Outer Continental Shelf Environmental Assessment Program

ver
for Kodiak

Final Reports of Principal Investigators

Volume 58 December 1988

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Oceanography and Marine Assessment
Ocean Assessments Division
Alaska Office

U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Alaska OCS Region
OCS Study, MMS 89-0002

"Outer Continental Shelf Environmental Assessment Program Final Reports of Principal Investigators" ("OCSEAP Final Reports") continues the series entitled "Environmental Assessment of the Alaskan Continental Shelf Final Reports of Principal Investigators."

It is suggested that sections of this volume be cited as follows:

Truett, J. C., and P. C. Craig (editors). 1986. Evaluation of environmental information for the Unimak Pass area, Alaska. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 58(1988):1-392.

Dupré, W. R. 1980. Yukon Delta coastal processes study. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 58(1988):393-447.

OCSEAP Final Reports are published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Ocean Assessments Division, Alaska Office, Anchorage, and primarily funded by the Minerals Management Service, U.S. Department of the Interior, through interagency agreement.

Requests for receipt of OCSEAP Final Reports on a continuing basis should be addressed to:

NOAA-OMA-OAD
Alaska Office
Federal Bldg., U.S. Court House Room A13
222 West Eighth Ave., #56
Anchorage, AK 99513-7543

Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 58

December 1988

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Oceanography and Marine Assessment
Ocean Assessments Division
Alaska Office

U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Alaska OCS Region

OCS Study, MMS 89-0002

Anchorage, Alaska

The facts, conclusions, and issues appearing in these reports are based on research results of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which is managed by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funded (wholly or in part) by the Minerals Management Service, U.S. Department of the Interior, through an Interagency Agreement.

Mention of a commercial company or product does not constitute endorsement by the National Oceanic and Atmospheric Administration. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

The content of these reports has not been altered from that submitted by the Principal Investigators. In some instances, grammatical, spelling, and punctuation errors have been corrected to improve readability; some figures and tables have been enhanced to improve clarity in reproduction.

Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

VOLUME 58 DECEMBER 1988

CONTENTS

EVALUATION OF ENVIRONMENTAL INFORMATION FOR THE UNIMAK PASS AREA, ALASKA

Edited by

Joe C. Truett and Peter C. Craig

LGL Ecological Research Associates, Inc.
1410 Cavitt Street
Bryan, Texas 77801

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 677

December 1986

ACKNOWLEDGMENTS

This study was funded by the Minerals Management Service, Department of the Interior, through an Interagency Agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program.

The financial support of the Minerals Management Service (MMS) of the Department of the Interior is gratefully acknowledged. Individuals of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce in Anchorage, Alaska, were extremely supportive throughout the preparation of this report. Paul Becker, NOAA's contracting officer's technical representative, was particularly helpful and understanding; his support is very much appreciated.

During this project, contact was made with a large number of scientists who provided information and interpretations that have benefited this report. We would specifically like to acknowledge the contributions of:

Paul Anderson, National Marine Fisheries Service (NMFS)
Richard Bakkala, Northwest and Alaska Fisheries Center (NWAFC)
Jim Blackburn, Alaska Department of Fish and Game (ADFG)
Richard Dugdale, University of Southern California
Kathy Frost, ADFG
Steve Hoag, International Pacific Halibut Commission
Pat Holmes, ADFG
John Kelly, University of Alaska
Larry Malloy, ADFG
Bob Otto, NMFS
Sherry Pearson, NMFS
Lael Ronholt, NWAFC
James Schumacher, NOAA Pacific Marine and Environmental Lab
Arnie Shaul, ADFG
Art Sowls, U.S. Fish and Wildlife Service (USFWS)
Marilyn Dahlheim, NMFS
Anthony DeGange, USFWS
Doug Forsell, USFWS

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

PART I. ECOSYSTEM ANALYSIS

PART I. ECOSYSTEM ANALYSIS

1. SUMMARY

This report identifies and describes the important biological resources of the marine environment of the eastern Aleutian Islands, Alaska, between 164° and 170° W (herein called study area), and discusses the physical and chemical processes and components that support these resources. It evaluates the potential effects of oil and gas activities on the biota and identifies information needs. It is based solely on a review and analysis of existing information. Major points follow under the headings History of Investigation, Marine Mammals, Birds, Fish, Invertebrates, Primary Production, Physicochemical Processes, and Regional Comparisons and Potential Impacts. Points considered very important are underlined.

History of Investigation

- Scientific investigation began in the eastern Aleutians with Vitus Bering's "Great Northern Expedition" in 1741, but was very limited in extent up to 1955. Since 1955, increasingly extensive oceanographic and biological studies have been conducted, culminating in large, multidisciplinary programs (mainly focused on the nearby southeastern Bering Shelf) of the late 1970's and early 1980's, funded by the National Science Foundation (NSF), Minerals Management Service (MMS), and the National Oceanic and Atmospheric Administration (NOAA).

Marine Mammals

- <u>Unimak Pass and adjacent passes are a major migration corridor for marine mammal populations entering and leaving the Bering Sea</u>; the eastern Aleutians area also hosts concentrations of feeding whales in summer; these previously supported a whaling station at Akutan.

- Several baleen whales, in particular fin, sei, minke, and humpback, appear to concentrate in the study area to feed in summer; others such as right and blue whales probably once did but were severely decimated by whaling. These whales congregate to feed on the area's zooplankton community.

- Other marine mammals also are abundant in the area; included are those that feed mainly on benthos (sea otter), cephalopods (sperm whale, fur seal), fish (Dall's and harbor porpoises, Steller's sea lion, fur and harbor seals), and other mammals (killer whale). In terms of total biomass, the mammals as a group are overwhelmingly water-column feeders, consuming secondary or tertiary production that probably results largely from upwelling in the area.

- Some mammals (e.g., gray whale, fur seal) use the area primarily as a migration corridor and secondarily or not at all as a feeding area.

Birds

- Similarly to mammals, great numbers of birds, primarily seabirds, use the study area as a migration corridor and/or as a feeding area. Migrants funnel through the area because of the location of Unimak Pass as the easternmost large pass between the North Pacific Ocean and the Bering Sea. Birds congregate to feed on the upwelling-supported ecosystem. Enhancing the area's use for feeding is the presence of large seabird colonies; approximately 1.5 million birds attend nesting colonies on islands in the study area.

- Most of the abundant seabirds (Northern Fulmar, shearwaters, storm-petrels, auklets) feed heavily on the zooplankton--euphausiids, copepods, and pelagic amphipods. Others feed on a combination of zooplankton and forage fish (kittiwakes, gulls) or primarily on fish (murres, puffins). Both the zooplankton and fish prey are probably supported largely by phytoplankton production from upwelling in or near the study area.

- The eastern Aleutians may support moderate numbers of wintering waterfowl (e.g., Emperor Goose, seaducks), and Unimak Pass itself is a migration corridor for some waterfowl (e.g., Steller's Eider) and some shorebirds (e.g., phalaropes).

Fish

- Waters adjacent to the study area on either side (Bering Sea and Gulf of Alaska) are among the world's richest fishing grounds. The four major groups abundant in and near the study area are salmon (mainly pink salmon), forage fish (herring, capelin, sand lance), groundfish (pollock, Pacific cod, halibut, sablefish, and others), and a variety of inshore species.

- Relatively small numbers of salmon spawn on islands in the study area; relatively large numbers of salmon move through island passes on their way to (adults) or from (juveniles) mainland spawning streams that discharge into the Bering Sea. Major foods of salmon are zooplankton and sometimes (for adults) forage fishes.

- Among forage fish, Pacific herring is probably the most common species in the eastern Aleutians, though this is not certain because very little information exists for the other two common species, sand lance and capelin.

Spawning populations of herring in the area are small relative to those elsewhere in the Bering Sea, but relatively larger numbers feed there in summer. Capelin and sand lance are abundant in the study area at various times of year, particularly in summer, but few data documenting their seasonal distribution in or use of the area are available. All these forage fish are zooplanktivorous, feeding primarily on such groups as copepods, euphausiids, and pelagic amphipods.

- The southeastern Bering Sea is well known for its abundance of groundfish--pollock, Pacific cod, Pacific halibut, yellowfin sole, Pacific Ocean perch, sablefish, and others. These species are relatively abundant in the study area as well, especially the eastern part; much of the commercial catch occurs along the continental shelf break near Unimak Pass. Pollock are apparently the most abundant, constituting about 80% of the commercial groundfish harvest in the study area; Pacific cod are also relatively abundant. There are fewer halibut, ocean perch, sablefish and others. Groundfish distributions and abundances are affected in the study area by water temperature regimes, seabed topography, and substrate characteristics. Most species feed on such near-bottom prey as shrimps, crabs, mysids, and amphipods; pollock, less benthic in habitat than most, is more zooplanktivorous.

- Populations of inshore fishes are undoubtedly small in comparison with those of the more offshore species, though knowledge of this fish community is limited. The diversity of topography, substrates, and attached algal communities in the study area promotes great diversity in species numbers and trophic niches in this group.

Invertebrates

- Invertebrates of importance in this area include zooplankton, cephalopods, epibenthos, and, to a lesser extent, infauna. Commercially harvested epibenthic species--king, Tanner, and Dungeness crabs and shrimps--have been studied most extensively. Little sampling in the study area has been conducted for the other groups, despite their importance in vertebrate food chains.

- Zooplankton in the study area exhibits extremely high productivity and is composed of both shelf and oceanic forms. There is high productivity of copepods (and probably of euphausiids, pelagic amphipods, and others as well) along the north side of the study area which appears to be a consequence of the deep ocean nutrients upwelled into the area. High diversity in zooplankton species is caused by the location of the study area between shallow shelf and deep ocean environments and along the transport route of the Alaska Coastal Current.

- Squids and octopuses, important foods of vertebrates in the study area, seem to concentrate along the shelf break and other steeply sloping areas in and near the eastern Aleutians. Squids and octopuses feed mainly on water-column and benthic prey, respectively. Data on cephalopods in the study area are extremely limited.

- The epibenthos includes all the species of commercial importance in the study area--king, Tanner, and Dungeness crabs and shrimp. All are important prey for benthic-feeding fishes and mammals, and in turn consume plankton detritus (mainly in their early life stages), polychaetes, molluscs, and other benthic-dwelling prey. All these species exhibit extreme interannual variations in recruitment and abundance (Tanner crabs probably less so than others), with resulting annual variations in commercial catches.

