15	20	242	8
17	4	6	1	12	19	242	8
18	0	2	0	2	17	242	8
19	2	8	0	10	16	242	9
20	0	12	3	16	14	242	9
21	4	6	1	12	13	242	9
22	4	0	0	4	12	242	10
23	2	2	0	4	11	242	10
24	2	0	0	2	10	242	11
25	2	0	0	2	9	242	12
26	2	0	0	2	8	242	100
27	0	0	0	0	0		--
Total	526	635	144	1,311	1,029		

found in small amounts. The volume of contents in Kenyon's sample averaged 850 ml and ranged from 120-1,900 ml.

In his summary of the biology of the bearded seal, Burns (1967) reported on the examination of 23 stomachs from seals collected near Nome, Gambell, and Wainwright. In May, brachyuran and anomuran crabs (Hyas coarctatus and Pagurus spp.) made up 57% of the contents; shrimps (Sclerocrangon boreas and Pandalus spp.), fishes (saffron cod, arctic cod, and sculpins), and sponges comprised the remainder. In July-August, clams (Serripes groenlandicus, Spisula sp., and Clinocardium sp.) made up 25-43% of the volume of food; shrimps, crabs, and isopods were also commonly found. The largest volume of food found by Burns in a stomach was 2,800 ml, and the average 854 ml.

Johnson et al. (1966) examined the stomach contents of 164 bearded seals collected near Point Hope and Kivalina from November 1960 through June 1961. June was the only month in which a large sample (129) was obtained. Shrimps, crabs, and clams were the most common food items, with other benthic invertebrates found in small quantities. Fishes (sculpins and arctic cod) usually comprised less than 10% of the total volume.

Results of Soviet investigations of the foods of bearded seals in the Bering Sea are reported by Kosygin (1966, 1971). Stomachs from 565 seals collected in March-June of 1963-65 were examined; 152 contained food. More than 30 species of crustaceans, several molluscs, four species of annelids and priapulids, sponges, pogonophorans, and approximately 15 species of fishes were identified from these stomach contents. Tanner crabs made up 53-76% of the food. Shrimps, particularly Argis lar, snails, and polychaetes were also important foods. Octopus, priapulids, and fishes (particularly pricklebacks and flatfishes) were eaten regularly but usually in smaller amounts. Kosygin noted considerable constancy in the diet from year to year, which he explained by the fact that the seals tend to be found in the same area 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 exclusion of the seals from certain feeding areas by heavy ice fields. No age- or sex-related differences in diet were noted. The average amount of food in the stomachs decreased from April to June. The maximum contents reported by Kosygin was 2.8 kg in an 11+-year-old female that had been eating capelin.

Lowry et al. (1979; 1980d; 1981a, b) report and summarize the results of OCSEAP studies conducted from 1975 through 1979 on the foods of bearded seals found in the Bering and Chukchi seas. In total, they examined 424 stomachs containing food, of which 17 were from the southern and eastern Bering Sea, 131 from the northern Bering Sea, 42 from two villages in Bering Strait, and 234 from the Chukchi Sea (Tables 11.24-3 and 11.24-4). Throughout the Bering and Chukchi seas, crabs (Chionoecetes opilio and Hyas spp.), shrimps (Argis spp., Crangon spp., Eualus spp., and Pandalus spp.), and clams (mostly Serripes groenlandicus) made up

Table 11.24-3. Summary of information on foods of bearded seals from the southeastern Bering Sea, March-May 1975-78 (Lowry et al. 1981a).

LOCATION	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 VOL. (ml)	1011.5		342.0		137.9		3.0	
COMPOSITION OF SAMPLE	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.
Shrimp	--		64		39		100	
Brachyuran crabs	92		22		18			
Isopods	--		--		10			
Fishes	2		--		19		--	
Saffron cod		--		--		5		--
Pollock		5		--		7		--
Sculpins		--		--		85		--
Flatfish		10		--		--		--
Eelpout		84		--		--		--

Table 11.24-4. Summary of information on spring-summer foods of bearded seals from the northern Bering Sea (Lowry et al. 1981a).

LOCATION	Savoonga		Gambell		St. Lawrence Is.		Nome		Diomede		Wales	
DATES	May-June 1975-79		April-June 1975-79		May-June 1978		May-June 1975-79		May-June 1975-79		June-July 1977-78	
SAMPLE SIZE	42		58		10		21		24		18	
MEAN VOL. (ml)	429.9		452.4		595.3		436.1		555.6		307.0	
COMPOSITION OF SAMPLE	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.	% vol.	% no.
Clams	5		11		22		56		3		2	
Shrimp	22		15		41		32		17		46	
Brachyuran crabs	34		43		13		3		35		45	
Fishes	29		16		3		2		29		4	
Saffron cod		--		--		17		27		--		79
Arctic cod		--		3		27		--		10		2
Sculpins		95		94		56		63		87		17

the bulk of the bearded seal diet (usually more than 70% of the volume and no less than 55%), while fishes were generally of minor importance. The fishes most commonly eaten were sculpins and saffron cod. Lowry et al. (1980a) found the differences in foods of male and female bearded seals to be slight and probably not significant. However, they found marked age-related differences in foods (Table 11.24-5). Seals 3 or more years old ate more clams and fewer shrimps. Furthermore, in Bering Sea samples the species composition of shrimps eaten changed from predominantly family Hippolytidae in pups to predominantly family Pandalidae in older seals. Generally, the importance of isopods and saffron cod decreased with age, while brachyuran crabs, sculpins, and flatfishes were of greater importance in the diet of older seals.

Major seasonal differences in the proportions of various prey items in the diet were reported by Lowry et al. (1980a), although few specimens were available from the autumn-winter period (Table 11.24-6). Fewer clams and fishes and more shrimps and brachyuran crabs were eaten in autumn-winter.

Lowry et al. (1980d) also analyzed year-to-year changes in prey utilization at Nome and Diomede (Table 11.24-7). Their results suggest long-term changes in food availability. Clams were the primary food found in seal stomachs at Diomede in 1958 and 1967. Since 1975, clams have been a minor component of the food, accounting for less than 10% of the stomach contents. Lowry et al. (1980a) suggest 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.

The foods of bearded seals are similar throughout their circumpolar range (Table 11.24-8). Decapod crustaceans and molluscs comprise most of their food.

Food Requirements

We know of no published studies on the food or energy requirements of bearded seals.

New or Unanalyzed Specimens

We know of one partially processed collection of bearded seal specimens. The sample includes measurements, reproductive tracts, claws or teeth, and stomach contents from 83 seals (21 males and 62 females) collected on the joint US/USSR Steller Sea Lion/Ice Seal Research Cruise of the ZRS *Zvyagino* in March-April 1981 in the southwestern Bering Sea. It is our understanding that all reproductive material is being analyzed by Soviet scientists. The National Marine Mammal Laboratory has the stomach contents samples and data, and expects to have results available sometime within the next year or so (George Antonelis, pers. commun.). Preliminary findings of stomach contents analysis are presented in the cruise report for the *Zvyagino* cruise.

11.24-5. Major foods of bearded seals by age class. Values represent percent of total stomach contents volume for invertebrate taxa and total fish material and percent of the total number of fishes eaten for individual fish taxa (Lowry et al. 1980a).

	Shishmaref			Bering Sea		
	Pups N = 38	1 and 2 yrs old N = 21	≥ 3 yrs old N = 91	Pups N = 52	1 and 2 yrs old N = 31	≥ 3 yrs old N = 50
Clam	4	11	19	2	3	25
Snail	--	--	1	--	--	2
Shrimps	59	47	30	45	26	27
Brachyuran crab	6	20	24	28	38	27
Isopod	18	9	8	1	*	*
Fishes	7	11	6	13	26	10
Saffron cod	51	18	30	41	5	4
Arctic cod	*	*	1	5	2	6
Sculpins	28	55	25	47	89	77
Flatfishes	20	25	37	*	1	1
MEAN VOL (ml)	325	462	492	213	578	670

* Indicates values less than 1%.

Table 11.24-6. Major foods of bearded seals collected in the Bering Sea by time period. Results are presented as in Table 11.24-5. 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 (Lowry et al. 1980a).

	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
Shrimps	20	94	53	73
Brachyuran crab	23	80	37	91
Fishes	16	78	5	82
Saffron cod	3	4	4	36
Arctic cod	9	17	5	27
Sculpins	82	46	76	54
Flatfishes	--	--	3	46
MEAN VOL (ml)	662	--	743	--

* Indicates values less than 1%.

Table 11.24-7. Percent of total stomach contents volume which consisted of clams in bearded seals collected at Nome and Diomede 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	--	Only two primary foods (9/17) [1]
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 1962b.

* Indicates values less than 1%.

Table 11.24-8. Summary of the major prey of bearded seals in regions other than the Bering Sea.

Region	Winter	Spring	Summer	Autumn	Source
Northwest Greenland	Gastropods, crustaceans, holothuroids, cephalopods, polychaetes, arctic cod--no seasonality indicated				Vibe 1950
Eastern Canadian Arctic		Shrimps, spider crabs, gastropods, holothuroids, octopus, polychaetes, arctic cod			Dunbar 1941, 1949; Mansfield 1967
Barents and Kara seas		Shrimps, isopods, gastropods, arctic cod		Shrimps, gammarid amphipods, char, sand lance, arctic cod	Chapskii 1938, Tarasevich 1963
Southern Sea of Okhotsk/ Sakhalin		Tanner and spider crabs, shrimps, bivalves, gastropods, octopus, sand lance, flounder			Inukai 1942, Wilke 1954, Fedoseev and Bukhtiyarov 1972, Nikolaev and Skalkin 1975
Northern Sea of Okhotsk		Spider crabs, shrimps, gastropods, bivalves, octopus, echiuroids, holothuroids, fishes		Crabs, shrimps, sponges	Pikharev 1940, Fedoseev and Bukhtiyarov 1972, Nikolaev and Skalkin 1975
Chukchi Sea		Shrimps, crabs, clams, isopods, sculpins, saffron cod, flatfishes			Johnson et al. 1966, Lowry et al. 1980a
Beaufort Sea	Arctic cod, spider crabs, shrimps	Shrimps, hermit and spider crabs, clams, isopods, octopus		Shrimps, spider crabs, arctic cod, gammarid amphipods, octopus	Lowry et al. 1979

11.25 Polar bear

Population Status

Polar bears are distributed throughout the north polar basin, particularly in association with shorefast and drifting pack ice (Lentfer 1972). Based on the results of tagging studies as well as on morphometrics and tissue contaminant levels, Lentfer (1974) concluded that bears off Alaska comprise two partially discrete populations, with the division between the two groups corresponding approximately with a line extending northwest from Point Lay (Figure 11.25-1). Bears north and east of that line form the northern population and appear to restrict their movements to the Beaufort and northeastern Chukchi seas. Some bears from the western population may move between Wrangel Island and the northern Bering Sea.

Polar bears are regularly associated with sea ice and normally occur in the Bering Sea only during ice-covered months (approximately December through May). They regularly occur in variable numbers as far south as St. Lawrence Island (Fay 1974) but are uncommon south of there (ADF&G, unpubl.) (Figure 11.25-1). Local distribution and movements are known to be related to ice conditions and ice motion (Lentfer 1972). Migration routes have not been well defined, but Bering Strait is of obvious importance to bears that winter in the Bering Sea.

The number of polar bears in the waters off Alaska is not precisely known. Estimates range from approximately 5,700 to 9,500 (NOAA 1979), with the western group containing about twice as many animals as the northern group. Lentfer et al. (1980) concluded that the population was stable or increasing slightly during the period 1967-1976. The number of bears entering the Bering Sea each year is not known but is probably small. Of 3,507 bears harvested in Alaska from 1961 through 1979, only 332 (9.5%) were taken south of Bering Strait (ADF&G, unpubl.).

Data on population characteristics of Alaskan polar bears have been recently analyzed and summarized (Lentfer et al. 1980). Males 3 to 19 years of age are physiologically capable of breeding but may not all do so due to social and behavioral requirements. Some females are capable of breeding at 3 years of age; the average age of first breeding is 5.4 years. The mean breeding interval for females is 3.6 years, which combined with an average litter size of 1.65 indicates an average of 0.46 young per adult female per year. Survival rates cannot be accurately calculated at present, but data indicate higher survival rates for young animals and females. The overall composition of the population has been estimated at 32% young (0-2 years old), 43% older females, and 25% older males.

Diet Composition

We have located no direct information on foods of polar bears in the Bering Sea. Elsewhere in their range, while on the sea ice, they

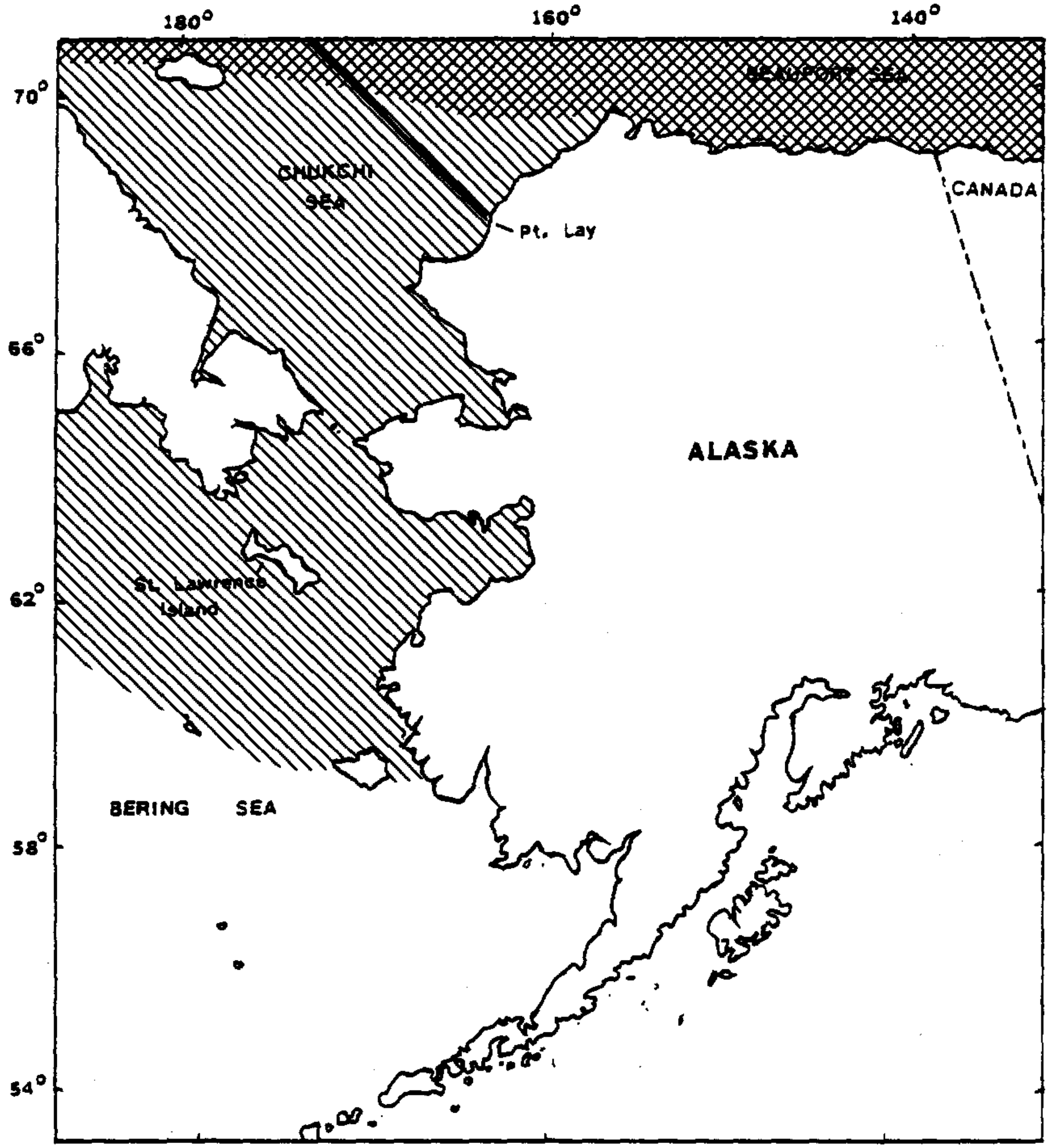

Figure 11.25-1. Approximate winter \\\ and summer /// distributions of polar bears in Alaskan waters. Diagonal line from Point Lay is the approximate division between northern and western groups.