- The infauna is of less direct importance to man, though there is potential commercial interest in razor clams in the area, and diving ducks, sea otters, and flatfishes often feed heavily on the infauna. Most infaunal species of interest are detritivores and/or planktivores. Their distributions and abundances in the study area are strongly influenced by substrate type and water depth.

Primary Production

- Phytoplankton is by far the major primary producer in the study area, though eelgrass and benthic algae are locally important in shallow areas. The annual production of phytoplankton in the study area is quite large, apparently driven largely by nutrients upwelled from deep Pacific and Bering Sea waters, and probably peaks in late spring and early summer.

Physicochemical Processes

- Physical and chemical processes operating in and near the study area strongly influence the area's biological productivity and composition. These processes are, in turn, dependent on circulation and other processes in the Gulf of Alaska to the south and the Bering Sea to the north. Two processes--circulation and upwelling--are of extreme importance to the biota.

- Water movement through the study area is dominated by two currents that originate in the North Pacific Ocean--the Alaska Coastal Current and the Alaska Stream. The Coastal Current, originating on the continental shelf of western

Canada, flows north to the northern Gulf of Alaska, then westward to Unimak Pass, remaining on the shelf and nearshore. Its water quality is strongly influenced by freshwater input along its length. Most of the Coastal Current appears to move through Unimak Pass, making a U-turn and then flowing northeastward along the north side of the Alaska Peninsula. The Alaska Stream also originates in the North Pacific. It moves parallel to and in the same direction as the Coastal Current, but is off the shelf. Little of the Alaska Stream flows through the eastern Aleutian passes, especially the relatively shallow Unimak Pass; most enters the Bering Sea in the far western Aleutians. But once in the Bering Sea, a strong component of the Alaska Stream moves eastward along the north side of the Aleutians, turning northwestward as it meets the shelf break just north of Unimak Pass.

- Upwelled deep Pacific water is detectable in the western passes of the study area, notably Samalga Pass. This water then apparently moves eastward on the north side of the Aleutians, passes through the study area, and perhaps moves then onto the Bering Shelf. This upwelled water appears to support a relatively rich biological community along the north side of the study area; secondary production as a consequence of this upwelling seems to peak in the vicinity of Unimak Pass. Measures of partial pressures of CO_2 in the air and surface waters in the study area, plus limited nutrient analyses, have helped confirm the existence of upwelled water in the area.

- Hydrocarbons in the waters and sediments in and near the study area seem to be entirely of recent (within the last few millenia) biological origin rather than from petroleum.

- The eastern Aleutian Islands area is young and geologically active; this has important implications for potential hazards to (and thus environmental effects of) activities related to oil and gas development in the area. Volcanism and seismicity are of particular concern.

- Volcanic activity built the Aleutian Islands; it has been, and remains, a dominant force in shaping habitats and creating hazards to human activity. Nearly a score of volcanoes, several of which have been recently active, are in the eastern Aleutians. Two seismic gaps, one of them major, exist near the eastern end of the study area, suggesting that large earthquakes capable of generating giant tsunamis (tidal waves), are likely to occur in the Unimak Pass area within a few decades.

- Bottom sediments in the eastern Aleutians are derived largely from volcanic materials and tend to be coarse. Bedrock, boulders, and gravel dominate the shallows; sand and silt dominate the deeper waters.

- Suspended sediment loads decrease rapidly with distance from shore. Relatively high turbidities observed in deeper waters of the Unimak Pass area are probably attributable to enhanced primary productivity caused by upwelling, i.e., abundant phytoplankton in the water column.

- Heavy metal concentrations in suspended particulates vary with tidal cycles and among replicate samples; those in bottom sediments vary with mean grain size; and those on the shelf near the study area resemble, in general, those elsewhere on the Alaskan Shelf.

Regional Comparisons and Potential Impacts

- Processes and components viewed as important in terms of comparing the study area with adjacent environments and assessing the potential effects of OCS activities on the important species include the following:

    Circulation and Upwelling
    Transport of Eggs and Larvae
    Water Temperature Distributions
    Topographic Characteristics
    Substrate Type and Depth
    Productivity of Inshore Habitats
    Zooplankton Communities
    Cephalopod Abundance
    Crab Abundance
    Groundfish Abundance
    Herring Migration and Abundance
    Salmon Migration
    Bird and Mammal Feeding Concentrations
    Bird and Mammal Migration Corridors

- Major differences and few similarities exist between the ecosystem of the eastern Aleutians and that of the adjacent North Aleutian Shelf. The main cause of these differences is the difference between the two areas in their physical environment--water movement patterns, emergent topographic features, and subsea topography and substrates. Though both the physical and biological differences are large, some similarities exist because (a) the areas are adjacent and thus share species with broad distributions and flexible habitat requirements, and (b) some water, after leaving the eastern Aleutians, moves directly onto the North Aleutian Shelf, transporting with it nutrients, plankton, and possibly higher food-chain components from the eastern Aleutians.

- The physical environment is important in determining the susceptibility of the biota to potential impact from oil and gas development. Potential hazards that could lead to increased opportunity for oil spill include stormy, foggy seas and possibly tsunamis from major earthquakes. The existence of Unimak Pass as a favored passage for both oil industry and migrating animals would tend to bring the biota into proximity with potentially adverse activities. Based on known wind and current conditions, oil spills tnat occur southeast of and within Unimak Pass might be transported through the pass and onshore. However, for spills north of the pass, the action of weather and sea conditions on oil possibly depresses the chances for adverse biological effect--trajectories of oil spills north of the area would be away from the concentrations of animals, and the typically stormy seas and rapid water movement would quickly remove most of any oil that did reach the eastern Aleutians.

- Extensive and numerous reviews of the potential effects of OCS activities on mammals, birds, fish, and invertebrates of nearby areas, coupled with information from this study, suggest tnat the biota most likely to suffer significant adverse impacts from OCS development are populations of marine mammals and birds. The mammals most susceptible to impact are those that insulate themselves with fur (fur seal, sea otter) and/or concentrate in the Unimak Pass area (fur seal, Steller's sea lion). The birds at high risk are diving species that congregate in the Unimak Pass area (mostly alcids). Fish and shellfish are not likely to suffer measurable impact except very locally. Effects on food-webs are extremely unlikely to be detectable at the consumer level.

- Several information needs limit an evaluation of potential effects of OCS activities to the important biota. New research efforts that could be most productively applied at this time are (a) collection of more data on distributional patterns of the important species (mammals and birds) in time and space, (b) analysis of underlying reasons (e.g., food distributions, effects of water movement) for the observed distributions of the important species as a basis from which to better predict the distributions, and (c) analysis of the relationships of these distribution patterns to timing, spatial extent, and nature of expected OCS activities.

2. INTRODUCTION

"After God finished moulding the earth he found a lot of mud sticking on his fingers--'hell' He said, and snapped the mud off. And where it landed made the Aleutians". (Miller, n.d.)

The Aleutian Islands form a perforated chain between the Pacific Ocean and the Bering Sea. Unimak Pass and adjacent areas in the eastern Aleutian Islands are important passageways for animal populations migrating between the northwestern Gulf of Alaska and the Bering Sea. Unimak Pass is also a potentially important marine transportation corridor for development and production of petroleum in Outer Continental Shelf (OCS) lease areas in the Bering and Chukchi seas. Further, the potential exists for petroleum to be discovered in the immediate area of the eastern Aleutians. Thus, there is potential for conflicts to develop in this area between oil and gas development and biological resources important to people.

The National Oceanic and Atmospheric Administration (NOAA) has contracted with LGL Ecological Research Associates, Inc. (LGL) to evaluate existing data to determine the potential for such conflicts to develop in the Unimak Pass area, and to identify information gaps that need to be filled before such potential conflicts can be fully analyzed. The following report is the response of LGL to the terms of this contract (NOAA Contract No. NA-85-ABC-00143), funded by the Minerals Management Service (MMS).

A. OBJECTIVES

The objectives of this report are to:

(1) Identify and describe the physical and biological processes, and the biological resources sustained by these processes, for the Unimak Pass area. The biological resources that are important to people and the physical and biological processes on which they depend in the area are described. Comparisons of these biota and processes

with those described in previous and ongoing ecological investigations of the Alaska Peninsula are a part of these descriptions.

(2) Identify information needs related to biological resources, ecological processes, and physical oceanographic processes that limit the evaluation of potential effects of oil and gas activities on biological resources in the area of study. Areas in which additional information should be gathered to increase the confidence in predictions of the potential impacts of oil and gas activities on biological resources and their supportive processes are described. The general susceptibilities of the resources and processes to oil-and-gas-related impacts are discussed.

(3) Prepare an annotated bibliography of available information. An annotated bibliography of information relevant to objectives (1) and (2) is provided. The bibliography includes all physical process and biological information found that applies directly to the Unimak Pass study area.

B. STUDY AREA

The study area extends along the Aleutian Island chain from Unimak Island to 170°W longitude (Fig. 2-1). For this review we have examined all relevant work conducted within about the 200-m depth contour in this area, as well as any additional reported studies performed elsewhere that had obvious implications for describing (1) the biota that occur in, and (2) the processes operative in, the study area.

C. METHODS

The materials reviewed for this report include information that describes the study area biota, the important processes supporting biota, and the susceptibility of the biota and the processes to oil-and-gas related activities in the area. Searches for and perusal of published

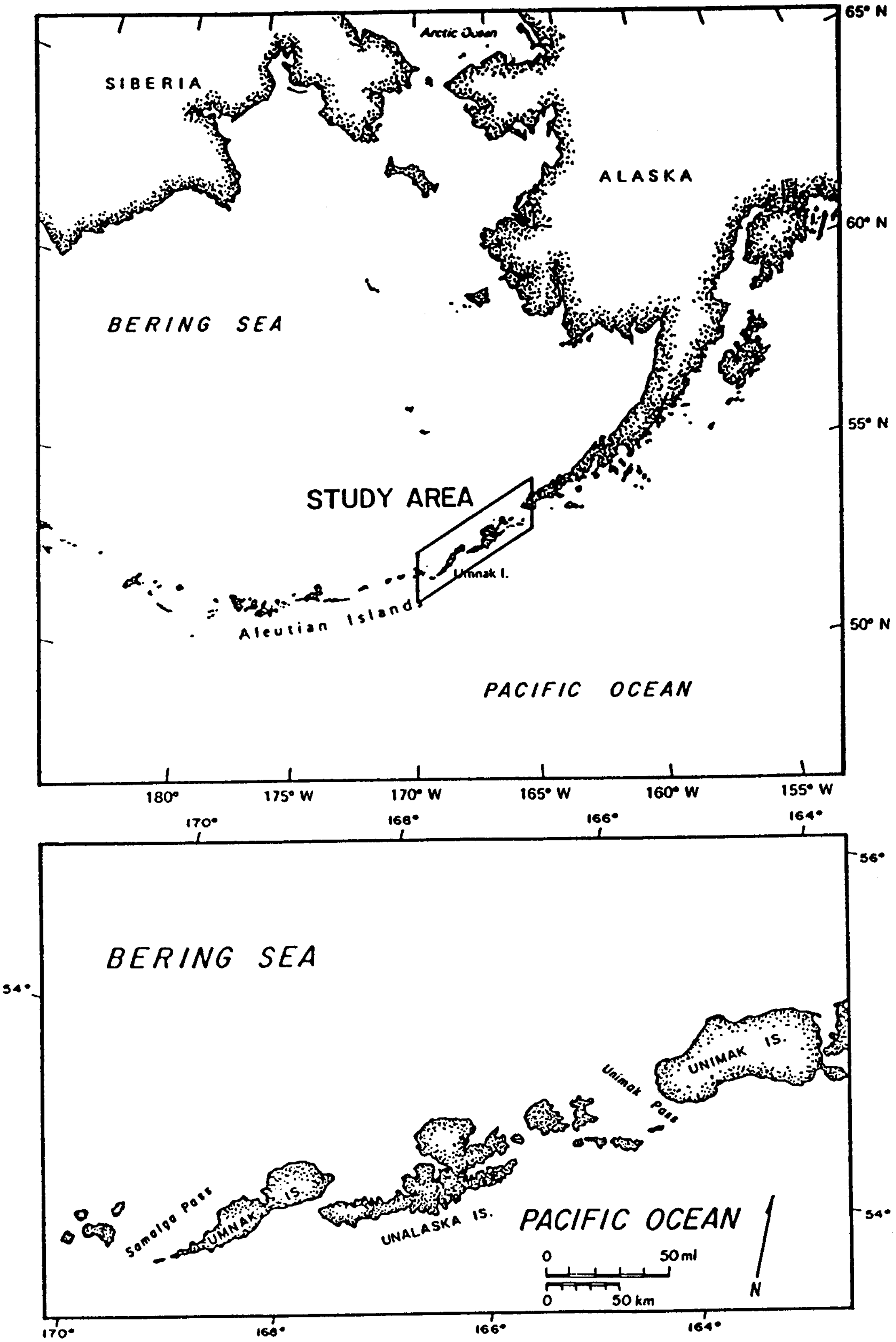


Figure 2-1. Study area in the eastern Aleutian Islands.

literature and unpublished reports and data, and verbal interviews with scientists who have worked in the region, are the primary sources of information. A computer search of several databases complemented these methods.

Search for Materials

Three points are important in how the search for information was conducted:

(1) A number of reviews and/or bibliographies already existed that identified or described previous research conducted in and near the study area. This reduced the time that would have been otherwise required to assemble the published and unpublished information. Included are U.S. Department of Commerce (1984, 1986), Wall and Macy (1976), SAI (1980), Pace (1984), Hameedi (1982), and Thorsteinson (1984). These reviews identified much of the relevant literature.

(2) A relatively large proportion of the existing literature was not very useful for describing important processes in the study area or identifying information needs important in OCS impact analysis. A large amount of effort was spent gleaning from the available information that which was useful for characterizing the study area.

(3) A computerized search was conducted using seven databases: Aquaculture (NOAA/EDIS/ESIC/LISD), Aquatic Sciences & Fisheries Abstracts (NOAA/Cambridge Scientific Abstracts), BIOSIS Previews 1969 to 1976 (BioSciences Information Service), BIOSIS Previews 1977 to Present (BioSciences Information Service), ENVIROLINE (Environment Information Center, Inc.), SCISEARCH 1974 to Present (Institute for Scientific Information) (Non-subscriber), Zoological Record (BioSciences Information Services). Key words used in these searches (Table 2-1) focused on area and subject. It should be noted that these computerized searches were

Table 2-1. Key word roots used in the searches of computerized databases for environmental information about the Unimak Pass study area, Alaska.

WORD CATEGORY					
Area	Marine Mammals	Birds	Fishes	Invertebrates	Other
Aleutian Islands	Gray whale	Duck	Salmon	Zooplankton	Oceanography
Unimak Pass	Northern fur seal	Seabird	Cod	Copepod	Pollution
Unalaska Island	Fin whale	Auklet	Flatfish	Jellyfish	Current
Dutch Harbor	Sea otter	Shearwater	Demersal	Euphausiid	Temperature
Alaska Peninsula	Stellar's sea lion	Murre	Bottomfish	Mysid	Salinity
Umnak Island	Minke whale	Puffin	Pelagic	Polychaete	Water
Chuginadak Island	Dall's porpoise	Swan	Herring	Amphipod	Primary production
Samalga Pass	Killer whale	Scoter	Halibut	Chaetognath	Phytoplankton
Umnak Pass	Harbor porpoise	Eiders	Capelin	Gastropod	Detritus
Akutan Pass	Harbor seal	Oldsquaw	Sand lance	Snail	Circulation
Akun Island	Whale	Petrel	Pollock	Bivalve	Marine
South Bering Sea	Seal	Gull	Larvae	Clam	Chlorophyll-a
North Pacific Ocean	Sea otter	Kittiwake	Fishery	Decapod	Domain
	Sea lion	Bird	Egg	Crustacea	Meteorology
	Porpoise	Fulmar	Sole	Benthic	Storm
	Cetacean	Shorebird	Smelt	Barnacle	Alaskan stream
	Pinniped		Flounder	Isopod	Hydrography
	Walrus		Sculpin	Echinoderm	Geochemistry
	Dolphin		Commercial	Dollar	Earthquake
				Starfish	Tectonic
				Brittle	Sediment
				Crangonid	Carbon
				Shrimp	Nutrient
				Crab	Particulate
				Plankton	Hazard
				Shellfish	Hydrocarbon
					Water quality
					Productivity
					Environmental (impact)
					Geology
					Chemistry
					Ecology
					Biology
					Microbiology
					Intertidal
					Seaweed
					Photosynthesis
					Pollution

relatively unproductive; far more information was acquired manually than was listed in all databases combined, and the databases identified virtually no information we did not find through other methods.

Analysis and Synthesis

An important need was to focus the analysis and synthesis so that time was not wasted on information that did not relate in some way to making OCS oil and gas leasing decisions. We assumed that the information affecting leasing decisions would deal directly or indirectly with species of commercial, subsistence, or recreational benefit to humans (i.e., "important" species). Given this assumption we followed a sequential approach for information analysis that is reflected in the organization of this report:

(1) First, we described the populations of the important species that use the study area. This description included the major food web components and habitat features on which the populations depend.

(2) Second, we examined the food web components and the physical processes important to these populations.

(3) Third, we considered how potential oil and gas activities might directly affect the important species populations or their major food web components, or how the activities might interact with the physical environment to affect the populations or food web components.

(4) Last, we identified and described the specific information that remains to be gathered before accurate predictions about the effects of oil and gas development can be made. Relative priorities among these information needs are discussed.

Comparisons With Adjacent Areas

One of the project requirements was to compare biological and physical processes operative in the Unimak Pass study area with those of the nearby North Aleutian Shelf off the Alaska Peninsula. Three relevant Alaska Peninsula projects (all OCSEAP-funded) useful for such comparisons were a literature review and synthesis (Pace 1984), the on-going North Aleutian Shelf (NAS) Ecosystem Study (LGL 1986), and a study of fishes along the north Alaskan Peninsula (Houghton et al. 1986).

Preparation of Annotated Bibliography

A conventional approach was used to compile the annotated bibliography. As each article or other piece of information was reviewed, a one-fourth to one-half page abstract of it was prepared. These were then combined into a bibliography alphabetized by authors' last names and cross-referenced by subject (see Part II of this report).

Interviews

Interviews with scientists knowledgeable about the region were conducted by the project investigators. Each investigator interviewed individuals who appeared to be able to provide important information in addition to that available in printed form. Most of the persons interviewed were in the Pacific Northwest or in Alaska. They are listed in the Acknowledgements section of this report.

3. HISTORICAL SKETCH OF SCIENTIFIC INVESTIGATIONS

by Donald W. Hood

The first recorded discovery of land in the vicinity of Unimak Pass was by Vitus Bering in 1741 on his second voyage known as "The Great Northern Expedition". Bering commanded the vessel St. Peter, with Chirikov as Captain of the St. Paul. Leaving from Okhotsk Sea in search of land east of Kamchatka Peninsula, they sailed southeast seeking the mythical Gama Land that many map makers had placed in the North Pacific. At the time, the Aleutian Islands were unknown. After sailing to latitude 46°N, passing beyond the area where Gama Land was supposed to be, they soon found that they had been duped by careless cartography. Caught by fog, the ships lost contact and after much searching for each other, they sailed on eastward separately.

Chirikov first sighted land at the southern end of the Alexander Archipelago at latitude 55°N. On his return west, he spotted land on the north end of the Kenai Peninsula, but then lost contact with land by sailing south to the middle of the Gulf of Alaska. After a month of stormy, foggy weather, and with essentially no navigation aids but a compass, Chirikov found himself off the island of Unalaska. He continued to see land occasionally as he progressed west on a zigzag course. Chirikov's crew suffered from cold, hunger, and scurvy. They could not maintain the ship's sails and finally limped home to Kamchatka on having lost 21 of the original crew of 85 men after only five months at sea.

Meanwhile, Bering sailed eastward where the first land observed was Mount St. Elias and other peaks of the coastal range. George Steller, the ship's physician and expedition scientist, was the first scientist to view the expansive region of the North Pacific Ocean and it's bordering lands. Steller was an overly sensitive man with a colossal ego, yet clearly talented. Bering, though kind to Steller, found his abrasive assertiveness difficult as evidenced by his reluctance to allow Steller to accompany the first landing party on American soil--mainly in search of fresh water--on Kayak Island. Steller prevailed and was able to report on the evidence for human habitation. He observed and described *Cyanocitta stelleri*, or Steller's Jay as it came to be called, and found in this land many other strange and colorful birds and plants including the salmonberry, common to the Pacific northwest.