are known to consume seals, walruses, and belukha whales (Freeman 1973, Stirling and McEwen 1975, Eley 1978, Smith 1980). When on land during the summer they feed on a variety of foods, including birds, algae, and grasses (Russell 1975), as well as sometimes preying on seals swimming near the shore (Furnell and Oolooyuk 1980). Throughout most of their range, ringed seals are the most important prey (Stirling and McEwen 1975), although in some areas bearded seals and walruses may also be important (Eley 1978, Smith 1980). Eley (1978) examined the remains of 71 pinnipeds killed by polar bears in Alaskan waters; 65 were ringed seals, 5 were bearded seals, and 1 was a walrus. Carrion, including carcasses of gray whales and walruses, is commonly scavenged by bears near St. Lawrence Island and the northeastern Bering Sea coast (ADF&G, unpubl.). Seasonal variations in diet undoubtedly occur in relation to patterns of prey availability. However, such variation has not been documented due to the fact that almost all data on polar bear predation have been gathered during late winter and spring.

Food Requirements

Based on tracking and observations of marked bears, Eley (1978) estimated that on the average one ringed seal was killed every 6.5 days. Best (1977), using a model which incorporated bear size and calorific requirements and ringed seal size, body composition, and caloric value, calculated that a 27.8-kg ringed seal could supply the energy requirements of a 229-kg bear for 6.4 days.

New or Unanalyzed Data

Ongoing programs concerning the distribution, ecology, and population characteristics of polar bears are being conducted by the USFWS. A considerable amount of the data which have been collected has been incompletely analyzed and reported. Included are data on age and cranial measurements of harvested bears, as well as observations of productivity, mortality, distribution, and movements.

11.26 Sea Otter

Population Status

Sea otters are a marine member of the order Carnivora and are the smallest of marine mammals (Johnson 1976). According to Johnson (1976), two subspecies are recognized: Enhydra lutris gracilis from the Kuril Islands and southern Kamchatka, and E. l. lutris which ranges from the Commander Islands east and south to Alaska and southern California. Further subspecific classification was once thought valid for sea otters in California; however, recent evidence suggests the differences in California otters are manifestations of the southern extremes of a cline rather than sub-speciation (Roest 1973).

Sea otters inhabit the nearshore North Pacific and are seldom seen in waters deeper than 30 fathoms. In the Bering Sea, sea otter habitat varies from rocky intertidal areas with dense macroalgal flora, such as much of the Aleutian Islands, to extensive shallow, offshore areas, such as is found off Unimak Island and in southern Bristol Bay (Kenyon 1969). Formation of sea ice in Bristol Bay can drastically affect distribution of sea otters in that area (Schneider and Faro 1975).

Prior to commercial exploitation, sea otters were distributed more or less continuously from Baja California northward along the Pacific coast of North America; throughout the Gulf of Alaska including Prince William Sound; along the Alaska Peninsula and continuously through the Aleutian, Pribilof, and Commander Islands; along the Kamchatka coast; and through the Kuril Islands to southern Sakhalin and northern Hokkaido.

Sea otters were heavily harvested until 1911, when they were protected by international treaty. At that time, remnant, isolated populations existed at the Kuril Islands, Kamchatka Peninsula, Medny Island, Rat Islands, Delarof Islands, Sandman Reefs, southeastern Bristol Bay, Shumagin Islands, Kodiak Archipelago, Prince William Sound, Queen Charlotte Islands, and Point Sur, California (Kenyon 1969). The total sea otter population in 1911 probably did not exceed a few thousand animals.

The remnant population nuclei have grown and expanded, repopulating much of their former range in Alaska. The current total worldwide estimate of sea otters is approximately 132,000. This estimate includes 1,600-1,800 in California; 50 in Oregon, Washington, and British Columbia; 101,000 to 121,000 in Alaska; and 9,000 in the USSR (Klumov 1968, Wild and Ames 1974, Johnson 1976). Schneider (pers. commun. and unpubl. ms.) estimates 55,100 to 73,700 in the Aleutian Islands, 11,700 to 17,200 on the north side of the Alaska Peninsula, and 10 on the Pribilof Islands. Klumov (1968) estimated the Commander Islands population to be 2,000 in 1968. This gives a range of 68,810 to 92,910 sea otters in the Bering Sea.

Kenyon (1969) measured newborns and adults collected at Amchitka Island. The mean weight for newborn males was 1.75 kg and the mean length was 55.2 cm (n = 4); mean weight for female pups was 1.96 kg and the mean length was 53.9 cm (n = 7). For adults, the mean weight of males was 28.3 kg and the mean length was 135.0 cm (n = 79). Mean weight for females was 21.1 kg and the mean length was 125.2 cm (n = 254). Schneider (unpubl. ms.) agrees with Lensink (1962) and Kenyon (1969) that sea otters can give birth and mate at nearly any time of year, although information collected in the Aleutian Islands indicates a peak of breeding in September and October and a peak in births in May. The normal annual cycle of the female in the Aleutians appears to be breeding in the autumn, birth of the pup in the spring, and rearing the pup for 1 year prior to breeding again (Schneider, unpubl. ms.). Although this gives a 2-year breeding cycle for sea otters in the Aleutian Islands, recent evidence from California (Loughlin et al. 1981) and Prince William Sound (Johnson 1979) suggests annual breeding. The 2-year breeding cycle in the Aleutians is probably a result of less desirable nutritional conditions experienced when sea otter populations reach higher densities, and the annual reproduction noted in Prince William Sound is probably a manifestation of superior nutritional conditions at the present time. Schneider (unpubl. ms.) noted that even in the Aleutian sample the otters appeared physiologically capable of annual breeding.

Kenyon (1969) estimated the age at reproductive maturity for females as 3 years, although he questioned the adequacy of his data. Schneider (unpubl. ms.) found that most females breed in autumn when they are 3 years old and probably bear their first young the following spring when they are 4 years old.

Twinning was noted in 2% of the pregnancies examined by Schneider (unpubl. ms.); however, he thought it unlikely that a female could support twin pups through the entire 1-year nursing period.

Schneider (unpubl. ms.) combined his sample of 261 with Kenyon's (1969) 58 to determine a fetal sex ratio slightly but significantly biased toward females (57%). Schneider (unpubl. ms.) also reported that females have a greater life expectancy than males and that the percentage of females in some Aleutian Island populations may exceed 60%.

Mortality among juveniles at Amchitka Island appeared to be high between 1940 and 1965, due principally to death caused by injury in rough seas, disease, and starvation leading to enteritis (Kenyon 1969). Kenyon estimated the annual mortality of the Amchitka Island population was 8 to 11%, although as Johnson (1976) points out this estimate was based on limited data. The estimate was also made on a population which was at or near carrying capacity and which had already significantly altered its habitat and reduced important food species. Schneider (pers. commun. in Johnson 1976) found that, of 2,000 females for which age was determined, only five or six were 20 years or older; the oldest was 23 years. Schneider and Faro (1975) documented substantial mortality of otters in Bristol Bay due to malnutrition as a result of extensive sea ice formation in 1971 and 1972.

Diet Composition

Sea otters eat a wide variety of bottom-dwelling invertebrates and will also eat fishes if the invertebrate populations become depleted (Kenyon 1969, Calkins 1978). In the Aleutian Islands, benthic invertebrates (mostly sea urchins) comprised the entire diet of newly established otter populations, whereas fishes were the major prey of long-established populations, probably due to changes in prey availability (Estes et al., in press). Sea otters are highly opportunistic feeders and will exploit and often deplete whatever species might be available.

Most studies of sea otter feeding habits have been of a qualitative nature, using direct observations of otters eating foods, scat analysis, or analysis of habitat to determine what foods are available (Barabash-Nikiforov 1935, Williams 1938, Shitikov 1971, Shitikov and Lukin 1971, Calkins 1978, Estes et al. 1978)

Table 11.26-1 presents the results of food habits studies from the Bering Sea, which relied on scat analysis and direct observations of sea otters feeding. These studies indicate that sea urchins and molluscs are the major foods, with crabs and fishes of lesser and variable importance. However, Kenyon (1969) points out that fecal samples should not be used for quantitative analysis and may distort results of qualitative assessments of sea otter food habits. Otters do not always ingest diagnostic hard parts of all food species, particularly in the case of octopus and many fishes. Other hard parts, such as sea urchin tests, appear disproportionately abundant. Sea otters must defecate on land in order to provide for fecal analysis; this does not happen in all parts of the sea otters' range. Weather conditions and geographical features can also influence fecal analysis studies.

Kenyon (1969) presents the most complete food habits study of sea otters in the Bering Sea, based on stomach contents of 309 otters from Amchitka Island. He reported the food species found by frequency (Table 11.26-2) and also reported volumetric data for major groups (Table 11.26-3). In terms of volume, fishes were the most important (50%), followed by molluscs and echinoderms.

Wilke (1954) and Burgner and Nakatani (1972, cited in Estes et al. 1978) also found molluscs, echinoderms, and fishes to be major foods at Amchitka (Table 11.26-3). However, as noted by Estes et al. (in press), the proportion (volume) of fish in the diet increased substantially between 1954, when the otter population was newly established, and 1962-1963 and 1970, when it was at equilibrium density. The diet also became markedly more diverse during that time (Estes et al. 1978).

Table 11.26-1. Summary of information on foods of sea otters in the Bering Sea.

SOURCE	Barabash-Nikiforov 1935	Williams 1938	Kenyon 1969	Estes et al., in press	Estes et al., in press
LOCATION	Commander Islands	Aleutian Islands	Amchitka Island	Amchitka Island	Attu Island
DATES	1930-32	23, 24 July and 6 August 1936	February-April 1959	1976-77	1976-77
SAMPLE TYPE	Feces	Feces	Feces	Direct observations of feeding	Direct observations of feeding
SAMPLE SIZE	approx. 500	70	422	580	563
ANALYSIS	% of total volume	% of total volume	% occurrence	% occurrence	% occurrence
Sea urchins	59	78	95	47	74
Molluscs	23	13	46	5	6
Crabs	10	4	16	--	4
Fishes	7	3	15	12	1

Table 11.26-2. Major food items in 309 sea otter stomachs from Amchitka Island, Alaska (Kenyon 1969).

Group and species	Total no. occurrences	Percent of all prey occurrences
Annelida	13	2
Arthropoda	62	7
Hermit crab (Pagurus sp.)	15	
Crabs	25	
Mollusca	269	31
Chitons (Cryptochiton stelleri, Mopalia sp., Tonicella sp.)	21	
Limpet (Acmaea sp.)	20	
Snail (Buccinum sp.)	17	
Other snails	20	
Mussels (Musculus vernicasa and Volsella volsella)	95	
Pearlymonia (Pododesmus macroschisma)	50	
Other pelecypods	13	
Octopus	30	
Echinodermata	317	37
Blood star (Henricia sp.)	28	
Six-rayed star (Lepasterias sp.)	57	
Other starfishes	26	
Green sea urchin (Strongylocentrotus drobachiensis)	180	
Sea cucumber (Cucumaria sp.)	26	
Vertebrata	176	22
Rock greenling (Hexagrammos superciliosis)	15	
Red Irish Lord (Hemilepidotus hemilepidotus)	36	
Globefish (Cyclopterichthys glaber)	109	
Other fishes and fish eggs	16	

Table 11.26-3. Summary of information on foods of sea otters at Amchitka Island, based on analysis of stomach contents.

SOURCE	Wilke 1957	Kenyon 1969	Burgner and Nakatani 1972 (cited in Estes et al. 1978)
SAMPLE PERIOD	1954	1962-63	1970
SAMPLE SIZE	5	309	49
ANALYSIS	% of total volume	% of total volume	% frequency of occurrence
Annelids	--	1	2
Crabs	--	<1	22
Molluscs	8	37	38
Sea urchins	86	11	82
Fishes	6	50	44

Kenyon (1969) reported on the stomach contents of two adult otters collected in 15-20 fathoms of water north of Unimak Island in July 1960. By volume, the contents were 63% clam, 17% hermit crab, 14% fish (greenling), and 5% tanner crab. The stomach of a pup collected in the same area contained milk and clams.

Several studies have been conducted in the Kuril Islands and have been cited and summarized in Estes et al. (in press). These include Miyatake (1940), Nikolaev (1963), Maminov and Shitikov (1970), Shitikov (1971), Shitikov and Lukin (1971), Shitikov (1973), and Shitikov et al. (1973). In all studies, some combination of sea urchins, mussels, clams, chitons, octopus, and fishes comprised most of the diet. Shitikov and Lukin (1971) attributed regional differences in the diet to corresponding regional variation in biomass of the different species of prey. Seasonal changes in the diet of otters in the Kurils were described by Shitikov (1971). Urchins and molluscs were the main prey in winter; during summer, fish, fish eggs, crabs, and octopus became important foods.

Little is known about age-related differences in the diet of otters. Shitikov (1971) found that fish eggs were eaten more by females and young than by males. Estes et al. (in press) observed that pups (about 6 months old) brought up sea urchins, fish eggs, and molluscs but apparently could not catch fishes or octopus. They also observed that males caught more octopus, fishes, and large crabs than did females.

Much, generally qualitative, information is available on foods of sea otters in other parts of their range, particularly off the California coast. A wide array of prey are eaten, including sea urchins, snails, clams, abalone, crabs, fishes, and seabirds (Ebert 1968, Calkins 1978, VanWagenen et al. 1981). Observations indicate that sea otters are efficient and adaptable predators (see Shimek 1977) and are able to rapidly reduce populations of epifaunal and infaunal invertebrates (Lowry and Pearse 1973, Miller et al. 1975).