Later in the cruise, Bering made contact with the Aleut natives on one of the eastern Aleutian Islands, but it is not clear which island they were from, nor is it known whether Bering actually penetrated the Bering Sea on this expedition. The emaciated crew of the St. Peter, suffering from drinking alkaline water obtained on Nagai Island and from the persistent scourge of scurvy, landed on Bering Island in the Western Aleutians with few able-bodied men remaining. Here Vitus Bering died as a result of illnesses acquired on this ill-fated cruise. Steller continued his remarkable scientific effort during this period. His most important work--dissecting and describing the Steller's sea cow--provides the only description of this magnificent beast before its extinction a few decades after its discovery in 1742.

This voyage of Vitus Bering brought scientific discovery to the Aleutian Islands and the northern Gulf of Alaska. Steller's observations of marine animals, birds and plants were the first and only significant biological studies made in this region until the Harriman Expedition in 1899 and cruises of the Albatross at the turn of the century (Albatross 1902-1911, Harriman Alaska Expedition 1910).

Physical oceanographic studies of the North Pacific began after the last important Discovery cruise of Malaspina in 1794. Emphasis was placed on depth and temperature measurements. The first extensive observations in the North Pacific were made by Kruzenstern on the Nadiejeda in 1803-1806. His measurements of water temperature to 400-m depths and observations of atmospheric pressure stimulated the preparation of his atlas of the Northeast Pacific about 25 years later. Although there is evidence that surface observations of temperature and even density were made in the Aleutian area by early whalers, sealers and cod fishermen, these data are not documented. Not until 1888 when the U.S. Fish Commission Steamer Albatross commenced a series of cruises did surface and bottom temperatures become recorded in the literature (Townsend 1901).

Flow of water through the passes has been an important consideration since oceanographic studies began along the Aleutian Islands. Aboard the Albatross in Unalga Pass in July 1888, Tanner et al. (1890) observed that the tide rushed through the narrows with great force, causing heavy rips and at times overfalls, but was quite smooth at the time of high water. Rathbun (1894) observed, in 1890, that tidal currents in the Bering Sea near the Alaska Peninsula were strongest near Unimak Pass with the flood to the northward and the ebb to the south with the flood being far the stronger. There are no records in western literature of any subsequent studies of flow in the passes until 1933 when the USS Garnett began the Aleutian Island survey. Results of this and an investigation aboard the USCGC Chelan of a region north of Unalaska Island were reported by Barnes and Thompson (1938). Flow through the Aleutian passes, according to available information before 1974, has been summarized by Favorite (1974).

Knowledge of the oceanographic and biological conditions in the Aleutian area prior to 1955 was very limited, as was information on the North Pacific Ocean (Fleming 1955). In 1955 a new surge of activity, brought on by a major international survey of the North Pacific Ocean Committee (NORPAC 1960) and the commencement of extensive field studies by the International North Pacific Fisheries Commission (INPFC). NORPAC obtained an extensive synoptic oceanographic data set for summertime conditions in the North Pacific and, although limited data in the Aleutians were obtained, NORPAC deduced from geopotential typography that (1) all the flow of the westerly currents along the Alaska Peninsula was discharged into the Bering Sea mostly through Unimak Pass, and (2) any residual westward flow terminated near 175°W. However, the former was physically impossible because of the shallow depth of Unimak Pass (60 m) and the second unlikely as indicated by Mishima and Nishizawa (1955), Koto and Fujii (1958), and Sugiura (1958), although it agreed with the observations of Barnes and Thompson (1938).

INPFC, responding to the need for year-round studies of the relationship of the high seas salmon to their environment, conducted extensive investigations in the Aleutian Islands for many years (Favorite 1974). These efforts, plus those of the Faculty of Fisheries of Hokkaido University at Hakodate on the Oshoro Maro and an extensive, primarily biological study by the USSR on the Vityaz, constituted the bulk of efforts that obtained oceanographic data in the vicinity of the Aleutian Islands until the mid 1960's. About 1965 a new kind of interdisciplinary effort was beginning to evolve--that of relating nutrient availability for phytoplankton productivity to physical processes in the ocean.

In 1966 a cruise of the RV Acona operated by the Institute of Marine Science of the University of Alaska began a series of interdisciplinary studies in the Unimak Pass area as well as the deep basin of the Bering Sea (Hughes et al. 1974) and the eastern Bering Sea shelf (Hood and Calder 1981). During the 1966 cruise, Dugdale and Goering (1967) distinguished between new primary production (based on nitrate uptake by phytoplankton) and regenerated primary production (based on recycled nitrogen in the form of ammonium) in the Unimak Pass area. It was on this cruise that upwelling, as a result of deeper water moving over the shallower sills of the island passes, was suggested. This phenomenon was investigated extensively by Kelley and Hood (1971) and Kelley et al. (1974) in which the partial pressure of molecular CO_2 in the surface water was used to map upwelling areas.

Based on the observations of upwelling on the north side of the island passes and the northeasterly flow of the North Aleutian Current, Kelley et al. (1971) speculated that the entire area north and west of Unimak Pass was bathed in nutrient-rich water. This and subsequent observations indicated that this area may be an upwelling-supported ecosystem similar to other upwelling areas of the world (R.C. Dugdale, Univ. Southern California, pers. comm.).

By the mid-1970's the most intensive and extensive interdisciplinary oceanographic studies that have occurred in any area in the high northern latitudes, except perhaps for the North Sea, began near the eastern Aleutians. Most of this activity was along the Alaska Peninsula and eastern Bering Sea shelf under sponsorship of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) and the National Science Foundation (Hood and Calder 1981, Pace 1986, McRoy et al. 1986, LGL 1986). While these studies greatly increased our understanding of the region, including Unimak Pass, little or no work was conducted in any of the western Aleutian passes and relatively little within Unimak Pass itself.

4. SYSTEM COMPONENTS AND PROCESSES

A. MARINE MAMMALS

by Declan M. Troy

Unimak Pass is one of the major migration corridors for mammal populations entering and leaving the Bering Sea (Thorsteinson 1984). Unimak Pass and the eastern Aleutian Islands are clearly shown to have high use by whales relative to neighboring areas (Fig 4A-1). Most large cetacean species appear to enter the Bering Sea in greatest numbers in June between eastern Aleutian Islands (Braham et al. 1977). The diversity and seasonal abundance of marine mammals in and adjacent to Unimak Pass and along the continental slope can be found in no other part of Alaska and perhaps the world (Braham et al. 1982). The ecological significance of this region to marine mammals (as well as to other wildlife and fishes) is not yet fully understood, but in sheer numbers and multitude of species it is a region of primary importance because of the concentration of major portions of regional populations of several species. Major portions of gray whale and northern fur seal populations move seasonally through the pass. Indeed, gray whale migration appears to be restricted to Unimak Pass itself.

The eastern Aleutian Islands previously attracted dense enough aggregations of several species of large whales to support a permanent shore based whaling station at Akutan (Reeves et al. 1985). Populations of these whales, all considered endangered, have not recovered and populations using the study area remain depressed (Stewart et al. 1985).

The most standardized and comprehensive (greatest temporal coverage and sampling of all species) survey effort covering our area of interest is the aerial surveys conducted as part of the North Aleutian Shelf investigation (LGL 1986). Coverage by this study in the area of interest was limited to Cape Mordvinof to Akun Island and only the north portion of Unimak Pass (Bering Sea side). These data (Table 4A-1) show sea otter, northern fur seal, Steller sea lion, Dall's porpoise, and gray whale to be the most regularly encountered marine mammals.

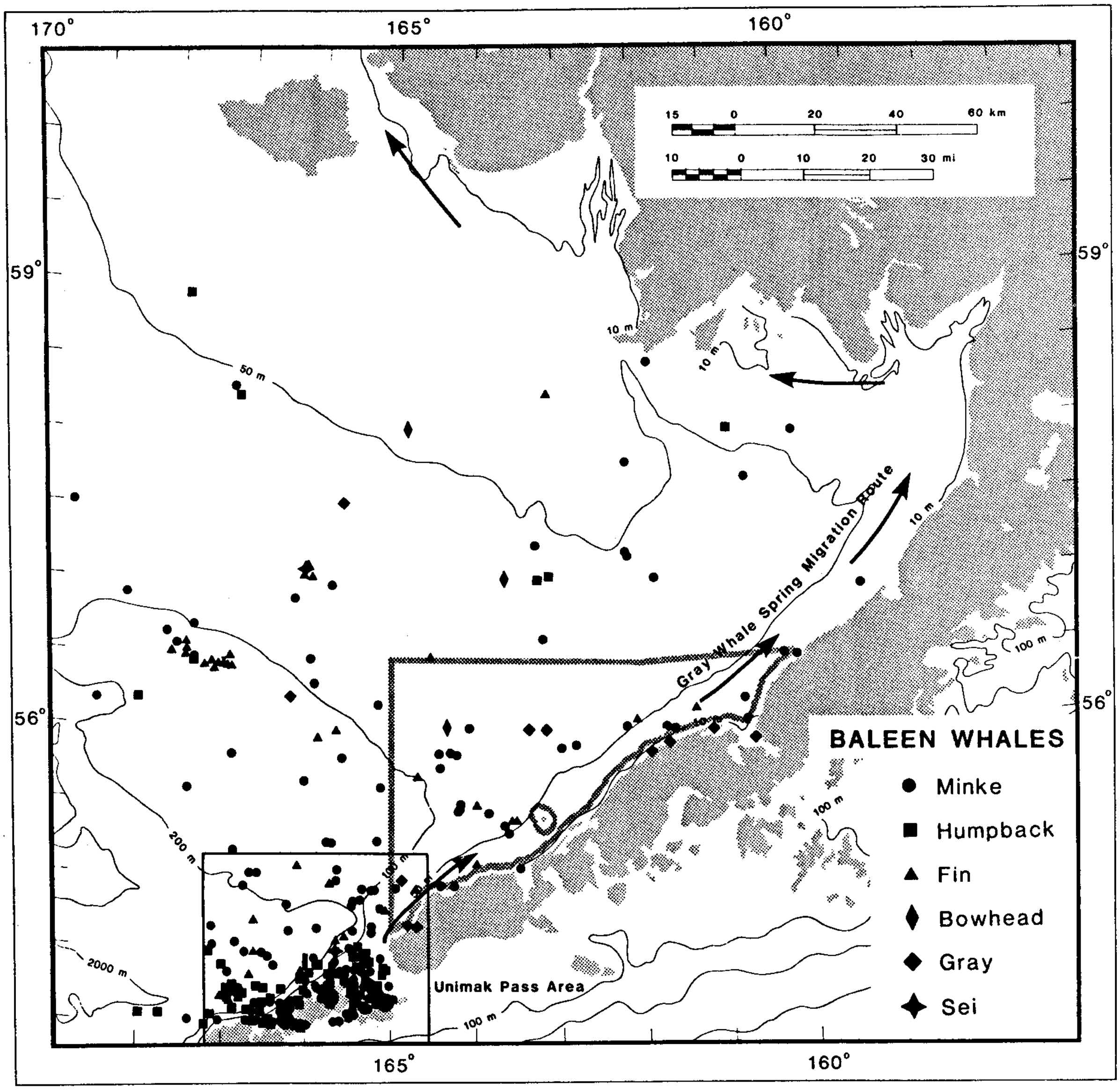


Figure 4A-1. Cetacean sightings in Unimak Pass and North Aleutian Shelf waters (from Armstrong et al. 1984).

Table 4A-1. Densities of marine mammals (animals/km^2) in Unimak Pass recorded during North Aleutian Shelf aerial surveys (LGL 1986).

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Brown Bear	0.00	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Sea Otter	0.03	0.02	0.03	0.02		0.08		0.05		0.08	0.15	0.12
Steller's Sea Lion	0.27	0.60	0.35	1.42		0.00		0.04		0.13	0.00	0.66
Northern Fur Seal	0.00	0.02	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Walrus	0.00	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Harbor Seal	0.00	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Killer Whale	0.00	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Pacific White-sided Dolph	0.00	0.00	0.00	0.01		0.00		0.00		0.00	0.00	0.00
Harbor Porpoise	0.01	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Dall Porpoise	0.00	0.00	0.00	0.00		0.01		0.00		0.01	0.00	0.00
Gray Whale	0.00	0.00	0.00	0.03		0.01		0.00		0.00	0.00	0.03
small whale	0.00	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
fishing boat	0.00	0.00	0.00	0.01		0.00		0.00		0.01	0.00	0.00
ship	0.00	0.01	0.01	0.01		0.00		0.00		0.00	0.00	0.00
TOTAL	0.30	0.65	0.38	1.51		0.10		0.10		0.23	0.15	0.80

More detailed information on a selection of marine mammals occurring in the area is presented below. The selection comprises those species that are particularly numerous in the area (e.g, Steller sea lion), those that are largely restricted to the area at least seasonally (e.g, northern fur seal and gray whale), or are now endangered but known to have previously occurred in large numbers in the study area and may continue to be found in it.

Sources of Information

Many surveys of marine mammals, especially endangered whales, have included our area of interest in their regions of coverage. These survey programs were usually broad in scale with the eastern Bering Sea serving as the study area. In reviewing these reports it is evident that, by necessity, sampling within a small area such as the eastern Aleutians is very limited; it is thus often difficult to ascertain the occurrence of sightings within our study area. However, these studies provide useful overviews for placing the eastern Aleutian region in perspective with reference to the surrounding Bering Sea and North Pacific. We relied heavily on the materials provided by Leatherwood et al. (1983), Lowry et al. (1982b), and NOAA synthesis documents for neighboring areas, especially those for the North Aleutian Shelf (Thorsteinson 1984) and St. George Basin (Hameedi 1982).

Important Species

Right Whale (Eubalaena glacialis)

Although there are no confirmed recent sightings of this endangered species within the study area, right whales were probably taken by aboriginal hunters in the Aleutian Islands (Mitchell 1979) and by commercial whalers based at Akutan (see Leatherwood et al. 1983, Reeves et al. 1985). Right whale kills (prior to 1935) within and near the study area, including records from Unimak Pass itself are shown in Figure 4A-2 and are summarized in Reeves et al. (1985) and Brueggeman et al. (1986).

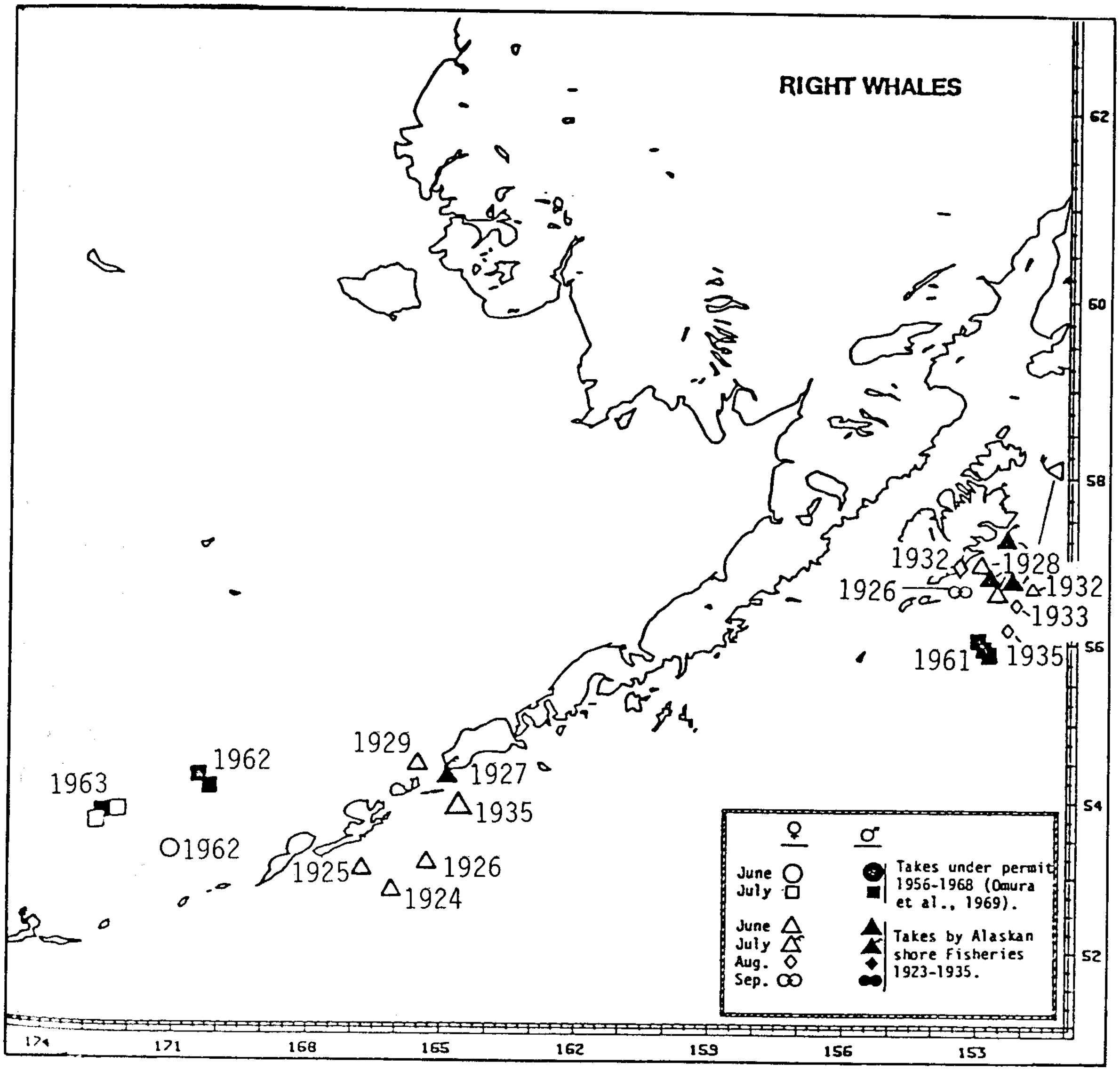


Figure 4A-2. Location of right whale kills by whalers from Akutan (1923-35) and Port Hobron (1926-35) and by Japanese pelagic whalers (1956-63) (from Leatherwood et al. 1983).

Modern sightings of this very rare animal are quite infrequent (see summary in Leatherwood et al. 1983) and no positive records within our study area are evident. However, there are records for the Bering Sea as recent as 1982 (Brueggeman et al. 1983) hence this species may still use the Unimak Pass area during migration.

Right whales occur in northern waters (north of 50°N) only during the summer (April-September). Pacific right whales, like other right whales, feed in surface waters on planktonic crustaceans, primarily copepods such as *Calanus cristatus* and *C. plumchrus*.

Gray Whale (*Eschrichtius robustus*)

The gray whale is the most numerous and most thoroughly-studied whale occurring within the study area. It is a coastal species with regular, well-defined patterns of migration. Although classed as an endangered species (reduced to low populations by intensive whaling), gray whales in the eastern Pacific have recovered to population levels at or near their pre-exploitation stock size (Braham 1984b). Results of the numerous recent studies of this species have been summarized by Lowry et al. (1982b).

The majority of the estimated 17,000 eastern Pacific gray whales (Rugh 1984, Reilly 1984) migrate annually from breeding/calving lagoons off Baja California and mainland Mexico to feeding grounds that extend from the central Bering Sea northward and eastward into the Chukchi and Beaufort seas. All (or most) of the gray whales entering the Bering Sea travel through Unimak Pass (Braham et al. 1982, Hessing 1981). The coastal distribution and absence of sightings of gray whales in the Fox Islands is evident in Figure 4A-3. Scattered groups summer along much of the migration corridor although none have been reported residing within our study area.