Based on observations of captive otters, Antonelis et al. (1981) suggested the following order of food preference: arthropods (crabs and lobsters), urchins, bivalves (clams and mussels), and gastropods (abalone, snails, and limpets).

Food Requirements

Morrison et al. (1974) found that 10 sea otters maintained in captivity under nearly natural conditions consumed one-fifth to one-fourth their weight in fish daily. Costa (1977) measured mean energy consumption of four captive sea otters and found that they consumed 234 kcal/kg/day of which 72% was metabolized. He then estimated the energy consumption of free-ranging otters to be 270 kcal/kg/day, which is 18% higher than the rate measured for captive otters. Kenyon (1969) states that juveniles required 25-30% of their body weight in food per day and adults required 20-23%. Estes et al. (1978) estimated that sea otters at a density of 20-30/km^2 would eat about 35,000 kg/km^2/year, or 3-5 kg/otter/day.

New or Unanalyzed Data

We are not aware of any new or unanalyzed data directly relating to sea otters in the Bering Sea and Aleutians, with the exception of one unanalyzed collection of scats from Amchitka Island. That collection is held by James Estes at the University of California, Santa Cruz. Numerous studies of sea otters in many parts of their range are presently ongoing and will provide considerable insight into important aspects of sea otter biology.

12.0 EVALUATION OF THE DATA BASE

12.1 Reliability and Availability

12.1.1 Diet Composition

Determination of the diet of marine mammal species is central to the assessment of their biological interactions with commercial fisheries. The principal methods by which this can be done are:

1) Direct observations of foods consumed in the wild

2) Observations of prey contained in gastrointestinal tracts, particularly stomachs

3) Observations of food remains in feces or vomitus

Direct observations of food consumed, while of great value in assessing diets of terrestrial species, are not usually applicable to marine mammals. The principal exception to this is the sea otter, which consumes a substantial portion of its prey while at the surface (e.g, Calkins 1978; Estes et al., in press), therefore at least allowing the identification of species included in the diet and perhaps some assessment of their relative significance. Similar observations have been made of killer whales and polar bears preying on other marine mammals. In other instances, observations of predator behavior in conjunction with observed prey availability have been used to infer feeding relationships (e.g., Kleinenberg et al. 1964, Nemoto 1978). Such observations must be interpreted with caution since in some instances erroneous correlations may be made, for example where sea lions present in rivers during salmon runs have been observed to prey more heavily on lamprey than salmon (Jameson and Kenyon 1977).

Most information on marine mammal foods has been obtained from the examination of stomach contents. Virtually all data have been collected from dead animals, including those killed intentionally for subsistence, commercial, or scientific purposes; those killed accidentally, particularly in fishing gear; and those naturally dead and washed ashore. Hall (1978) has devised a technique for recovery of stomach contents from live marine mammals. However, in addition to requiring live capture and restraint of animals, the technique may result in unknown biases in recoverable prey items and has not been used in field studies. The importance of prey species with persistent hard parts (such as otoliths of fishes and beaks of squids and octopus) can sometimes be assessed by recovering them from the intestinal tract. Frost and Lowry (1980) found close agreement between otoliths in stomachs and small intestines of ribbon seals, while Pitcher (1980), looking at harbor seals, found some differences between prey importance indicated by hard parts in stomachs and large intestines.

The importance of prey items in the stomach contents of marine mammals may be analyzed and expressed in several ways. The utility of and biases associated with the various measures have been discussed by Spaulding (1964) and Perez and Bigg (1981a) and will be only briefly considered here. Analysis of the contents of a particular stomach usually involves determination of the total mass (weight or water displacement volume) of stomach contents, which is then sorted into the lowest possible taxonomic categories. The number of individuals in each category is usually estimated (either by counts of intact individuals or persistent hard parts) where possible, and the amount of material (weight or volume) is determined. If stomachs are available from more than one individual, results can be expressed for each prey category as frequency of occurrence (number of stomachs containing the prey divided by the total number of stomachs in the sample), percent of total volume or weight, percent of total number, or some combination of those such as the Index of Relative Importance (IRI) or modified volume (see Perez and Bigg 1981a). While other expressions and indices are useful in determining relative importance of prey, only weight or volume directly measures the actual biomass of each prey item composing the diet. It is possible, however, to combine counts of individuals with measured or average sizes to estimate biomass contributed by some prey types. Frost and Lowry (1980) examined the relative importance of fish species in the diet of Bering Sea ribbon seals based on counts of otoliths, then corrected the results based on sizes of prey consumed, using equations relating sizes of otoliths to weights of fishes. Although ranked order of importance of prey changed only slightly, a major shift occurred in the estimate of quantitative proportions of pollock and eelpout eaten.

Several biases are possible when using stomach contents as indicators of prey consumed. Included are: 1) the relationship between when prey was eaten and when the predator was collected, 2) differential digestion rates of soft tissues of different prey species, 3) differential passage rates of persistent hard parts, and 4) inability to recognize and identify partially digested prey. There is little information available with which to evaluate the significance of these possible biases.

Analysis of feces or vomitus of marine mammals has the advantage that data can be collected without actual collection of the animals. However, apart from the physical difficulty of collecting specimen material (i.e., probably impossible for cetaceans and difficult for pinnipeds except in particular circumstances), major biases are associated with the collected data. Included are: 1) inability to identify dietary components that do not have persistent hard parts, 2) differential digestion of hard parts, and 3) differential methods and rates of passage of hard parts. An example of the latter is that by examination of vomitus one would conclude that fur seals eat only cephalopods, while feces would indicate a diet composed almost entirely of fishes. Prime (1979) discussed some problems involving relative digestion rates of otoliths.

The diet of marine mammals can be described at varying levels of detail. At the general descriptive level, diet can be expressed as a list of prey items or, preferably, a ranked list in which ranks indicate relative importance of the various prey. Information available from areas other than the Bering Sea may be of value at the general descriptive level. A quantitative description requires the measurement of amounts of foods consumed, as well as adequate sampling to detect variations in diet which may be associated with location, season, sex, or age class. This problem of obtaining a representative sample of foods eaten is of major importance. To accurately describe the average diet of a species in the Bering Sea requires samples which cover the entire area at all times of year, weighted in relation to marine mammal abundance in various areas and seasons. If significant age- and sex-related dietary differences occur the weighting values applied to abundance of the species must be separated by sex and age class.

Availability of data for the description of diets at the general and quantitative levels is indicated in Table 12.1.1-1. Two other types of information relative to diet are also included in Table 12.1.1.-1. Feeding strategy, which is an indication of dietary plasticity (i.e., the ability to exploit a variety of prey species or types), can to some degree be assessed through the examination of morphology of feeding apparatus (e.g., Nemoto 1970), or by noting general correlations between organisms consumed and those known to occur in the environment. The examination of prey selection requires comparable and concurrent measurements of types and sizes of prey consumed and those available in the area. In assigning values for the relative amounts of data available in all cases other than general description and feeding strategy, we have considered only sampling done in the Bering Sea. This appears justified since, for example, Lowry et al. (1980) documented substantial age-related dietary differences for ringed seals in the Bering and Chukchi seas but found no difference in the Beaufort Sea.

12.1.2 Food Requirements

Several sources of information may be used to estimate food requirements of marine mammals. They include:

1) Direct observations of feeding in the wild

2) Observations of quantities of stomach contents in collected animals

3) Feeding rates of captive animals

4) Metabolic studies and energetic calculations

Estimation of food requirements from observations of feeding in the wild suffers from the same problems discussed in section 12.1.1.

Table 12.1.1-1. Availability of data on diet composition of Bering Sea marine mammals.

	General description	Overall quantitative	Geographic variations	Seasonal variations	Sex variations	Age variations	Feeding strategy	Prey selectivity
MYSTICETE CETACEANS								
Gray whale	2	1	2	1	2	2	2	1
Fin whale	2	1	2	2	1	1	2	1
Minke whale	1	1	1	1	1	1	2	1
Blue whale	2	1	1	1	1	1	2	1
Sei whale	2	1	2	1	1	1	2	1
Humpback whale	2	1	2	1	1	1	2	1
Bowhead whale	1	1	1	1	1	1	2	1
Right whale	2	1	1	1	1	1	2	1
ODONTOCETE CETACEANS								
Sperm whale	2	1	2	2	2	1	2	1
Belukha	2	1	2	1	2	2	2	1
Beaked whales	1	1	1	1	1	1	1	1
Killer whale	1	1	1	1	1	1	2	1
Dall's porpoise	2	1	1	1	1	1	2	1
Harbor porpoise	1	1	1	1	1	1	2	1
PINNIPEDS								
Northern fur seal	3	3	2	2	3	2	3	1
Steller sea lion	1	1	1	1	1	1	2	1
Pacific walrus	2	2	2	1	2	1	2	1
Harbor seal	2	1	1	1	1	1	2	1
Spotted seal	2	1	2	1	2	2	2	1
Ribbon seal	2	1	2	1	1	1	2	2
Ringed seal	3	2	2	3	3	3	3	2
Bearded seal	3	2	2	2	3	2	2	1
CARNIVORES								
Polar bear	2	1	1	1	1	1	2	1
Sea otter	2	1	1	1	1	1	2	1

3 = extensive data; 2 = moderate data; 1 = little or no data

In addition, assumptions must be made regarding the proportion of total feeding which is observed and the sizes of prey items consumed.

Observations of quantities of stomach contents in collected animals are certainly of some value in determining food requirements. Maximum quantities found are an indication of the amount that can be consumed in a single feeding. In samples of several individuals, values of mean total contents are often very small in relation to presumed daily rations (e.g., see Lowry et al. 1980b). Mansfield and Beck (1977) found a reasonably close agreement between quantities of food in grey seal stomachs containing only slightly digested prey and generally accepted estimates of daily food requirements. In order to fully utilize this type of data, information is required on feeding times and periodicity as well as rates of digestion and passage of prey. Information on these subjects for balaenopterid whales in the southern hemisphere was summarized and analyzed by Lockyer (1976c).

A considerable amount of data is available on feeding rates of captive animals (e.g., see Keyes 1968 and Sergeant 1969). The major assumptions involved in extrapolating such data to animals in the wild are that caloric values of prey in the wild are similar to those fed in captivity and that energetic requirements of animals in captivity are similar to those in natural circumstances. In general, it seems that animals in captivity grow faster and are fatter than wild counterparts of comparable age, which suggests excessive feeding rates or reduced energy demands in captive animals. Nonetheless, extrapolations from feeding rates of animals in captivity have been commonly used for estimates of consumption in the wild (e.g., McAlister and Perez 1976). The degree of error associated with such calculations is not known. Keyes (1968) reported food consumption rates for pinnipeds in captivity ranging from 1.6 to 10% of the body weight per day; however, Geraci (1975) suggests that most animals require 4-7%.

The subject of marine mammal energetics is a relatively new field in which theory and data are being rapidly developed. Energetics studies as they relate to food requirements have been reviewed by McAlister (1981) and will be only briefly summarized here. Energy requirements for maintenance of marine mammals can be calculated based on considerations of surface area, ambient temperature, blubber thickness, energy required to warm and digest prey, etc. Calculations of this type have been made by Brodie (1975) and McAlister (1981). Metabolic studies (e.g., Miller 1978 and Ashwell-Erickson and Elsner 1981) can investigate caloric requirements in a variety of environmental, physiological, and behavioral conditions, which can then be extrapolated to annual budgets for individuals or populations. Generally speaking, metabolic studies are conducted only on small pinnipeds and small cetaceans; no direct measurements are available with which to check the accuracy of energy requirements calculated for large cetaceans.

Availability of data on food requirements of marine mammals is summarized in Table 12.1.2-1.

Table 12.1.2-1. Availability of data on food requirements of Bering Sea marine mammals.

	Observations in the wild	Quantities of stomach contents	Feeding rates of captive animals	Metabolic studies	Energetic calculations
MYSTICETE CETACEANS					
Gray whale		X	X		
Fin whale		X			X
Minke whale					X
Blue whale					X
Sei whale		X			
Humpback whale		X			
Bowhead whale					X
Right whale					
ODONTOCETE CETACEANS					
Sperm whale		X			X
Belukha		X	X		
Beaked whales					
Killer whale			X		
Dall's porpoise			X		
Harbor porpoise					X
PINNIPEDS					
Northern fur seal		X	X	X	X
Steller sea lion		X	X		
Pacific walrus		X	X		
Harbor seal		X	X	X	X
Spotted seal		X	X	X	X
Ribbon seal		X			
Ringed seal		X			
Bearded seal		X	X	X	X
CARNIVORES					
Polar bear	X				X
Sea otter		X	X	X	X

12.1.3 Population Status

A number of parameters are available which indicate the population status of marine mammals. Those that have been summarized in this report are listed in section 10.2. The reader should be aware that this list is not exhaustive; in particular, behavioral indicators were generally not included in this review. Some related aspects of marine mammal behavior and life cycles, particularly those related to phenology (i.e., timing and duration of events), were discussed in FAO (1978).

Distribution of marine mammals may be determined either through general, usually opportunistic observations or through directed surveys. Opportunistic observations are of value in determining overall range and to some extent seasonal occupancy of various parts of the range. Major changes in distribution may or may not be detected by such observations. Directed surveys are most useful for species which have restricted ranges and which are predictably visible for a large portion of the time. Determination of seasonal distribution requires repetitive surveys. If surveys are restricted to the known "normal" range of a species, distributional shifts may go unnoticed.

Reliable estimates of absolute abundance also require systematic directed surveys, which are often done from aircraft or ships. Confidence limits around mean estimates derived from surveys are usually unacceptably large (e.g., see Estes and Gilbert 1978 and Bouchet 1981). In addition, correction factors of unknown accuracy are often applied to density estimates in order to account for animals which are not visible at the time of the survey (e.g., Fay and Lowry 1981). Overall, results of efforts to date indicate that, with the exception of gregarious pinnipeds (e.g., sea lions and fur seals) and cetaceans which use very restricted migratory corridors (e.g., gray whales and bowheads), attempts to use survey data to estimate actual population size are not particularly fruitful. In the absence of directed surveys or counts, population sizes of many species have been estimated based on extrapolation of limited density observations or by "best guesses" of experienced and qualified observers. It is impossible to determine the reliability of these latter types of estimates, although the general agreement often found among qualified investigators is somewhat encouraging.

Without information on absolute abundance it may still be possible to determine relative abundance and trends in numbers for some species. The latter may be detected by counts made over time at locations where substantial proportions of the population are visible (e.g., Braham et al. 1980) or by sightings or catch-per-unit-effort data. This type of information, as well as data on historical and recent harvests, may be used to estimate the relationship between present and historical abundance (e.g., Fay 1957).