The northward migration occurs in two pulses, the first consisting of nonparturient adults and immature animals, the second principally of females and their calves of the year (Braham 1984a). These migrants move through Unimak Pass near the eastern shore (west coast of Unimak Island) between March and June (Braham 1984a) and then continue along a narrow

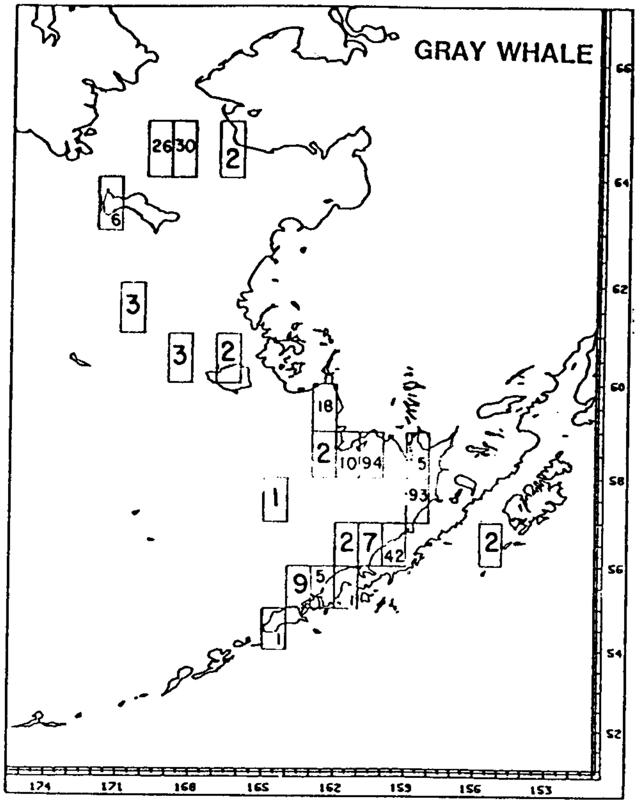


Figure 4A-3. Distribution of gray whale individuals observed in 1° blocks in the southeastern Bering Sea (from Leatherwood et al. 1983).

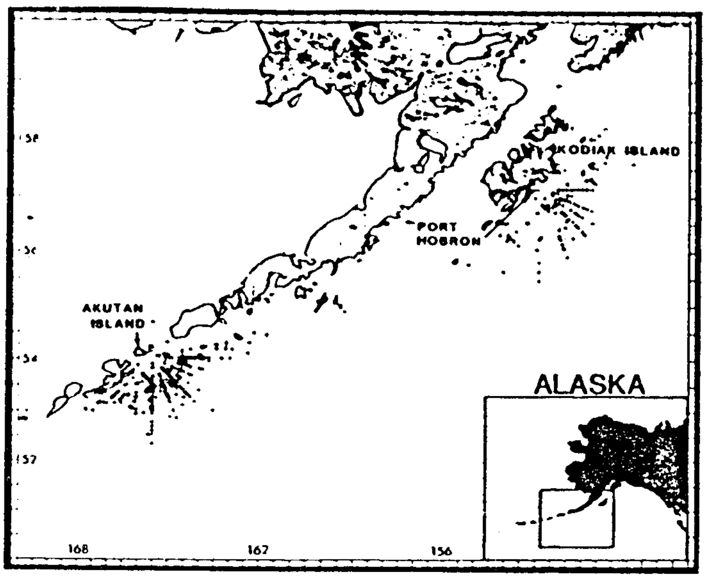


Figure 4A-4. Catch distribution of blue whales off Akutan Island and Port Hobron whaling stations, 1917-39 (from Brueggeman et al. 1985).

coastal corridor into Bristol Bay. A few may migrate directly northwestward to the Pribilof and St. Matthew islands.

The southbound migration has not been as clearly described. Based on shore censuses of gray whales migrating through Unimak Pass in fall 1977-79, Rugh (1984) concluded that the exodus from the Bering Sea occurs from late October through early January, with peak numbers passing during mid-November and mid-December. Again gray whales remain very close to shore as they transit the Unimak Pass area (Rugh and Braham 1979). Rugh (1984) found no whales more than 3.7 km west of Unimak Island; the observed whales moved by a median distance of 0.5 km from shore.

Gray whales feed almost exclusively on nektobenthic, epifaunal, and infaunal invertebrates (see Nerini 1984 for a complete list of known prey genera). Primary prey in certain parts of the northern Bering and Chukchi seas are ampeliscid and gammarid amphipods that form dense mats. The distribution of gray whales during the summer is probably determined by the presence of large amphipod beds. Important amphipods in the summer diet include Ampelisca macrocephala, Lembos arcticus, Anonyx nugax, Pontoporeia femorata, Eusirus sp., and Atylus sp. (Tomilin 1957). Gray whales also consume polychaetes, small bivalves, gastropods, ascidians, priapulids, isopods, mysids, herring and sand lance (Zimushko and Lenskaya 1970, Frost and Lowry 1981, Nerini et al. 1980). Gray whales, (contrary to previous belief) apparently feed during migration (Braham 1984a) although the frequency and intensity of feeding during migration is much less than during the summer. Despite intensive observation effort very little feeding activity has been observed in the Unimak Pass area (Nerini 1984) although Gill and Hall (1983), during an April aerial survey, classified 50% of the whales seen at Unimak Island as feeding.

Blue Whale (Balaenoptera musculus)

Another endangered species, the blue whale is not to be expected in any appreciable numbers within the study area. Historically vessels based at the Akutan whaling station regularly took blue whales (Reeves et al. 1985). Brueggeman et al. (1985) report that an average of 43.9 blue whales were taken per year from 1917 through 1939. Most of these were taken within 55 nm of the station, primarily south of the chain. Rice

(1974) considered the area south of the eastern Aleutian Islands between 160°W and 180° to have been a major summer concentration area. Use of the area (based on timing of captures) peaked in June. The available information suggests that the Bering Sea portion of our study area was historically of little importance to blue whales (Fig. 4A-4).

In most of the North Pacific, blue whales are primarily euphausiid eaters (Nemoto 1957, 1970; Kawamura 1980). Euphausiids preyed upon include Thysanoessa inermis, T. longipes, and T. spinifera. 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. According to Nemoto (1959), blue whale occurrence in the Bering Sea is related to euphausiid abundance in the area and further south. If euphausiids are abundant south of the shelf few blue whales move into the area.

Fin Whale (Balaenoptera physalus)

Fin whales were formerly abundant in the southeast Bering Sea and along the south side of the Aleutian Islands. This abundance is shown by the large numbers of fin whales killed by shore-whalers operating from Akutan (Reeves et al. 1985), by Japanese whalers operating around the Aleutians and along the continental shelf northwest from Akutan towards the Pribilofs (Nemoto 1963), and by Soviet whalers operating with pelagic fleet expeditions to the eastern Bering Sea (Berzin and Rovnin 1966 cited in Leatherwood et al. 1983).

The Japanese take in particular suggests an affinity of fin whales for the shelf edge north of the Aleutians. There were heavy catches from 1954 to 1964 in the waters between about 54°N and 55°N and 165°W and 172°W (Nemoto 1963, Nishiwaki 1966, Nasu 1966). This productive whaling ground for fin whales is centered in our area of interest. Nasu (1974) attributed concentrations of fin whales northwest of Unalaska Island to the presence of an oceanic front and associated high marine productivity.

Observations by Japanese scouting boats indicate that fin whales continue (1965-1979) to exist at relatively high levels of abundance in our area of interest (Wada 1980). Also, Figure 4A-1 shows that relatively large numbers of fin whales still occur in the Unimak Pass area and along the 100 m contour north of there. Lowry et al. (1982b) list the area "north of Unalaska Island" as one of the areas where fin whales are most often sighted. However, Leatherwood et al. (1983) did not record any fin whales in our area of interest.

All of the sightings of fin whales made by Leatherwood et al. (1983) were in water less that 110 m indicating that this species regularly inhabits continental shelf waters.

Leatherwood et al. (1983) encountered fin whales in the Bering Sea only between April and September. Most are presumed to be present for only the six-to-eight month spring-to-fall period, but there are records from off the Commander and Aleutian islands through October and November (Votrogov and Ivashin 1980). Some fin whales reportedly winter in the Bering Sea, e.g., near the Commander Islands (Barabash-Nikiforov 1938), and others may winter at the ice edge near St. Matthew Island (Brueggeman et al. 1983). The "American" stock may migrate annually between Baja California and the Bering and Chukchi seas (Lowry et al. 1982b). Migration in and out of the Bering Sea is via Unimak Pass, and perhaps to a lesser extent via other passes to the west.

Fin whales prey within the pelagic food web. Fin whales are probably the most polyphagous of the baleen whales (Lowry et al. 1982b). 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.

The diet comprises mostly euphausiids and copepods although fish are also taken and may be important in the northern Bering (Nemoto 1959). In the Bering Sea Thysanoessa inermis is the most important euphausiid prey of fin whales, as well as most other baleen whales. This euphausiid forms extensive swarms over the continental shelf margin from July to September (Nemoto 1970). Calanus cristatus is the most important copepod prey of fin whales in the Bering Sea (Nemoto 1959). Only the copepodite-5 stage, an immature form which is present in near-surface waters, is eaten by the whales. Copepods tend to be an important food item in spring and early summer when water temperatures are low; later in the year euphausiids assume greater importance.

The diet of 156 fin whales taken on the continental shelf consisted of 97% fish (mostly pollock), and only 3% copepods; the pollock were apparently restricted to fish less than 30 cm. Herring and capelin are also frequently eaten. Fin whales also eat Arctic cod, saffron cod, Pacific cod, Atka mackerel, rockfish, sand lance, smelt, Japanese anchovy, Pacific saury, and chum salmon, among others (Tomilin 1957). Squid are occasionally taken.

Sei Whale (*Balaenoptera borealis*)

Sei whales, in general, prefer subtropical to cold temperate pelagic regions and avoid polar waters (Tomilin 1957). Like other balaenopterids, sei whales apparently migrate to lower latitudes in winter and to high latitudes in summer. Thus, they would be expected well south of our area of interest during winter months. In summer, sei whales were found regularly at locations along the Aleutian Islands including Unimak Pass (Murie 1959, Nishiwaki 1966, Masaki 1977, and Wada 1980).

The sei whale population has been dramatically reduced since the early 1960's when intensive whaling began for this species. Sei whales were rarely taken by the shore whalers at Akutan during the first 40 years of the twentieth century (Reeves et al. 1985).

Sei whales feed on a variety of marine organisms but copepods dominate their diet (Gambell 1977, Nemoto and Kawamura 1977). In a sample of approximately 12,000 sei whale stomachs collected (21,713 stomachs were examined, 9665 were empty) in the North Pacific, copepods (*Calanus* spp.) were found most often (83%), followed by euphausiids (13%), fishes (3%), and squid (1%) (Nemoto and Kawamura 1977). Among the fishes eaten are smelt, sand lance, Arctic cod, rockfishes, greenlings (*Hexagrammos* sp.), pollock, capelin, and sardines. So few sei whales have been taken in the Bering Sea that there is little information on prey for that area.