Examination of biological parameters of individual marine mammals is critically dependent on accurate determination of age. For most species of pinnipeds and carnivores, this is done by examination of annuli in teeth or claws (see McLaren 1958). By examination of parts from known age animals a relationship of one annulus per year has been confirmed. However, this method is not without error caused by interpretation of lines as shown by Doubleday and Bowen (1980). Odontocetes also show lines or bands in the teeth which can be enumerated and correlated with size and presumably age. However, some debate still exists over the number of lines formed each year (e.g., Berzin 1964b, Ohsumi 1965, Sergeant 1973). The age of some baleen whales can be estimated by lines in ear plugs, but again the relationship between the number of lines and age has not always been cleary demonstrated (e.g., Zimushko 1969a, Rice and Wolman 1971). For some species (e.g., humpback and bowhead whales), reliable techniques for determination of age are not available.

Physical measurements may be used in conjunction with age determination as indices of marine mammal growth and condition. Techniques for making such measurements are reasonably standardized, and it is likely that error associated with the measurements themselves is slight and not significant. However, a substantial amount of variation occurs in parameters such as length, weight, and blubber thickness for individuals of a particular species and age (e.g., see Smith 1973). Sources of this variability are poorly understood but include at least size at weaning, habitat quality as indicated by food availability in the immediate and long-term sense, present reproductive state, and past reproductive history.

Samples of animals of known age and reproductive condition are useful for determination of population parameters such as productivity, mortality, and sex and age structure. Accurate determination of sex and age structure of the population is critical in this instance. In virtually all reported instances, samples of the population which have been collected are biased with respect to age and sex due to differential availability, distribution, or behavior of the various age and sex classes subject to harvest (e.g., see Burns and Frost 1979). Common practice has been to combine as many samples as possible and then to smooth the data such that they approximate the expected distribution of individuals among age classes in a stable situation. This undoubtedly introduces errors of unknown magnitude into estimates of productivity and mortality. However, given samples of reasonable size, relatively accurate estimates can be made of parameters such as average age at sexual maturity (DeMaster 1978).

Availability of data on indicators of population status is summarized in Table 12.1.3-1.

Table 12.1.3-1. Availability of data on indicators of population status of Bering Sea marine mammals.

	Distribution	Absolute abundance	Relative abundance	Trend	Physical measurements	Age at sexual maturity	Repro-ductive rates	Mortality rates	Sex and age structure
MYSTICETE CETACEANS									
Gray whale	2	3	2	3	2	2	2	1	1
Fin whale	2	1	2	2	1	2	2	1	1
Minke whale	1	1	1	1	1	1	1	1	1
Blue whale	2	1	2	2	1	1	1	1	1
Sei whale	2	1	2	2	2	2	2	1	1
Humpback whale	2	1	2	1	1	1	1	1	1
Bowhead whale	1	2	2	1	1	1	1	1	1
Right whale	1	1	2	1	2	1	1	1	1
ODONTOCETE CETACEANS									
Sperm whale	2	2	2	2	2	2	2	2	2
Belukha	2	2	2	1	1	2	1	1	1
Beaked whales	1	1	1	1	1	1	1	1	1
Killer whale	1	1	1	1	1	1	1	1	1
Dall's porpoise	2	2	2	1	2	1	1	1	1
Harbor porpoise	1	1	1	1	1	1	1	1	1
PINNIPEDS									
Northern fur seal	3	3	3	2	3	3	2	2	2
Steller sea lion	2	2	2	2	2	1	1	1	1
Pacific walrus	2	3	2	2	2	3	2	1	2
Harbor seal	2	2	1	1	2	2	1	1	1
Spotted seal	2	2	1	1	2	2	2	1	1
Ribbon seal	2	2	1	1	2	2	2	1	1
Ringed seal	2	2	1	1	3	3	3	2	2
Bearded seal	2	2	1	1	2	3	3	2	2
CARNIVORES									
Polar bear	2	2	1	1	2	3	2	1	1
Sea otter	3	3	2	2	2	2	2	1	1

3 = extensive data; 2 = moderate data; 1 = little or no data

12.2 Data Requirements and Utility

12.2.1 For Conceptual Assessments

It is comparatively easy to document which species of marine mammals consume commercial fish species. Analysis of opportunistically obtained specimens and observations of distribution and behavior of animals in fishing areas are usually adequate to detect which target species are eaten by marine mammals. For most species a careful evaluation of all available food habits data can provide a semi-quantitative assessment of the dietary importance of commercially exploited prey, as has been done by Fiscus (1979, 1980), Frost and Lowry (1981a), and Lowry and Frost (1981). An evaluation of this type for Bering Sea marine mammals and fisheries is given in Table 12.2.1-1, based on the data summarized in section 11.0. However, such an evaluation must be accepted with caution since reasonably adequate descriptons of diet for mammals of the Bering Sea, including at least seasonal and geographical resolution, are available only for fur seals and perhaps ringed seals, bearded seals, and walruses (Table 12.1.1-1).

In considering the likelihood that a particular species of marine mammal may be affected by Bering Sea commercial fisheries, three factors other than the types of food consumed appear to be of major importance. Those are:

1) Feeding strategy; i.e., specialist vs. generalist

2) Overall importance of feeding which occurs in the Bering Sea in the annual nutrition of individuals and the population

3) Relationship of the present population to carrying capacity; i.e., is per capita food availability presently limiting population size?

Given the presently available data base, these factors cannot be rigorously evaluated. They can, however, be assessed to some degree based on data in section 11.0. For example, although many types of prey are eaten by both walruses and bearded seals, walruses obviously specialize in clams, while bearded seals can and do eat large amounts of clams, shrimps, crabs, snails, and fishes. Minke, fin, and humpback whales are generalists, while right and bowhead whales are much more specialized.

Although distinctions are not completely clear-cut, residency of Bering Sea marine mammal species can be largely classified into three categories: 1) year-round residents (harbor seal, ribbon seal, sea lion, some belukha whales, Dall's porpoise, and harbor porpoise); 2) summer seasonals (fur seals, sperm whales, and all baleen whales except bowheads); and 3) winter seasonals (ringed seals, bearded seals, most walruses, and bowhead whales). Generally speaking, feeding in the Bering Sea is most important for resident species and summer seasonals,

Table 12.2.1-1. Importance of present and potential commercial fishes and shellfishes in the diets of Bering Sea marine mammals.

	COMMERCIAL FISH SPECIES/GROUP											
	Present								Potential			
	Ground-fish	Herring	Salmon	Halibut	Squid	King crab	Tanner crab	Snails	Capelin	Saffron cod	Shrimp	Clams
MYSTICETE CETACEANS												
Gray whale	0	1	0	0	0	1	1	1	1	0	1	1
Fin whale	3	3	1	0	3	0	0	0	3	2	0	0
Minke whale	3	2	0	0	2	0	0	0	2	1	0	0
Blue whale	0	1	0	0	1	0	0	0	1	0	0	0
Sei whale	1	1	0	0	1	0	0	0	1	1	0	0
Humpback whale	3	3	1	0	1	0	0	0	3	3	1	0
Bowhead whale	0	0	0	0	0	0	0	0	0	0	0	0
Right whale	0	0	0	0	0	0	0	0	0	0	0	0
ODONTOCETE CETACEANS												
Sperm whale	2	1	1	1	3	1	1	0	1	0	0	0
Belukha	2	3	3	1	1	0	1	1	2	3	2	0
Beaked whales	1	0	1	0	3	0	0	0	0	1	0	0
Killer whale	2	2	2	1	1	0	0	0	1	1	1	0
Dall's porpoise	2	2	1	0	3	0	0	0	3	0	1	0
Harbor porpoise	2	2	1	0	1	0	0	0	2	3	1	0
PINNIPEDS												
Northern fur seal	3	2	1	0	3	0	0	0	3	0	0	0
Steller sea lion	3	2	1	1	1	0	0	0	2	1	1	0
Pacific walrus	0	0	0	0	0	1	1	2	0	0	1	3
Harbor seal	3	3	1	1	1	0	0	0	3	0	2	0
Spotted seal	3	3	1	0	1	0	0	0	3	3	2	0
Ribbon seal	3	1	0	1	2	0	0	0	2	2	3	0
Ringed seal	1	1	0	0	1	0	1	0	1	3	3	0
Bearded seal	1	0	0	0	0	1	3	2	0	1	3	3
CARNIVORES												
Polar bear	0	0	0	0	0	0	0	0	0	0	0	0
Sea otter	1	0	0	0	0	2	2	2	0	0	0	2

3 = Known major
2 = Potentially major
1 = Known or potentially minor
0 = Probably not eaten

although winter feeding in the Bering is considered important for ice seals and walruses. Summer feeding in the Bering Sea may be somewhat optional for most baleen whales since their relative summer distributions in the Bering and North Pacific appear to fluctuate in different years, presumably based on where optimum feeding conditions exist (e.g., see Bryant et al. 1981).

We have considered two factors as indicative of the relationships of populations to carrying capacity. First is the present abundance compared to historical levels as indicated by direct estimates of population sizes or by harvest records. Second is the recent trend in abundance. Obviously, it is unlikely that a population that is increasing in numbers or is at a low level compared to previous abundance will presently be limited by food availability. Where no data on abundance are available, we have considered populations to be stable and at abundance levels comparable to historic.

We have assigned ranked values to feeding characteristics, based on whether they suggest a probable interaction with fisheries, and to population size and trend values, based on whether they indicate probable food limitation (Table 12.2.1-2). A species which is stenophagous on commercially exploited prey, uses the Bering Sea as a major feeding area, and is near carrying capacity would receive high ranks (maximum total of 15). Conversely, a mobile and omnivorous species which consumes prey not exploited by fisheries, feeds only briefly in the Bering Sea, and is below carrying capacity would receive low ranks (minimum total of 5).

Results of this analysis, considering all factors combined (Table 12.2.1-3), produce total rank values ranging from 13 (highest probability of significant interaction) to 8 (lowest probability of interaction). Characteristics of species in each of the rank values will be briefly discussed as categories 1 (ranked value of 13) through 6 (ranked value of 8).

Category 1

Based on this assessment, the species for which there is greatest potential for interaction are the northern fur seal, Steller sea lion, and harbor seal. For all three species the Bering Sea is a major feeding area, and commercially exploited fishes (principally pollock, herring, and salmon) comprise substantial portions of the diet. In addition, although they are somewhat opportunistic, much of their intensive feeding may be limited by the proximity of terrestrial hauling areas. Based on available data, populations are probably at levels close to carrying capacity, and reductions in prey abundance would be likely to affect ingestion rates and population productivity.

Table 12.2.1-2. Criteria for assigning ranked values of the likelihood of marine mammal-fishery interactions in the Bering Sea. Low values indicate that the described characteristics suggest a low probability of significant interactions.

	Feeding			Relation to carrying capacity	
Rank value	Composition of the diet	Feeding strategy	Importance of Bering Sea as feeding area	Relative population size	Population trend
1	Feed principally on noncommercial species	Omnivorous with high mobility of predators and prey	Important only for a small fraction of annual nutrition or feeding available elsewhere	Greatly reduced	Increasing
2	Feed moderately on commercial species	Moderately diverse diet (opportunistic)	Moderately important	Slightly reduced	Stable
3	Feed heavily on commercial species and use size classes similar to those targeted on	Stenophagous or with low mobility of predators and prey	Major feeding area without other regular or optional feeding grounds	Comparable to historic	Declining

Table 12.2.1-3. Ranked values of the likelihood of marine mammal-fishery interactions in the Bering Sea, based on characteristics of feeding and population status.

	Feeding			Status		
Species/group	Diet composition	Feeding strategy	Bering Sea importance	Relative size	Population trend	Total
MYSTICETE CETACEANS						
Gray whale	1	3	3	3	1	11
Fin whale	2	1	2	1	2	8
Minke whale	2	1	2	2	2	9
Blue whale	1	3	1	1	2	8
Sei whale	1	3	1	1	2	8
Humpback whale	2	1	2	1	2	8
Bowhead whale	1	3	1	1	2	8
Right whale	1	3	1	1	2	8
ODONTOCETE CETACEANS						
Sperm whale	1	1	2	2	2	8
Belukha	3	2	2	3	2	12
Beaked whales	1	1	2	3	2	9
Killer whale	2	1	1	3	2	9
Dall's porpoise	2	2	2	2	2	10
Harbor porpoise	3	1	3	3	2	12
PINNIPEDS						
Northern fur seal	3	2	3	2	3	13
Steller sea lion	3	2	3	2	3	13
Pacific walrus	1	3	3	3	1	11
Harbor seal	3	2	3	3	2	13
Spotted seal	2	2	3	3	2	12
Ribbon seal	2	2	3	2	1	10
Ringed seal	1	1	2	3	2	9
Bearded seal	2	1	2	3	2	10
CARNIVORES						
Polar bear	1	2	1	3	2	9
Sea otter	2	2	3	3	2	12

Category 2

Species in this category also rely on the Bering Sea as an important feeding area and are thought to be presently near carrying capacity. In the case of the sea otter the probability of interactions with fisheries is lessened slightly due to a moderate proportion of commercial species in the diet. Although belukha and harbor porpoise forage extensively on commercial species, their mobility may reduce the probability of significant interactions. We have considered that commercial species comprise only a moderate portion of the diet of spotted seals since much of their feeding occurs in the northern Bering Sea and is concentrated on species that are not presently fished commercially.

Category 3

The gray whale and walrus share a number of common characteristics. Population sizes of both are at, if not above, historical levels and may still be increasing. The Bering Sea is a major feeding area for both, and they show little feeding plasticity, specializing in comparatively sedentary invertebrates which are of no present commercial importance. Nonetheless, commercial fishing or other activities which either directly or indirectly affect populations of their prey could have major effects on the status of walrus and gray whale populations.

Category 4

Species in this category exhibit a variety of characteristics. Placement of Dall's porpoise in this category rather than the previous one is based on the judgment that the Bering Sea is of only moderate importance for feeding since animals in the Bering Sea comprise only a small portion of the North Pacific population. In any event, the population is probably somewhat reduced due to mortality caused by direct fishery conflicts and is less likely to be food limited. The Bering Sea is an important feeding area for ribbon seals, and a substantial portion of their known diet consists of commercially harvested species. However, their population size, although it has recently increased, may still be somewhat below historical levels. Bearded seals are highly omnivorous and include only a moderate proportion of commercial species in their diet.

Category 5

The species in this category, killer whale, minke whale, beaked whales, ringed seal, and polar bear, do not depend extensively on commercially harvested species, depend only in part on the Bering Sea for their annual nutrition, and are relatively mobile and opportunistic in their feeding.

Category 6

This category includes the sperm whale and all species of baleen whales except the minke and gray whale. Populations of the included baleen whales are all greatly reduced, which suggests that they are presently far below the point of food limitation. Species that eat commercially exploited fishes (fin and humpback whales) are highly mobile and opportunistic, while the prey of more stenophagous species (blue, sei, bowhead, and right whales) are not commercially harvested. Based on available information, the sperm whale is relatively euryphagous and concentrates its feeding on noncommercial species.

12.2.2 For Calculations of Amounts of Fishes Consumed

In instances where marine mammal diets include substantial amounts of commercially exploited species, it is valuable to know the actual quantities of those species consumed. Although the degree of complexity included can vary considerably (see section 9.5.2.1), such calculations are based on the simple equation:

$$\text{Amount of prey consumed} = \text{biomass of predator} \times \text{food consumption rate} \times \text{proportion of prey species in diet}$$

Methods of estimating input values for each data category on the right side of the equation are summarized in Table 12.2.2-1. Obviously, the data inputs can be based on estimations and measurements of varying refinement. The accuracy of results depends not only on the methodology used to derive input values but also on the variation associated with measured values and errors involved in estimations.