Minke Whale (Balaenoptera acutorostrata)

The minke whale has a worldwide distribution. Because of its small size, however, it was not a major target of commercial whalers in most areas until the reduction in populations of larger, more valuable species required a shift in whaling effort. The lack of whaling effort has resulted in a poor historical record for this species in comparison with that of the previously discussed whales.

Minke whales are common during the spring and summer months in the Bering Sea and coastal Gulf of Alaska (see Stewart and Leatherwood 1985). Frost et al. (1982) state that this species is most abundant in the Aleutians from May to July. The minke whale is the most numerous baleen whale in the study area (Braham et al. 1977). Scattergood (1949) learned from employees of the American Pacific Whaling Company that minke whales were abundant near Akutan although they were infrequently taken.

Minke whales are found in shallow shelf waters as well as deep areas far from shore (Fiscus et al. 1976, Lowry et al. 1982b, Strauch 1984, Armstrong et al. 1984). It has been suggested that minke whales occupy the St. George Basin year-round, with greatest concentrations in summer (May to July) near the eastern Aleutian Islands (Braham et al. 1982). Sightings indicate that winter densities are lower and that the animals are generally found farther from shore during winter.

Direct evidence concerning diets of minke whales in the southeast Bering Sea is sparse, but Frost and Lowry (1981) indicated that euphausiids and pelagic and semidemersal fishes, including herring, are taken. Leatherwood et al. (1983) reported seeing minke whales swim through (and presumably feed upon) schools of fish (thought to be herring) in Bristol Bay.

In the North Pacific, euphausiids and shoaling fishes are major foods of minke whales; pelagic squids and copepods are of lesser importance (Nemoto 1970). The euphausiid Thysanoessa inermis again appears to be the most important invertebrate. Fish taken include herring, Atka mackerel, capelin, Pacific cod, Arctic cod, saffron cod, pollock, sand lance, Pacific saury, sardines (Sardinops sagax), and anchovy. Minke whales are often seen near the surface pursuing small pelagic fish; this results in reports of their associations with seabirds (Stewart and Leatherwood 1985).

Frost and Lowry (1981) reported on the stomach contents of a minke whale stranded on Unalaska Island (our area of interest); it contained only pollock.

Humpback Whale (Megaptera novaeangliae)

The humpback whale is another endangered species occurring within our area of interest, formerly in some abundance. At least 1793 humpbacks were landed at Akutan from 1914 to 1939 (Leatherwood et al. 1983). Humpbacks were caught mainly in the Pacific, Unimak Pass, and the Bering Sea just north of the pass (Reeves et al. 1985). Large numbers of humpbacks could still be found around the eastern Aleutians and south of the Alaska Peninsula from 150°W to 170°W (Rice 1974) during the early 1960's. Berzin and Rovnin (1966 cited in Leatherwood et al. 1983) considered "the center of the summer habitat" of humpbacks in the North Pacific to be between 145°W and 170°W, south of the Aleutians, and "to the north of Unimak Strait."

Recent observations indicate that humpbacks continue to be widely distributed during summer on the continental shelf of the southeastern Bering Sea (mostly outside our area of interest) (Nemoto 1978, Strauch 1984) and in the Unimak Pass area (Braham et al. 1982, Figure 4A-5). All observations of humpback whales made by Leatherwood et al. (1983) were in shallow shelf waters less than 154 m deep.

The sightings in the Unimak Pass area demonstrate that humpbacks are commonly seen there, mainly along the narrow shelf to the west of the pass. Judging by seasonal plots, humpback distribution expands during summer and fall into many parts of the southeastern Bering Sea as well as along both the north and south sides of the Aleutians. Humpback whale use of the area of interest is likely to be predominantly from April through October.

Humpback whales prey within the pelagic food web. In the North Pacific, both zooplankton and fishes are major foods of humpbacks (Nemoto 1957, 1959, 1970; Tomilin 1957; Kawamura 1980; Winn and Reichley 1984). In the northern part of the North Pacific, Nemoto (1959) found only

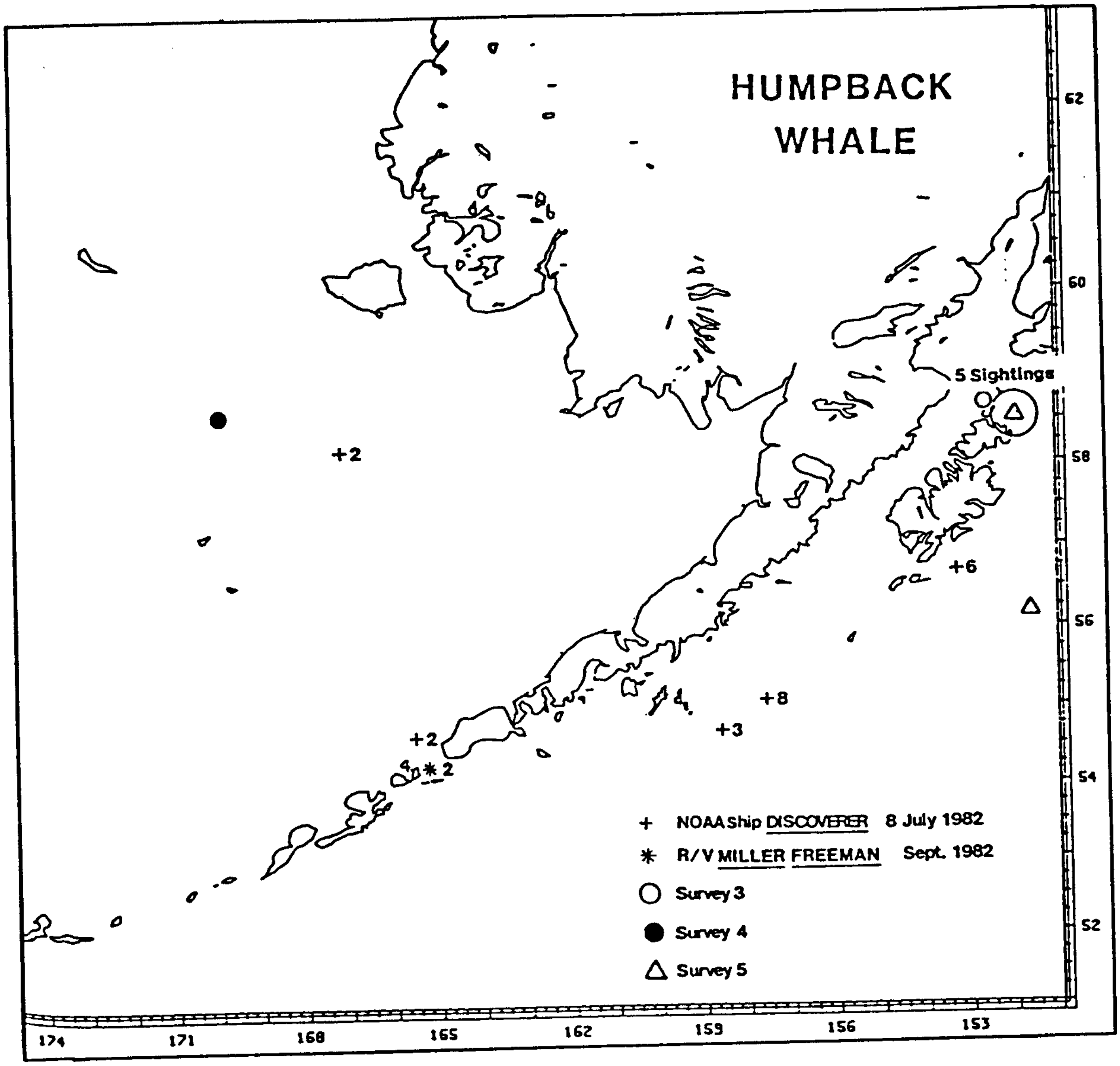


Figure 4A-5. Sightings of individual humpback whales in recent surveys in the southeastern Bering Sea (from Leatherwood et al. 1983).

euphausiids in 203 of 272 stomachs containing food. Fifty-three stomachs contained only fishes, and the remainder was a combination of fishes and euphausiids. Squids were present in only two stomachs. The pollock in the diet are predominantly of fish 40-50 cm in length (larger than the size class selected by fin whales). Near Attu and south of Amchitka humpbacks eat Atka mackerel (Nemoto 1957), whereas in other portions of the Aleutians they feed on euphausiids and pollock (Nemoto 1959). Other fish eaten by humpbacks include herring, capelin, sand lance, smelt, cods, salmon (pink and chum), rockfishes, greenling, saffron cod, and Arctic cod (Nemoto 1959, Tomilin 1957).

Sperm Whale (Physeter macrocephalus)

Large numbers of sperm whales were caught in the North Pacific by nineteenth century whalers, but most of this activity took place well south of our study areas, in fact south of 40°N (Bannister and Mitchell 1980). However, sperm whales were taken by the Akutan whalers (Reeves et al. 1985).

Berzin (1971) mentions a herd of 80-100 sperm whales north of the eastern Aleutians during January 1964 but this species occurs this far north mainly during summer and fall, in or near Unimak Pass and on the continental slope west of the pass. In September, many of the sperm whales that summered there begin to move south. Very few females have been recorded in the Bering Sea; most remain south of 45°N. (The paucity of female sperm whales within our area of interest is evident in the maps in Smith 1980.)

Sperm whales show a clear preference for deep waters at the shelf edge, on the continental slope, or over deep offshore canyons. Berzin (1971) states that the range of sperm whales is approximately limited by the 300 m isobath. The distribution in the eastern Bering Sea shows a remarkably close correlation with the shelf edge (Nishiwaki 1966). The narrow shelf along the south side of the eastern Aleutians ensures that sperm whales appear regularly within the area of interest.