Swartzman and Haar (1980) reviewed estimates of quantities of fishes consumed by fur seals and other marine mammals in the Bering Sea and Aleutian region. Ranges in estimates based on feeding information and runs of PROBUB to generate equilibrium fish stocks were 219,000-849,000 mt/yr for total food consumption by fur seals and 812,000-1,478,000 mt/yr for total fish consumption by pinnipeds. Estimates of finfish consumption by pinnipeds in the Bering Sea presented by McAlister and Perez (1976) and McAlister (1981) vary greatly (Table 12.2.2-2). Apparently, changes in estimates of fish consumption are due both to changes in methodology (especially the energetic requirements equation used in McAlister (1981)) and revised values for input parameters. It appears that the major changes in consumption estimates for Steller sea lions and ringed seals are due mostly to changes in estimated population sizes.

In order to estimate the effects of variability and errors of input parameters on the accuracy of food consumption estimates, we have used the calculations of McAlister (1981) and assigned reasonable error bounds for each input parameter, using fur seals as an example.

Table 12.2.2-1. Methods of estimating input values for calculating quantities of food consumed by marine mammals, ranked in order of increasing accuracy and utility.

Biomass of predator	Food consumption rate	Composition of diet
1. based on estimated abundance and average size	1. based on extrapolations from captive animals, observations of stomach contents, or energetic calculations without physiological studies	1. based on estimated average diet
2. based on measured abundance and average size	2. based on energetics calculations with supporting physiological studies	2. based on average diet calculated from observations of prey consumed
3. based on sex and age distribution of population and age-weight relationship for each sex	3. based on measured food consumption in the field	3. based on above, with consideration of seasonal and geographical variations
4. same as above, but gridded by area and season		4. based on above, with consideration of age- and sex-related differences

Table 12.2.2-2. Estimates of finfish consumption (10^3 mt) by pinnipeds in the eastern Bering Sea.

Species	McAlister and Perez 1976	McAlister 1981	Change
Northern fur seal	375	419	+ 44
Steller sea lion	742	129	- 613
Harbor and spotted seal	485	307	- 178
Ringed seal	246	569	+ 323
Ribbon seal	121	103	- 18
Bearded seal	148	113	- 35
Total	2117	1640	- 477

Calculations are as follows:

The general McAlister estimate for consumption by mammal species is:

$$TP_i = k_1 W_i^{k_2} \cdot CF_i \cdot 10^{-6} \text{ (metric tons/g) } [f_{si} P_{is} h(T_s) + (1-f_{si}) P_{iw} \cdot h(T_w)]$$

The equation consists of a weight effect, ($k_1 W_i^{k_2}$) times an average population estimate for summer and winter in the eastern Bering Sea, a temperature effect, and conversion factors.

TP_i = total annual predation by predator species i (metric tons/yr)

P_{is} = estimate of population for species i in eastern Bering Sea in summer

P_{iw} = estimate of winter population of species i

W_i = weight of species i (kg) (average weight assumed)

T = water temperature (°C)

T_s = average summer temperature

T_w = average winter temperature

h(T) = a function of how metabolic demand for food increases with decreasing water temperature

CF_i = conversion factor for grams of prey of i consumed per kilocalorie consumed (g/Kcal)

f_{si} = number of days of the year the summer population of species i is there

k_1, k_2 = parameters for weight effect on daily ration

Assumptions made regarding data inputs are:

1) Weight effect - McAlister assumes k_2 ranges from 0.6 to 0.63, although values as high as 0.75 were postulated by some investigators. McAlister uses k_2 = .606; we use a range of from 0.6 to 0.75; k_1 is assumed to be 437 Kcal. We assume it has a $\pm$ 10% error bound.

2) Average weight - McAlister assumes 36 kg average weight. Because the effect of weight on consumption is nonlinear, using a constant or average weight will bias consumption calculations. The

calculation using average weight will tend to overestimate the consumption rate since $\frac{\Sigma W_d^{k_2}}{n} < \left(\frac{\Sigma W_d}{n}\right)^{k_2}$ for $k_2 < 1$ where W_d is the average weight of animals of age d. The magnitude of the bias depends on k_2 and the W_d where these are the weights for the dth age class. We assume a 10% maximum overestimate and a minimum of no overestimate.

3) Population estimate - McAlister gives 4.45×10^5 and 4.5×10^4 for summer and winter populations for the eastern Bering Sea. We assume $\pm$ 20% accuracy for this estimate.

4) Temperature effect - McAlister assumes a 5% increase in consumption for each degree drop in temperature below 20°C--the standard temperature used in most energetics experiments. This is based on average animal kinetics and an observed metabolic increase from 5.8 to 6.8 Kcal per kg per degree C drop in temperature below 25°C. We assume the temperature coefficient may be between 4% and 7% increase (over BMR at 20°C) for each degree drop in temperature.

5) Temperature estimates - McAlister uses a summer temperature of 7°C and a winter temperature of 2°C for the Bering Sea. We assume maximum temperatures of 2°C and 7°C and minimum temperatures of 0°C and 6°C for winter and summer, respectively.

6) Summer and winter seasons - McAlister assumes summer and winter are each 182 days long. For a minimum consumption estimate, we assume summer to be only 150 days and winter 214 days long.

7) Conversion factor CF - McAlister doesn't give the value he used. By using all his other assumptions and calculating a total consumption of 493×10^3 metric tons, we calculated a conversion factor of 0.863 g/Kcal, which is in the range of conversion factors given for wet weight energy equivalents given by McAlister for typical seal prey (Table 8 in McAlister gives 1/CF in the range from 2.1 (herring) to 0.83 (flounder)). We assume the estimate is $\pm$ 15%, probably an underestimate in light of seasonal variability in diet and in the energy content of diet items.

With these assumptions, we have made following estimates: McAlister's estimate (TP_i) is:

$$TP_i = \underset{\substack{\text{(weight}\\ \text{effect)}}}{437\ (36)^{.606}} \cdot \underset{\text{CF}}{(.863)}\ [\underset{\text{Pop. summer}}{4.45 \times 10^5} \cdot \underset{\substack{h(T_s)\\ (7^\circ C)}}{1.65} \cdot \underset{\substack{\text{summer}\\ \text{days}}}{182}$$

$$+ \underset{\text{Pop. winter}}{4.54 \times 10^4} \cdot \underset{\substack{h(T_w)\\ (2^\circ C)}}{1.90} \cdot \underset{\substack{\text{winter}\\ \text{days}}}{182}] \cdot 10^{-6}\ \frac{\text{metric ton}}{\text{g w/w}}$$

$$= 493 \times 10^3 \text{ metric tons consumed}$$

The maximum consumption estimate (TP_{max}) is:

$$TP_{max} = \underset{\substack{\text{max. wt.}\\ \text{effect}}}{481 \cdot (36)^{.75}} \cdot \underset{CF_{max}}{1.0}\ [\underset{P_s \text{ max}}{5.34 \times 10^5} \cdot \underset{\substack{h_{max}\\ (6^\circ C)}}{1.98} \cdot \underset{\substack{\text{summer}\\ \text{days}}}{182}$$

$$+ \underset{P_w \text{ max}}{5.45 \times 10^4} \cdot \underset{h(0^\circ C)}{2.40} \cdot \underset{\substack{\text{winter}\\ \text{days}}}{182}]\ 10^{-6}\ \frac{\text{metric ton}}{\text{g w/w}}$$

$$= 1529 \times 10^3 \text{ metric tons}$$

The minimum consumption estimate (TP_{min}) is:

$$TP_{min} = \underset{\substack{\text{min. wt.}\\ \text{effect}}}{393\ (36)^{.6}}\ \underset{\substack{10\%\\ \text{bias}\\ \text{for any}\\ \text{wt.}}}{(.9)}\ \underset{CF_{max}}{.73}\ [\underset{P_s \text{ min}}{3.56 \times 10^5} \cdot \underset{\substack{h_{min}\\ (7^\circ C)}}{(1.52)} \cdot \underset{\substack{\text{min}\\ \text{summer}\\ \text{days}}}{150}$$

$$+ \underset{P_w \text{ min}}{3.6 \times 10^4} \cdot \underset{\substack{h_{min}\\ (2^\circ C)}}{(1.72)}\ \underset{\substack{\text{max}\\ \text{winter}\\ \text{days}}}{(215)}] \times 10^{-6}\ \frac{\text{metric tons}}{\text{g w/w}}$$

$$= 209 \times 10^3 \text{ metric tons}$$

The range in calculated estimates is from 209,000 to 1,529,000 mt, as compared to the "best" estimate of 493,000 mt. This suggests that, if small errors of 10-20% occur in the input parameters for a species with a good data base such as the fur seal, the total estimated quantity of food consumed may vary by as much as 730%. This is not meant to imply that the actual amount of fish consumed is likely to approximate the high or low estimate. In fact, unless all errors in assumptions are cumulative, one would expect the actual value to be closer to the best estimate than to either extreme. However, one must bear in mind the magnitude of error possible in even such simple calculations. Large errors in calculations of quantities consumed would be possible for species for which little or no data are available about parameters such as population size and residence time (see section 12.1.1).

12.2.3 For Correlative Assessments

The category which we have called correlative assessments includes determination of interactions based on concurrent measurements of changes in prey stocks and marine mammal parameters. It is obviously critical to determine that changes in prey stocks have occurred in the feeding areas of the marine mammal concerned, and, if the change is to be attributed to a fishery, data must be available to support that assumption. Although general information on fluctuations in stock biomasses in the Bering Sea is available, the data are not of the proper nature and resolution to establish that changes in food availability for marine mammals have occurred (see review in Swartzman and Haar 1980).

It is important to note three things regarding correlative evaluations. First, the values of these parameters must be known, not just in a general sense, but with sufficient accuracy and known variability that changes can be detected and their significance evaluated. Second, depending on the parameter chosen for monitoring, the lag time between the initiation of a change until the time it is discernible may be as much as several years (e.g., see Bowen et al. 1981). Third, the confidence that can be put on any evaluation based on correlations between fishery and marine mammal data will depend on the strength of the correlation and the ability to exclude other possible causative factors.

Potentially useful parameters for evaluating status of marine mammal populations have been presented and discussed by Eberhardt and Siniff (1977). Swartzman and Haar (1980) have examined available indices of fur seal status with respect to their utility for determining whether fisheries have affected the population. With particular respect to marine mammal-fishery interactions, we suggest the following as possible responses of marine mammals to changing food supplies. These are approximately ranked in a decreasing order of sensitivity.

1) changes in quantity and kinds of prey consumed
2) changes in individual condition, e.g., fatness
3) changes in individual growth rates
4) changes in juvenile survival rates
5) changes in age of attainment of sexual maturity
6) changes in reproductive rates
7) changes in behavior or distribution

8) changes in mortality rates
9) changes in population size.

A major problem with use of these parameters for correlations is that single parameters may respond differently or perhaps not at all to changes in food availability. For example, if both population density and carrying capacity decline, individual growth rates could increase if the net effect is an increase in per capita food availability (Berdine, cited in Swartzman and Haar 1980).

Determination of changes in diet composition is complicated by factors discussed in section 12.1.1, with the added requirement that two accurate measurements of food composition must be made at different points in time. This will be very difficult since many, if not most, marine mammals feed on patches of several different prey types which may vary in space and time. However, with carefully controlled sampling, this may be possible for some species, especially if prey availability is measured concurrently.

Sampling and analysis problems relating to determination of indices of individual and population status were discussed in section 12.1.3. Due to problems in obtaining accurate and unbiased age samples, it is unlikely that indices requiring a knowledge of population age structure, such as survival and mortality rates, will be of much value in correlative assessments. However, for some species, particularly those that use terrestrial hauling areas, some direct assessment of mortality and survival may be possible (e.g., Fay and Kelly 1980 and fur seal data summarized in Swartzman and Haar 1980).

Although growth and condition can be determined relatively simply by measuring size, weight, and blubber thickness or blubber weight, significant individual variability in these measures may obscure trends. Fay and Kelly (1980) have suggested a recent change in blubber thickness of male walruses, and Innes et al. (in press) may have detected a change in growth rate of harp seals. Changes in individual condition will obviously be detected more rapidly by indices such as blubber thickness than by growth rates, except perhaps as growth measured during nursing or the first year of life.

DeMaster (1978, 1981) has provided formulas with which determinations and comparisons of age of first reproduction can be made. He estimated that to statistically detect changes in the average age at first reproduction of 1/2 year requires a sample size of 25 individuals in each age class for which the probability of reproducing is greater than zero but less than the maximum value. For most marine mammals there are probably four to seven such "indeterminate" age classes. To determine mean age of sexual maturity with such accuracy from examination of age and reproductive condition of a sample of individuals in a population would require a sample in excess of 1,000, assuming a 1:1 sex ratio and normal distribution of individuals in age classes. A much smaller number of known-age marked females which could be annually observed would be adequate. Reproductive rates can also be calculated from examination of age and reproductive condition of large samples, or they can be estimated from counts of females and young in birthing areas. The latter technique has been used for fur seals (reviewed by Swartzman and Haar 1980) and may also be applicable to some other species of pinnipeds. Stirling et al. (1977) have combined a variety of information to prove a decline in productivity of ringed seals in the eastern Beaufort Sea during 1974-75. Time lags between initiation and detection of effects are a major complicating factor.

Changes in distribution and abundance will be difficult to detect for most species due to many factors which ultimately result in wide confidence limits around population estimates. The variation associated with abundance estimates of Dall's porpoises based on different analytical techniques and data sets (Bouchet 1981) is a good example of this problem. Using the best estimate (i.e., showing least variability and based on the most extensive data base) for abundance of Dall's porpoises in the Bering Sea in 1978 of 46,021 ± 22,019 (mean and 95% confidence limits), a population change of approximately 44,038 individuals (95.7%) would have to occur in order to be statistically detected by a subsequent survey of comparable quality. Obviously, a change in population size will have to be well underway before it can be detected.

12.2.4 For Predictive Assessments

In this section we will primarily discuss the data requirements and the utility of available data for the construction of models useful for examining and predicting results of marine mammal-fishery interactions in the Bering Sea. The utility of models themselves has been discussed by Hammond (1980) and Swartzman and Haar (1980). Some presently available models were presented in section 9.5.2.2, and a framework for suggested development of models was presented in section 9.5.3. Since data requirements for existing models are generally well documented, we will concentrate on data needed to address the questions in section 9.5.3.

The questions relative to marine mammal-fishery interactions in the Bering Sea which we consider can be addressed by models and simulations are summarized in Table 12.2.4-1. The questions may be addressed at various levels of detail, as suggested in section 9.5.3. In the framework presented, input requirements for each question are generally distinct, while results obtained in the process of answering each provide at least part of the information required to address the next question. While recognizing the close links among the questions, we will, for the sake of organization and convenience, discuss data requirements and utility for each separately. Many of these factors have been discussed in previous portions of section 12.0.

Table 12.2.4-1. Framework for questions related to predicting interactions between marine mammals and commercial fisheries in the Bering Sea.

<u>Question 1</u>

How do fisheries and marine mammal (and other top predator) consumption affect the abundance and composition of stocks of target species and prey?

<u>Question 2</u>

How are the quantities and kinds of prey consumed by marine mammals affected by changes in prey density and composition of prey stocks?

<u>Question 3</u>

What is the effect of a change in food intake (or metabolic status) on individual marine mammal parameters such as growth, maturation, and survival?

<u>Question 4</u>

How do changes in parameters of individuals affect future marine mammal populations?

Question 1

Examination of how fisheries removals and predator consumption affect stocks of fishes and prey obviously requires data on characteristics of organisms removed from the ecosystem by both, as well as knowledge of the effects of environmental variability and interactions among organisms at all trophic levels. Development of such multi-species simulations usually suffers in varying degrees from two types of data-related problems. First, desirable or necessary data on existing characteristics and functional relationships may not be available or reliable. Second, particularly in complex ecosystems such as the Bering Sea, it is difficult to incorporate all types of available data and possible interactions into the structure of the model in such a way that the calculations are produced efficiently but still accurately simulate the ecosystem being considered. It is invariably necessary to make choices among an array of model types based on conceptions of ecosystem characteristics and availability of data (Larkins 1980, Swartzman and Haar 1980). Options which we consider of particular relevance to Bering Sea marine mammal-fishery interactions are:

1. whether or not to consider effects of environmental factors in addition to predation and fisheries; i.e., an environmentally coupled model

2. whether to consider the system as spatially homogenous or spatially segmented

3. whether to consider prey, target species, and predator stocks as well as fisheries removals only in terms of biomass or as explicit size and age classes.

The presently existing DYNUMES model is biomass based, environmentally coupled (incorporating such factors as temperature effects, starvation, and migration), and spatially gridded in blocks of 100 km^2. Use of a biomass-based model results in computational savings, while spatial gridding is costly (Larkins 1980). As discussed in section 9.5.2.2, the only marine mammal data required by DYNUMES is a single estimate of quantities various types of prey consumed. The utility of available data for making such calculations was reviewed in detail in section 12.2.2.

Based on our review of marine mammal data, it is evident that the types and size classes of fishes consumed by marine mammals may vary by geographical location and age and sex of the marine mammal. Frost and Lowry (1980) and Bukhtiyarov et al. (in press) documented probable selectivity in size of prey consumed by ribbon and spotted seals, characteristics of which may depend on the particular prey species. Seaman et al. (1982) documented differences in size of saffron cod consumed by young and older belukhas. Swartzman and Haar (1980) concluded that fur seals eat mostly pollock smaller than those taken by the fishery, while sea lions appear to eat mostly large pollock (Lowry and Frost, unpubl.). Since to our knowledge all fisheries are in some manner selective with respect to size or sex of the target species, it appears that the size and age class distribution of fishes consumed and harvested must be included in any model of the effects of such removal on prey stocks (see Level 2, Question 1, in section 9.5.3). Known geographical variability in predator diets requires the incorporation of spatial gridding. Based on availability of data, a breakdown similar to that shown in Figure 10.2-1 may be more appropriate than the small grid size used in DYNUMES. We cannot evaluate the utility of incorporating environmental factors in a model of this type. However, it seems unlikely that such considerations would greatly affect accuracy of computations. Environmental factors may best be investigated by DYNUMES or some similar model, using outputs from a spatially gridded, predation/harvesting model with explicit sex and age (or size) classes.

Critical data needs for such a model are:

1. sex and age class composition of prey and target species populations

2. sex and age class characteristics of fishery harvests

3. sex and age class characteristics of fishes eaten by marine mammals

Some information is available on sizes of prey eaten by virtually all species of marine mammals, and more is probably available in the raw data form. For some types of prey relatively straightforward techniques are available for determination of sizes consumed (e.g., Frost and Lowry 1981c).

Question 2

If it can be shown that fisheries and predation affect the abundance and characteristics of fish stocks, it then becomes of interest to know how such changes affect the quantities and kinds of food consumed by marine mammals. There is presently little conclusive information on how marine mammals respond to changing prey abundance, and, in fact, most of the available hypotheses are based on observations of other types of organisms. Information on species other than marine mammals, as well as data on marine mammals in areas other than the Bering Sea, may be of value in selecting and testing likely hypotheses. As such, we can deal only partially with this question, which undoubtedly merits a much more thorough review.

Lowry and Frost (1981) suggested that feeding patterns of most pinnipeds depend on three major interacting elements:

1. anatomical and physiological adaptations of predators which place bounds on their ability to capture prey

2. characteristics of prey populations, particularly their patterns of distribution and abundance

3. behavioral adaptations of species, in particular predator-prey interactions

They suggest that much of what is observed at the empirical level as variations in a marine mammal's diet is explained by factor 2 above. The examination of feeding strategy therefore requires not only observations of foods eaten but concurrent measurements of availability and characteristics of prey. Relevant information located during this project will be briefly discussed as it relates to each of the optional hypotheses presented in section 9.5.3.

The optimal foraging hypothesis considers that predators take the types of prey that will maximize the caloric gain per unit of time spent feeding. It appears that life history strategies of most marine mammal species are adapted to take advantage of optimum foraging conditions. Perhaps the best example of this is the seasonal feeding and fasting pattern of most large whales (Brodie 1975). The seasonal distribution of many piscivorous pinnipeds (e.g., harbor, spotted, ringed, and harp seals) and some odontocetes (belukhas and harbor porpoises) appears closely correlated with concentrations of spawning pelagic and semi-demersal fishes. In such spawning areas, fishes may be most easily and rapidly located and consumed, and are in addition likely to have the maximum caloric value. Characteristics of bearded seal predation on tanner crabs may be relevant in this context. Lowry and Frost (unpubl.) have observed that bearded seal stomachs often contain only abdominal flaps of ovigerous female crabs, suggesting that the caloric gain of catching and processing the egg mass is greater than that obtained by utilizing the entire animal. Stirling and McEwan (1975) have suggested that polar bears optimize the caloric value of their food by eating primarily the blubber of seals. Since most marine mammal species maintain significant energy reserves in the form of blubber, optimal foraging for them must be viewed more on an annual rather than a daily or instantaneous basis.

The hypothesis that prey consumption drops as a function of total prey density has intuitive appeal and is fairly easy to incorporate into models. Accurate sampling of prey density and consumption rates is obviously critical. This type of response may occur in the spring feeding of ribbon seals in the Bering Sea (Frost and Lowry 1980). Frost and Lowry (unpubl.) have data on quantities of arctic cod in ringed seal stomachs, as well as some concurrent indices of cod abundance. Although major regional differences occur in quantities of cod in stomachs, comparisons of individual stomach contents with measures of prey availability have been inconclusive. However, general observations of a variety of species suggest that most intensive feeding occurs when and where prey are abundant.

It has been postulated that in some instances the preference of a predator depends primarily on the relative size of predator and prey. Although most species are size selective in some fashion, the utility and relevance of this hypothesis with respect to marine mammals is open to question. Without a rigorous review, it is apparent that prey consumed by many species range in weight over at least three orders of magnitude. An obvious extreme example is the killer whale, which feeds on organisms ranging in size from herring to blue whales. Frost and Lowry (unpubl.) have collected ringed seals whose stomachs contained thousands of amphipods with an average individual weight of 0.01 g, while Smith (1977) documented a ringed seal feeding on a wolffish (Anarhichas sp.) which was longer than the seal and weighed 13.6 kg with some portions missing. Modeling of ingestion based on prey size may be of some value for baleen whales where physical characteristics of the baleen may affect the efficiency with which various sized prey can be caught.

The possibility that marine mammals respond to changes in prey abundance through behavioral compensations such as migrating or changing prey selectivity appears quite likely in some cases. The utility of such assumptions with respect to simulating changes in ingestion is unclear. Migrating to where preferred prey are adequately abundant might result in no change in diet, while postulating changes in preference requires a consideration of possible mechanisms, some of which have been discussed above. General observations of the relationship between abundance of marine mammals and their prey usually indicate a close correlation for mobile species. However, environmental constraints on appropriate habitat limit the magnitude of movement, which is also dependent on life history characteristics of the species and individual parameters such as physical condition and reproductive status. Most cetaceans are comparatively free to range throughout the year, while pinnipeds are generally restricted during the pupping and breeding seasons to relatively specific habitats.

Question 3

The question of how biological parameters of individual marine mammals respond to changing ingestion rates is central to any prediction of how populations may respond to changing food availability. As such, this is a special case of determining the nature of density-dependent responses in marine mammals. In section 9.5.3 we proposed two levels at which this question may be addressed. The first level is an empirical model involving correlation of some measure of food intake with some particular parameter. Therefore, data requirements are generally similar to those discussed under correlative assessments (section 12.2.3), and the utility of conclusions drawn from such models will be limited by similar problems. In our review of data from the Bering Sea, the only information we found which is potentially useful for such an assessment is the data on blubber thickness and mortality of walruses presented by Fay and Kelly (1980). Some relevant information may become available from further analysis of fur seal data (see

Swartzman and Haar 1980), and relevant information is available from other species and areas, as has been discussed elsewhere in this report.

The second possible level of consideration involves a model which uses energetics information to simulate how energy from ingested prey is allocated among maintenance, growth, and reproduction. Fairly detailed energetics information is available for some species (e.g., Lockyer 1976c and Ashwell-Erickson and Elsner 1981), which has primarily been used for the estimation of amounts of prey required for growth and maintenance of individuals and populations. In the proposed model, information of this type is used in the reverse direction; i.e., to simulate how changing ingestion rates affect growth, maturation, reproductive success, and survival. In addition, less complete data sets can be used to check hypotheses with respect to mechanisms of energy allocation and probable thresholds which affect allocations. Further conceptual development of this type of model is required before a detailed discussion of data requirements and utility can be given.

Question 4

Addressing the question of how changing parameters of individuals may affect future marine mammal populations is in some ways the most straightforward. Simulation of such effects using a Leslie matrix requires basic population data (e.g., sex and age structure and age-specific reproductive and mortality rates), the availability and utility of which were discussed in sections 12.1.3 and 12.2.3. In addition, some assumptions must be made with respect to how these parameters change in response to ingestion, which is the weak link since, as noted above, little if any useful data on this topic are available for marine mammals in the Bering Sea. The Monte Carlo simulation model suggested in section 9.5.3 depends entirely on results from the energetics model discussed in question 3 above and likewise cannot be discussed in detail at the present stage of development.

12.3 Major Data Gaps

12.3.1 Diet Composition

Based on our evaluation (Table 12.1.1-1), a description of the diet for most species of Bering Sea marine mammals will be based on little data. For several species (minke whale, bowhead whale, beaked whales, killer whale, harbor porpoise, and Steller sea lion) we consider available data inadequate even for a nonquantitative description. The lack of data on those species is due largely to the fact that most of them have not been targets of significant commercial or subsistence harvesting in the Bering Sea. Although some information is available on seasonal and regional dietary variations, for many species, with the exception of the fur seal and perhaps the walrus, ringed seal, and bearded seal, available data are not adequate for a quantitative estimate of the overall Bering Sea diet. Analysis of existing specimens and data may substantially increase information available for Dall's porpoises and Steller sea lions. An assessment of general feeding strategy can be made for all species; however, information on prey selectivity is scant, primarily due to the lack of concurrent prey sampling in most food habits studies.

12.3.2 Food Requirements

Estimates of food or energy requirements are available for all species except beaked whales (Table 12.1.2-1). These estimates may be derived from one or more techniques. For large cetaceans they are generally based on calculated energetic requirements, sometimes with consideration of observed stomach contents and feeding periodicity. Information on feeding rates of captive animals is available for most small cetaceans and pinnipeds. More relevant data from this source are undoubtedly generated daily in numerous oceanaria. Particularly good information on energy requirements is available for fur seals, harbor seals, spotted seals, ringed seals, and sea otters, all of which are small in size and easy to maintain in experimental situations.

12.3.3 Population Status

Some information on indicators of population status is available for most species of Bering Sea marine mammals. The principal exceptions are species which have not been significantly harvested (minke whale, beaked whales, killer whale, and harbor porpoise). Information on sex and age structure and mortality rates is particularly lacking for most species due to the difficulty of accurately sampling the population. Extensive or moderate data are available on distribution, abundance, physical measurements, and age at sexual maturity for most species of pinnipeds. Less data are available on those subjects for most cetacean species.

13.0 DISCUSSION AND CONCLUSIONS

13.1 Overview

There is no question that competition occurs when fisheries harvest species that are significant components of marine mammals' diets. Other, more complex interactions are possible, but they cannot appropriately be termed competition, which refers only to mutual attempts to gain a common object or goal. Even in the simplest cases it has proven extremely difficult to measure the magnitude of competition or to assess the likely effects on fishery harvests and marine mammal populations. This is due in large part to an inadequate data base on fishery harvest characteristics and the biology of target species and their predators. Also, available theory and models are deficient in at least two respects. First, there is at present little understanding of how marine mammals obtain their foods (especially in relation to changing prey abundances) and how the energy obtained from feeding relates to growth, maturation, reproductive output, and survival. Secondly, ecosystem models, which are needed to integrate environmental and biological factors and simulate effects of changes in various factors on system components, are at a primitive stage of development. Although ecosystem simulations are beginning to appear, they generally are difficult to understand, costly to develop and use, involve untested assumptions, and have not been verified with respect to how accurately the simulation corresponds to the actual ecosystem. Their present utility for management purposes is therefore open to question.

In some particular instances, observations have been made which suggest the probable nature of marine mammal-fishery interactions. Fay and Lowry (1981) present information which suggests that, although a commercially viable surf clam resource exists in southern Bristol Bay, successful development of a fishery is unlikely since walruses in the area are presently consuming in excess of the estimated sustained yield of the stock. Since a fishery would be size selective and limited to harvesting at or below the MSY level, it would likely have a less drastic impact on the clam resources than walruses, which consume all size classes of clams and whose annual consumption may exceed MSY several fold. Similarly, it has been adequately demonstrated that sea otters in California have a dramatic impact on commercial yields of some shellfishes, and, in fact, the presence of otters simply prevents significant human utilization of some species such as abalone (*Haliotis* spp.) (FAO 1978). Unfortunately, these examples deal with species that prey on sessile and weakly motile organisms and may not be relevant to interactions involving more motile prey such as finfishes, squids, and shrimps. The sampling required to detect the latter type of interaction is far more difficult.

Power and Gregoire (1978) have published a very significant study of the impact of freshwater seals on the fish community of Lower Seal Lake, Quebec. By comparisons with neighboring lakes, they determined that harbor seal (Phoca vitulina mellonae) predation has greatly modified the fish community by selecting "against species that are lake spawners and whose reproductive behavior results in aggregations of large mature fish at specific times and places in the lake." The population of lake trout (Salvelinus namaycush) has been most affected and "displays an almost classic response to overexploitation." They consider that the seal population consumes the potential fish yield annually and indicate that fishing in Lower Seal Lake is notoriously poor.

It therefore appears quite likely that marine mammals will affect fisheries, at least in some instances. Direct competition will occur when humans attempt to harvest the same species and sizes of organisms that are consumed by marine mammals. Populations of marine mammals existing at carrying capacity are likely to preclude commercial fisheries for their principal prey. In addition, baleen whales in particular prey on organisms which are major foods of commercially important fishes and may therefore affect exploitable stocks. However, it is important to recognize that some marine mammals may enhance fishery yields if they prey on predators or competitors of commercially desirable species. For example, sea otters consume invertebrates which feed on kelp (Macrocystis spp.), thereby enhancing development of kelp plants, which are harvested and used for various products. Although seals in Lower Seal Lake reduced the lake trout population, they apparently had little if any impact on brook trout (Salvelinus fontinalis), whose spawning sites are dispersed in tributary streams (Power and Gregoire 1978). In the Bering Sea, marine mammals consume considerable amounts of capelin and sand lance, which are probably trophic competitors of herring and pollock. Harbor seals and other marine mammals prey on cod which are commercially valuable but are also predators on juvenile king and tanner crabs.

Although it is known that fisheries usually affect the abundance and characteristics of target species stocks, we have located no conclusive evidence of instances where fisheries have affected marine mammal populations through alteration of their food supply. Schaeffer (1970), working in a relatively simple system with direct trophic linkages, has documented an impact of the Peruvian anchovetta (Engraulis ringens) fishery on guano birds. The lack of detectable impact of fisheries on marine mammals may be due in part to plasticity in diet and feeding strategy of many mammals and to the complexity of trophic connections in most ecosystems. There is no question that the sea otter, a species with a diverse and adaptable diet, has been able to expand into areas where some of their prey were being fished commercially. However, it has been suggested that the pollock fishery has prevented expansion of the Pribilof fur seal population. Obviously, as discussed above, direct competition is most likely when mammals and fisheries exploit the same species and size classes. Other possible effects of fisheries on the food resources of marine mammals are more difficult to conceptualize and evaluate. Harvests by fisheries may reduce food availability for one marine mammal species while enhancing prey abundance for one or several others. Harvests which reduce total stocks of pelagic and semi-demersal finfishes are likely to enhance availability of copepods and euphausiids for baleen whales, and the juvenation (shift in biomass from older to younger age classes) of pollock stocks may favor pinnipeds which prey on small pollock.

Many, if not most, major commercial fisheries have developed in areas where mammal populations have previously been reduced, and, in fact, exploitation of the presumed available surpluses resulting from such reductions is presently a major consideration in developing fisheries in areas such as the Antarctic. It is quite possible that the large pollock population in the Bering Sea has been fostered by reduced competition for food from large whales and perhaps reduced predation by fur seals and ribbon seals. Whether or not populations of other zooplankton and fish predators (e.g., seabirds, belukha whales, harbor porpoises, sea lions, and harbor seals) might have experienced and responded to increased prey availability is not known. Obviously, the Bering Sea is not a pristine ecosystem and the carrying capacity for each species as well as the interactions among species may not be what they were 50 or 100 years ago. These factors have undoubtedly changed many times, for example with the periodic exposure and flooding of the Beringian platform.

Agencies and persons concerned with maintaining healthy and stable marine ecosystems must choose the optimum method for allocation of resources among humans (= fisheries) and marine mammals. Although choices may sometimes be fairly clear, as in the case of the sea otter, this is far from true in the Bering Sea as a whole, where one must be concerned with optimizing populations of 26 species of marine mammals and harvests of nearly that number of other marine organisms. A comparison of past and present mechanisms and policies for fishery management suggests that the present situation is overall unlikely to negatively affect marine mammals. Provisions of the FCMA provide for the rebuilding of depleted stocks and harvests from those and other stocks in such a way that a sustained, optimum yield results. Indeed, present harvests include mostly traditionally exploited species, and overall harvest levels are below those of the recent past. Similarly, proximate plans for development of Bering Sea fisheries, i.e., a transfer of the allowable harvests from foreign to domestic fishermen, are unlikely to produce major direct impacts on mammal populations, although relevant economic and political factors may change.

Management philosophies and options for marine mammals are much less clear cut. Population status is generally considered in relation to carrying capacity, which is a dynamic, variable, and scarcely understood parameter and appears in some ways to be a poor choice for a benchmark. Other indicators such as the maintenance of marine mammals as significant functional elements of ecosystems defy quantification. Considerations of ecology, economics, and risk will have to be blended when attempting to manage fisheries and marine mammal populations in an optimum manner.

13.2 Food Consumption by Marine Mammals

Estimates of quantities and kinds of foods consumed by Bering Sea marine mammals have been used for two primary purposes. McAlister and Perez (1976) and McAlister (1981) have used such calculations to compare mammal predation with fishery harvests, while Laevastu and Favorite (1977) use estimates of mammal (and other top predator) consumption to drive a model which estimates sizes of fish stocks (PROBUB). Although these efforts involve the same agency (NMFS) and ultimately rely on the same data base, they do not utilize identical data sets as input parameters, and they use different mechanisms for calculating marine mammal consumption. Since they are presumably closely related with respect to reliability, we have concentrated on the report of McAlister (1981), which is most recent and generally more thoroughly documented. The reader should be aware that this is a draft report which, according to the author, contains only provisional data.

As discussed in section 12.2.2, calculations of amounts of food consumed depend on feeding rates, diet composition, and population abundance. McAlister (1981) produced formulae for computing food requirements based on the relationship between energetic needs and animal weight and environmental temperature. The assumption that energy requirements of all species increase with decreasing temperature appears highly questionable since Gallivan and Ronald (1979) have shown that harp seals have a thermoneutral zone spanning at least 28°C. Estimates of consumption rates based on captive animals might in some instances be substantially more accurate since available data indicate a fairly narrow range (see section 12.1.2).

Difficulties with respect to estimating the average diet composition of a species were discussed in section 12.1.1. In most cases (i.e., with the exception of the fur seal), we are unable to determine how McAlister (1981) utilized published data on foods consumed at specific areas and seasons to generate an average which reflects the seasonal distribution, abundance, and foods of a particular species. In most cases we do not consider the data adequate to generate an accurate average Bering Sea diet. In addition, the principal fishes eaten by some species such as ringed and bearded seals are not now commercially utilized but nonetheless are included in total finfish consumption, which can be misleading if compared to fishery yields or to estimated stocks of fishes in the area if non-commercial species are not included in the estimate of total finfish stocks.

It is difficult to accurately determine the size of most Bering Sea marine mammal populations. For example, in our review the only cetaceans for which we located published data relating to abundance in the Bering Sea were the Dall's porpoise, belukha whale, gray whale, and bowhead. In the case of Dall's porpoise, the mean estimate is subject to very wide confidence limits. For many pinnipeds (e.g., harbor, spotted, ribbon, ringed, and bearded seals and walruses), available Bering Sea population estimates are conservative abundance estimates made for management purposes, which may be far lower than the actual population size. In cases where published estimates apply to entire populations which may include other regions, it is unclear how one can determine the numbers actually occurring in the Bering Sea.

Even if adequate data were available on food requirements, diet composition, and population size of marine mammals, some degree of variability will be associated with measurements of the values. As we have demonstrated in section 12.2.2, the cumulative effect of variations in individual assumed values can result in very wide error bounds on the estimate of total food consumption.

We are forced to conclude that, with the available data base and methods and assumptions used in calculations, present estimates of finfish consumption by marine mammals are not reliable, and great caution should be exercised if they are to be used as an index of interactions between marine mammals and fisheries. We further conclude that marine mammal consumption estimates are not adequate or reliable for inputs to ecosystem models and that outputs from such models are highly questionable and should not be used for management. Although it is probable that improvements in calculations, methodology, and the data base can and will occur, it seems unlikely that accurate estimates will be easily attained. The degree of error which is acceptable in such estimates has not been determined.

13.3 Ecosystem-based Management and Predictive Assessments

Although it is a highly desirable long-term goal, ecosystem-based management which incorporates interactions among marine mammals and commercial fisheries is not presently practical for the Bering Sea. In fact, functional ecosystem models have yet to be developed and verified for much simpler marine systems or even for well-known terrestrial ecosystems. Present limitations of data and theory are so severe as to preclude most consideration of even partial segments of ecosystem-related questions. For example, the nature and magnitude of density-dependent responses of marine mammals are virtually unknown, and it has not been shown that any Bering Sea marine mammal population is limited by food availability.

Problems associated with DYNUMES (including its subsidiary models), the Bering Sea ecosystem model presently being developed, have already been discussed. To summarize, DYNUMES considers marine mammal consumption as constant inputs, which are used to set initial conditions in the simulation. It provides no mechanisms by which the effects of changing food availability on marine mammals can be investigated. It deals with fish stocks and fisheries and not with marine mammal-fishery interactions. As discussed in section 13.2, the questionable reliability of marine mammal consumption estimates, which are critical to the simulation, gives cause to question the utility and reliability of model outputs which depend on initial fish stock sizes since these are calculated from marine mammal consumption estimates.

Other models potentially useful for examining marine mammal-fishery interactions were discussed in section 9.5.2.2. In general, these are not ecosystem simulations but rather serve to organize ecosystem components in terms of their biomasses and trophic relationships. Effects of harvesting or other perturbations at various trophic levels may then be investigated. The utility of such models with respect to the Bering Sea has not been demonstrated. Due to the trophic diversity of the Bering Sea ecosystem, food webs are exceedingly complex and difficult to describe accurately, which will therefore require considerable "lumping" of organisms at various trophic levels. Although conceptually convenient and probably necessary, such a combining of distinct species greatly reduces the utility of a model for management purposes. For example, it is of little use to know that intensive fishing on pollock will reduce the biomass of pollock predators without knowing whether the affected predator species is a seabird, seal, or whale, and how the effect will be expressed.

In section 9.5.3 we presented a suggested framework for models addressing effects of fisheries on marine mammals, which were discussed more fully in section 12.2.3. Basically, this "system" begins with a sex- and age-class specific model which simulates the effects of predation and harvests on fish stock characteristics. The effect of altered fish stocks on population status of a marine mammal species is then considered by simulating: 1) the effect of changing fish stock characteristics on predator ingestion rate; 2) the effects of changed ingestion rates on growth, maturation, reproductive output, and survival; and 3) the result of changing vital parameters of individuals on the status of marine mammal populations. Although largely a single-species approach, separate consideration of these largely discrete and more manageable unit questions will probably yield information of practical value more quickly than attempts to simulate the interactions as a whole. For example, if the ingestion rate of a particular mammal species is found to be independent of prey availability over the entire range of anticipated prey stock fluctuations, commercial fishery activities are very unlikely to affect that species. Information gained from studies of other species and other ecosystems is likely to be of great value in developing and testing hypotheses to address these questions.

Finally, it is important to realize that results from a variety of types of models may be coupled in order to assess interactions among environmental factors, harvest policies and levels, and fish and mammal populations. For example, compartment trophic-level models may be used to predict fluctuations in zooplankton stocks, the effects of which on baleen whales can then be investigated using selection-ingestion-energetics models. The optimum blend of models may depend on the required resolution of results, as well as the specific mammal species and fishery being considered. Results from any and all modeling and simulation effects may be of value in the formulation of questions and directing of research.

13.4 Correlations and Monitoring of Effects

Although some data exist which indicate changes in status of marine mammal populations, it has proven very difficult to correlate such changes with activities of commercial fisheries. In fact, for a variety of reasons discussed in section 12.2.3, it is unlikely that such correlations will ever be conclusive. It is possible, in fact likely, that many observed changes in marine mammal population status will be due to "natural" factors that have no relation to commercial fisheries. Such appears to have been the case in the decline of ringed seal abundance and productivity in the eastern Beaufort Sea (Stirling et al. 1977) and the recent changes in physical condition of walruses (Fay and Kelly 1980).

Nonetheless, it appears advisable to document feeding ecology and vital parameters of species for which interactions with fisheries appear likely. Monitoring of such parameters may signal impending changes in population status regardless of whether or not the cause can be determined with certainty. In addition, the data obtained will be of considerable value for refining estimates of consumption of commercially important prey and for development and testing of models relative to feeding strategy, energetics, and population dynamics. Although it would obviously be desirable to investigate all aspects of feeding ecology and all possible vital parameters, some prioritization based on sensitivity (i.e., likelihood of detection of changes and probable lag times) appears necessary. We suggest the following prioritization of the most sensitive parameters for monitoring:

1. composition of the diet, including quantities, kinds, and sizes of prey consumed

2. feeding behavior, such as proportion of time spent feeding, distance traveled to feeding grounds, etc.

3. individual condition as indicated, for example, by individual energy (= blubber) reserves

4. growth rates, particularly of neonates and young animals

It is important to realize that the value of monitoring any parameter will depend largely on the accuracy and statistical reliability of the data gathered.

13.5 Conceptual Assessments

A major advantage of conceptual assessments such as those in section 12.2.1 is that data of adequate resolution and reliability are often available. However, although such assessments may estimate the likelihood of an interaction occurring, they do not measure, prove, or predict the effects. Nonetheless, they are of considerable value for directing attention and research and can be easily refined as more relevant data become available. Refined estimates of the quantities and size classes of prey consumed are of particular importance. For many species it would be desirable to investigate and document specific areas where interactions occur, rather than considering the Bering Sea as a whole, which implies an unrealistic homogeneity in the ecosystem.

14.0 RESEARCH PLAN

14.1 Introduction and Rationale

The overall objective of this research plan is to devise a framework for obtaining additional data needed:

1. to determine how marine mammals may affect and be affected by existing or proposed fishery management plans for the Bering Sea, and

2. to serve as input to a Bering Sea ecosystem model, specifically DYNUMES/PROBUB.

The data needed as inputs for DYNUMES/PROBUB are the quantities of foods of various types consumed by marine mammals, which is also the most basic information required to evaluate how marine mammals may affect commercial fish stocks. Based on our review of available data it is presently possible to devise a research plan to obtain the requisite data to address this topic.

Consideration of how fisheries (or fishery management plans) may affect marine mammals will require extensive development of theory and models as well as considerable experimentation and data collection. Not all of the required data is directly related to marine mammals. We consider that it is premature at this time to attempt to devise a synoptic research plan to address this topic. We will incorporate collection of relevant marine mammal data in the following research plan and will present some suggestions for further development of ecosystem level considerations in section 14.7.

14.2 Objectives

The principal objectives of the proposed research plan are to:

1. provide basic descriptive and quantitative information on foods, food requirements, and abundance of marine mammals, particularly in areas where they interact with commercial fisheries

2. develop baseline information concerning characteristics and biological parameters of marine mammals that are useful for monitoring status of individuals and populations

3. provide information of value for examining the relationship between food availability and marine mammal feeding and status

14.3 Prioritization of Marine Mammal Species

The research plan developed must consider the practicality of gathering data as well as the proximate need for information based on the likelihood of significant interactions with fisheries. The most important factors affecting the practicality of gathering data on a particular species are distribution, visibility, size, and access to specimen material, such as reproductive and gastrointestinal tracts.

We have evaluated the probability of obtaining additional data for each species based on general considerations of presently available technology and access to specimen material (Table 14.3-1). Generally, there is a high likelihood of gathering data on pinnipeds, carnivores, and small odontocetes, while information on most large cetaceans will be difficult to obtain due to their oceanic distribution and the cessation of commercial whaling.

In section 12.2.1 we assessed the present likelihood of interaction with commercial fisheries for each marine mammal species, which is summarized in Table 14.3-2. In further development of the research plan, we will consider only 12 species for which the probability of interaction is considered moderate or high. Of those species, eight feed largely on fishes, including commercially exploited fishes, while four feed on benthic organisms, of which comparatively few are now commercially important. Aspects of ecology, including trophics, of these benthic feeders are the subject of investigations being begun by NOAA/OCSEAP (sea otter and gray whales) and being proposed to NSF (principally walruses, but including gray whales and bearded seals). We have not had the opportunity to review research plans relevant to those species and therefore will for the present eliminate them from our considerations. We will primarily consider eight species in the development of a research plan. These are:

Northern fur seal	Harbor porpoise
Steller sea lion	Spotted seal
Harbor seal	Dall's porpoise
Belukha whale	Ribbon seal

14.4 Interactions with Fisheries

When considering the eight species just listed, it is obvious that the present fisheries of greatest concern are for groundfish (including squid), herring, and to a lesser extent salmon, while the potential target species of concern are capelin, saffron cod, and shrimps (Table 12.2.1-1). These fisheries and exploitable resources can be organized according to where interactions involving harvesting and predation occur. In the offshore southern area, generally the region from the Pribilof Islands to Unimak Pass and the Aleutian Islands, major target/forage species are groundfish (principally pollock and Pacific cod), squid, shrimps, salmon, capelin, and herring. All eight marine mammal species identified

Table 14.3-1. Present probability of obtaining marine mammal data relevant to interactions with fisheries in the Bering Sea.

	Diet composition	Food requirements	Abundance	Population status
MYSTICETE CETACEANS				
Gray whale	MOD	LO	HI	MOD
Fin whale	LO	LO	LO	LO
Minke whale	LO	LO	LO	LO
Blue whale	LO	LO	LO	LO
Sei whale	LO	LO	LO	LO
Humpback whale	LO	LO	MOD	LO
Bowhead whale	MOD	LO	HI	MOD
Right whale	LO	LO	LO	LO
ODONTOCETE CETACEANS				
Sperm whale	LO	LO	MOD	MOD
Belukha whale	HI	MOD	HI	HI
Beaked whales	LO	LO	LO	LO
Killer whale	LO	LO	MOD	MOD
Dall's porpoise	HI	MOD	HI	HI
Harbor porpoise	MOD	MOD	MOD	MOD
PINNIPEDS				
Northern fur seal	HI	HI	HI	HI
Steller sea lion	HI	MOD	HI	HI
Pacific walrus	HI	MOD	HI	HI
Harbor seal	HI	HI	HI	HI
Spotted seal	HI	HI	HI	HI
Ribbon seal	MOD	MOD	HI	HI
Ringed seal	HI	HI	HI	HI
Bearded seal	HI	MOD	HI	HI
CARNIVORES				
Polar bear	MOD	HI	HI	HI
Sea otter	HI	HI	HI	HI

Table 14.3-2. Summary of probability of interaction with commercial fisheries for Bering Sea marine mammals. Species are not prioritized within categories.

Probability of interaction	Category #	Species
HIGH	1	Northern fur seal
	1	Steller sea lion
	1	Harbor seal
	2	Spotted seal
	2	Belukha whale
	2	Harbor porpoise
	2	Sea otter
MODERATE	3	Gray whale
	3	Pacific walrus
	4	Dall's porpoise
	4	Ribbon seal
	4	Bearded seal
LOW	5	Killer whale
	5	Minke whale
	5	Beaked whales
	5	Ringed seal
	5	Polar bear
	6	Fin whale
	6	Blue whale
	6	Sei whale
	6	Humpback whale
	6	Bowhead whale
	6	Right whale
	6	Sperm whale

in section 14.3 prey on one or more of those species in that region. Fishery resources in more northern offshore areas (i.e., north of St. Matthew Island) are less well known (and not presently harvested in that area) but probably include herring, capelin, saffron cod, and shrimps. Interacting marine mammal species include belukha whales, spotted seals, ribbon seals, and perhaps harbor porpoises. Some of the same target/prey species are of greatest significance when they concentrate for spawning in and near the coastal zone. In southern areas (primarily south of Nunivak Island and including Bristol Bay), major interactions involve herring, capelin, and salmon, and belukha whales, harbor porpoises, Steller sea lions, and harbor seals. In northern coastal areas (principally the Yukon River delta and Norton Sound), sea lions rarely occur and harbor seals are replaced by spotted seals. Fish species are similar, with the addition of saffron cod. These relationships are summarized in Table 14.4-1. Based on our review of available information, it appears that at present interactions are least significant in the northern area, particularly offshore where intensive feeding by marine mammals has seldom been recorded. We suggest therefore that initial attention be given to coastal and offshore interactions in the southern Bering Sea, followed in priority by coastal interactions in northern areas.

14.5 Marine Mammal Data Requirements

Four general categories of data are needed for each marine mammal species in each area identified in section 14.4. Those are:

1. distribution, abundance, and behavior in relation to distribution of fishery resources

2. species, sizes, and quantities of prey consumed in relation to availability of food

3. condition indices

4. vital parameters

The first two categories must be investigated throughout the period during which each species occurs in the area, while the latter two may be best sampled at specific times and locations. The practicality of obtaining the requisite data as well as applicable techniques will vary both by species and area.

The distribution, abundance, and behavior of marine mammals can be examined through aerial and surface observations, as well as by use of telemetry. Surveys should be designed to produce the most reliable possible estimates of abundance of numerically dominant species and will be of greatest value when combined with observations of food availability and foods consumed. Telemetry can be useful in gathering behavioral data which may be required for abundance estimates.

Table 14.4-1. Summary of marine mammal species which interact with commercial fisheries in four main regions of the Bering Sea.

	Groundfish[1]	Herring	Salmon	Capelin	Saffron cod	Shrimp
OFFSHORE SOUTH	Fur seal Sea lion Harbor seal Spotted seal Ribbon seal Belukha? Harbor porpoise? Dall's porpoise	Fur seal Sea lion Spotted seal Ribbon seal Belukha? Harbor porpoise? Dall's porpoise?	Fur seal Sea lion	Fur seal Sea lion Spotted seal Ribbon seal Belukha? Harbor porpoise? Dall's porpoise		Harbor seal Spotted seal Ribbon seal Belukha?
COASTAL SOUTH		Sea lion Harbor seal Belukha Harbor porpoise?	Sea lion Harbor seal Belukha Harbor porpoise?	Sea lion Harbor seal Belukha? Harbor porpoise?		
OFFSHORE NORTH		Spotted seal Ribbon seal Belukha?		Spotted seal Ribbon seal Belukha?	Spotted seal Ribbon seal Belukha	Spotted seal Ribbon seal? Belukha?
COASTAL NORTH		Spotted seal Belukha Harbor porpoise?	Spotted seal Belukha Harbor porpoise?	Spotted seal Belukha Harbor porpoise?	Spotted seal Belukha Harbor porpoise	

[1] Including squid.

Investigations of food habits will in most cases require examination of gastrointestinal tracts. For some species only opportunistic samples will be available. However, for numerically abundant species, systematic collections of animals should be conducted which can also be of value for gathering data on condition and vital parameters. To the extent possible, collections should be made during or immediately after feeding episodes at each location and time period and should include a number of animals sufficient to allow the assessment of inter-animal variability in prey consumed. Timing of collections should coincide with periods of intensive feeding as well as other critical biological events (e.g., pre- and post-lactation). Analysis of gastrointestinal contents must include the composition of contents by volume (or weight) and number. In addition, the sizes of prey consumed, particularly for fishes, is of great importance. Time of collection and state of digestion and quantity of contents should be recorded. Concurrent quantification of available prey (in terms of species and size composition) should be done using the best available sampling techniques.

Relevant indices of condition include a number of possible behavioral parameters plus measurements of size, fatness, and physiological condition. It is not presently possible to evaluate which indices will be of greatest value for examining marine mammal-fishery interactions since the responses of marine mammals to changing food supplies are poorly known. We suggest that condition of mature females and growth rates and survival of neonates and subadults may be particularly sensitive.

Since the nature of density-dependent responses in marine mammals is poorly known and is likely to vary with the species and circumstances of concern, it is difficult to select which vital parameters will be most desirable to investigate. Considering both probable sensitivity and practicality of obtaining data, we suggest that age at sexual maturity, reproductive output, and reproductive success may be of greatest utility. Determination of these parameters is linked to examination of condition indices discussed above.

14.6 Suggested Methodology

14.6.1 Offshore Interactions

Included in offshore interactions are four species which may be associated with sea ice during part of the year--spotted seal, ribbon seal, sea lion, and belukha whale. Research on those species can best be accomplished from an ice-reinforced vessel equipped with a helicopter operating in the ice front during the period January-May. In addition to examining distribution, abundance, and foods, particular emphasis should be given to condition indices and vital parameters of ribbon and spotted seals since this is the area and time where they give birth and nurture their young.

In offshore open-water areas, helicopter-equipped vessels are also optimum for determining distribution and abundance of feeding marine mammals, as well as for collections of animals and their prey. Species of particular concern are fur seals, sea lions, and ribbon seals.[1] Vital parameters, condition indices, and behavior of fur seals and sea lions can best be monitored at terrestrial hauling and pupping areas which occur in the Aleutian and Pribilof Islands.

14.6.2 Nearshore Interactions

Distribution and abundance of marine mammals in coastal areas can be determined by means of land-based aerial surveys, while collections and observations from ships or boats will be needed to examine behavior, feeding, and prey abundance. Bristol Bay and Norton Sound probably provide optimum study areas for the southern and northern regions. Some information on foods, condition, and vital parameters may be obtainable from beach-cast animals, those incidentally caught in fishing gear, and animals taken in subsistence harvests. Harbor seals and sea lions haul out and can be observed in a number of locations. Marking and telemetry may be particularly applicable in studying nearshore interactions.

14.7 Modeling and Ecosystem Simulations

This project focused on a review of available data on feeding and status of Bering Sea marine mammals and was not intended to be an intensive review of existing and applicable models and simulations. However, in order to assess utility of available data and suggest priorities for future research, we conducted a partial review and assessment of numerical models. In this section we make some suggestions regarding future modeling efforts but must emphasize that this is not a comprehensive plan for research involving models and simulations.

Several programs and agencies are presently conducting research relating to various components of the Bering Sea ecosystem (Table 14.7-1). Although some major summaries of results have been published (e.g., for the NOAA/OCSEAP projects, Hood and Calder 1981), most of the projects are still ongoing and data are in various stages of analysis. The major multidisciplinary programs each have a specific emphasis. NOAA/OCSEAP has funded physical and biological studies relevant to possible impacts of offshore oil and gas development. NOAA/NMFS/NMML is studying finfish, shellfish, and marine mammal stocks and their

---

[1] An initial attempt at such a study dealing with fur seals was conducted by the NMFS/NMML in autumn 1982.

Table 14.7-1. Programs and agencies conducting research relating to the Bering Sea ecosystem.

Physical/chemical oceanography	Plankton and productivity	Fishes/fisheries	Seabirds	Marine mammals
NOAA/OCSEAP	NOAA/OCSEAP	NOAA/NMFS	NOAA/OCSEAP	NOAA/OCSEAP
PMEL	PROBES	PROBES	FWS	NMFS/NMML
PROBES		ADF&G	PROBES	FWS
		UW		UA
				ADF&G
				PROBES

important to Bering Sea resources, with emphasis on pollock. Groups such as UA, UW, FWS, and ADF&G are gathering data relating to the biology of fishes, seabirds, and marine mammals.

Although models of various levels of sophistication are involved in most if not all of the research programs, and the data requirements and products for them are closely linked, integration and coordination among programs are not generally apparent. We suggest that a workshop to consider possible integration of recently gathered information and to investigate the most productive directions for future work is appropriate. In addition to simulating ecosystem processes, attention should be given to identification of logical subunits for which models may be more readily developed and verified. The utility of various approaches for addressing management questions relating to fish and mammal stocks and their harvesting should be emphasized.

Realizing that ecosystem models which can generate reliable predictions useful for management of fish and mammal stocks may not become available for a decade or more, other models may be useful for directing research, estimating the probability of interactions, and investigating possible effects of predation and fisheries on fish stocks. We suggest the development of a model simulating the effects of harvesting and predation on fish stocks which incorporates discrete age or size classes. With respect to marine mammals, the proximate need is for models dealing with feeding ecology and energetics and how they are affected by prey availability. A review of the present state of knowledge of density dependence in marine mammals in greatly needed. This topic might well be addressed by a workshop.

Based on presently available data, likelihood of interaction with fisheries, and feasibility of future research, several species are obviously the most suitable subjects for feeding and energetic studies. They include fur seal, sea lion, harbor seal, spotted seal, belukha whale, and harbor porpoise. Since functional differences among major taxonomic groups are likely, research should address at least one species in each major taxon (i.e., otariid, phocid, odontocete). With respect to possible laboratory studies, three species seem particularly appropriate--fur seal, harbor seal, and belukha.

15.0 ABSTRACT

This report is a compilation, summary, and evaluation of all available information on feeding habits, food requirements, and population status of 26 species of marine mammals occurring in the Bering Sea/Aleutian Islands region. Although several species feed to a significant extent on present and potential commercial fish resources, available data are not adequate to determine how marine mammals may affect and be affected by commercial fisheries. A conceptual assessment based on feeding and population status information suggests a moderate to high probability of significant interactions for the following species: northern fur seal, Steller sea lion, harbor seal, spotted seal, belukha, harbor porpoise, sea otter, gray whale, walrus, Dall's porpoise, ribbon seal, and bearded seal. Predictive assessments of interactions based on ecosystems models and simulations are not presently possible. Due to deficiencies in the data base and variability of available data, correlative assessments and calculations of fish consumption by marine mammals are not presently reliable and adequate reliability will be difficult to achieve in the near future. A research plan is presented to address data needs for eight species of marine mammals which may interact significantly with present and potential commercial fisheries.

16.0 KEY WORDS

Bering Sea, Aleutian Islands, marine mammal-fishery interactions, marine mammals, feeding habits, food requirements, population status, cetaceans, odontocetes, mysticetes, pinnipeds, seals, sea lions, walruses, sea otter, polar bear, fisheries, groundfish, pollock, herring, salmon, squid, halibut, king crab, tanner crab, snails, capelin, saffron cod, shrimp, clams, ecosystem models, simulations.