Sperm whales feed primarily upon a deepwater based food web. Cephalopod mollusks are the primary prey type. Squid, especially those of the family Gonatidae, are heavily utilized by sperm whales, although onchoteuthids are also prevalent in stomach samples from the Bering Sea. In Aleutian waters (male) sperm whales fed primarily on Galiteuthis armata, Gonatus fabricii, and Taonius pavo (Tarasevich 1968b). A list of squid species found in Bering Sea and Aleutian sperm whale stomachs can be found in Laevastu and Fiscus (1978). There are few records of sperm whale stomachs with high bony fish counts, suggesting that fish are rarely the primary prey (see Braham et al. 1982). Tomilin (1957) found skates and sharks to be more important for sperm whales than were bony fishes, although the whales do eat such species as salmon, Pacific saury, pollock, greenlings, lancetfish, Pacific cod, smooth lumpsucker, rockfish, sculpins, and lamprey. Fishes were quite important in some samples from the Gulf of Alaska, the eastern Bering Sea (east of 170°E), and along the shelf break (Berzin 1959, Okutani and Nemoto 1964, Kawakami 1980). In the Bering Sea and along the Aleutian coasts between 180° and 160°W fish were found in 7-29% of sperm whale stomachs (Kawakami 1980). Tarasevich (1968a) found that fishes were eaten more frequently in spring than in summer and suggested that this is because squids do not become plentiful until summer. He also found that male sperm whales ate more fish than did females. The fishes most commonly eaten include rockfishes, cod, sharks, skates, lancetfish, lumpsuckers, lampreys, and rattails.

Killer Whale (Orcinus orca)

Killer whales occur in all oceans and may be encountered in marine waters anywhere. Killer whales occur both north and south of the Aleutians; they are particularly common in the eastern islands (Braham et al. 1977). Near the eastern Aleutian Islands killer whales occur primarily on the continental shelf in waters less than 200 m deep and along the 200 m contour northwest to 60°N (Braham and Dahlheim 1982, Braham et al. 1982) (Figure 4A-6).

Killer whales probably occur year round within the area of interest. Leatherwood et al. (1983) found that killer whales make equal use (sightings proportional to survey effort) of continental shelf, continental slope, and pelagic waters.

Killer whales are opportunistic feeders and have one of the most diverse diets of all marine mammals. The varied diet reported worldwide

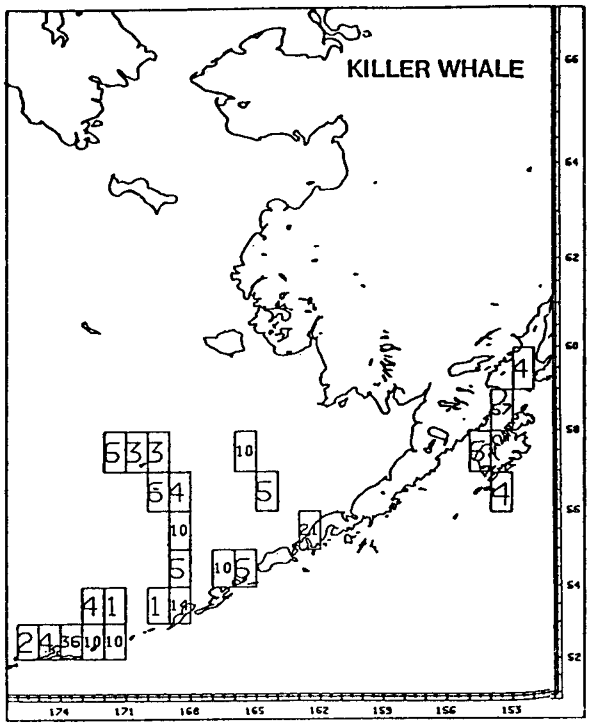


Figure 4A-6. Distribution of individual killer whales sighted in 1° blocks in recent surveys in the southeastern Bering Sea (from Leatherwood et al. 1983).

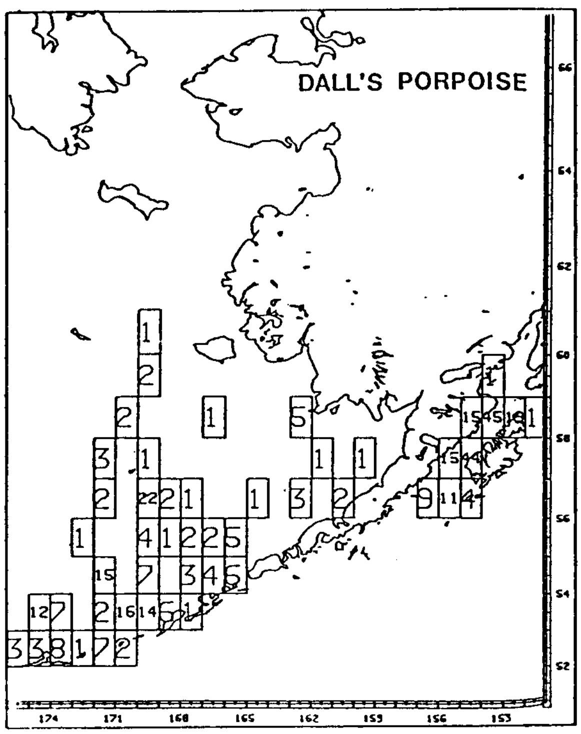


Figure 4A-7. Distribution of individual Dall's porpoises sighted in 1° blocks in recent surveys in the southeastern Bering Sea (from Leatherwood et al. 1983).

includes seals, sea lions, cetaceans, fishes, sharks, seabirds, sea turtles, and squids (Rice 1968, Caldwell and Caldwell 1969). Pods of whales use coordinated feeding behavior when preying on marine mammals (e.g., Smith et al. 1981) and perhaps also on fishes (herring) (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. Killer whales are opportunistic feeders (Dahlheim 1981); they appear to feed upon fish when locally abundant and to switch to marine mammals when fish are less available (Braham and Dahlheim 1982). Known marine mammal prey in the North Pacific and Bering Sea includes fur seals (Bychkov 1967); walruses; sea lions; elephant seals; harbor porpoises; Dall's porpoises; right, humpback, gray, fin, and minke whales; and sea otters (Tomilin 1957, Rice 1968). Principal types of fishes eaten are cods, flatfishes, and sardines (Nishiwaki and Handa 1958, Rice 1968, Fiscus 1980). Although in other areas killer whales are known to prey extensively on herring (Tomilin 1957, Dahlheim 1981), this relationship has not been documented in the Bering Sea.

Dall's Porpoise (Phocoenoides dalli)

Probably the most numerous cetacean in the area of interest, Dall's porpoise is present year-round. Dall's porpoise is distributed widely within the cool temperate to subpolar waters of the North Pacific. Most sightings in the Gulf of Alaska have been made in waters in the 7° to 14°C range (Braham and Mercer 1978). They are most abundant in deep pelagic waters and in areas along the continental shelf break. Summer observations, particularly June and July (e.g., Wahl 1978), indicate that Dall's porpoises are abundant near the Aleutian Islands and along the edge of the continental shelf, particularly from the Pribilof Islands to Unimak Pass (Fig. 4A-7). Migratory movements are not well understood but seasonal movements are evidently present (Braham et al. 1982). The distribution shifts southward in winter, with some animals leaving the Bering Sea (Fiscus 1980).

Observations of the stomach contents of porpoises caught in the Bering Sea and Aleutian Islands region by the Japanese high seas salmon gillnet fishery have provided information on their foods. Stomach contents from 457 Dall's porpoises taken incidental to the Japanese salmon fishery have been described in Crawford (1981). Squids, mostly belonging to the family Gonatidae, were the major volumetric (90%) constituent of the stomachs. Euphausids occurred in about 4% of the stomachs in insignificant quantities. Fishes were identified and enumerated, based on otoliths: 33 species of epi- and meso-pelagic fishes were found. Over 94% of the number of otoliths recovered were from fishes of the family Myctophidae (principally Protomyctophum thompsoni). 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.

Dall's porpoises feed primarily upon a deepwater-based food web. Small meso- and bathypelagic fishes and cephalopods are the primary prey type. Squid, especially those of the family Gonatidae are heavily utilized by Dall's porpoise. Myctophids constitute over 94% of all fish consumed by Dall's porpoise (Crawford 1981), with capelin, herring, hake, sand lance, cod, and deep sea smelts also constituents of their diet. Many of these prey species undergo a diel vertical migration toward the surface at night. Preliminary data suggest that Dall's porpoises take advantage of this movement by feeding primarily at night. Taxa occurring in stomachs of seven animals collected near Unimak Pass and in the Bering Sea were as follows (#stomachs in parentheses, 1 stomach was empty): squid (3), capelin (3), and pollock (1).

Available data have not been examined for seasonal and regional feeding patterns. Since almost all samples have been collected during the summer months, they are probably not adequate to examine seasonal dietary differences.

Harbor Porpoise (Phocoena phocoena)

Little detailed information is available regarding the distribution of this small but common cetacean. Records within the Aleutians are not numerous (Murie 1959, Alaska Maritime National Wildlife Refuge 1981). Seasonal shifts in abundance suggests migrations of some sort occur (Leatherwood and Reeves 1978) but data are insufficient to detail the patterns. In southern portions of their range, they are generally seen near the coast in waters less than 20 m deep (Leatherwood and Reeves 1978).

Leatherwood et al. (1983) did not encounter this species in our area of interest although they did frequently record harbor porpoises within Bristol Bay, generally (79% of observations) nearshore of the 128 m contour. They appear to be restricted to nearshore, southerly waters.

Stomachs from only three harbor porpoises taken in the Bering Sea have been examined (Frost and Lowry 1981, and unpubl.). All were animals caught in salmon nets in Norton Sound. Contents of all three consisted principally of small fishes and small amounts of benthic crustaceans. Based on identifiable remains (principally otoliths), 31 of 34 fishes eaten were saffron cods. In the Atlantic, herring, cod, and sand lance are major prey (Rae 1973, Smith and Gaskin 1974).

Steller Sea Lion (Eumetopias jubatus)

This species is more densely distributed in waters near the Aleutian Islands than elsewhere (see Kenyon and Rice 1961); here they are year-round residents. The total estimated population for the eastern Aleutians (including Amak Island and Sea Lion Rock) is 30,000. The number of sea lions within the area of interest has been changing markedly over the past couple of decades; therefore, population estimates for the area and for particular colonies or haulout areas should not be used as more than general indices of presence and relative importance. During winter there is apparently an influx of sea lions into the eastern Aleutians and northeastern Pacific Ocean. Numerous haulout areas and a few breeding rookeries are known from the area of interest.

Locations of rookeries and haulout areas are shown in Fig. 4A-8 (see also Table 4A-2). Important pupping areas are Adugak and Ogchul islands off the west end of Umnak Island; Bogoslof Island north of Umnak Island; the southwest end of Unalaska Island at Cape Izigan; Cape Morgan, on Akutan Island; and Ugamak Island in Unimak Pass. Bogoslof Island, Cape

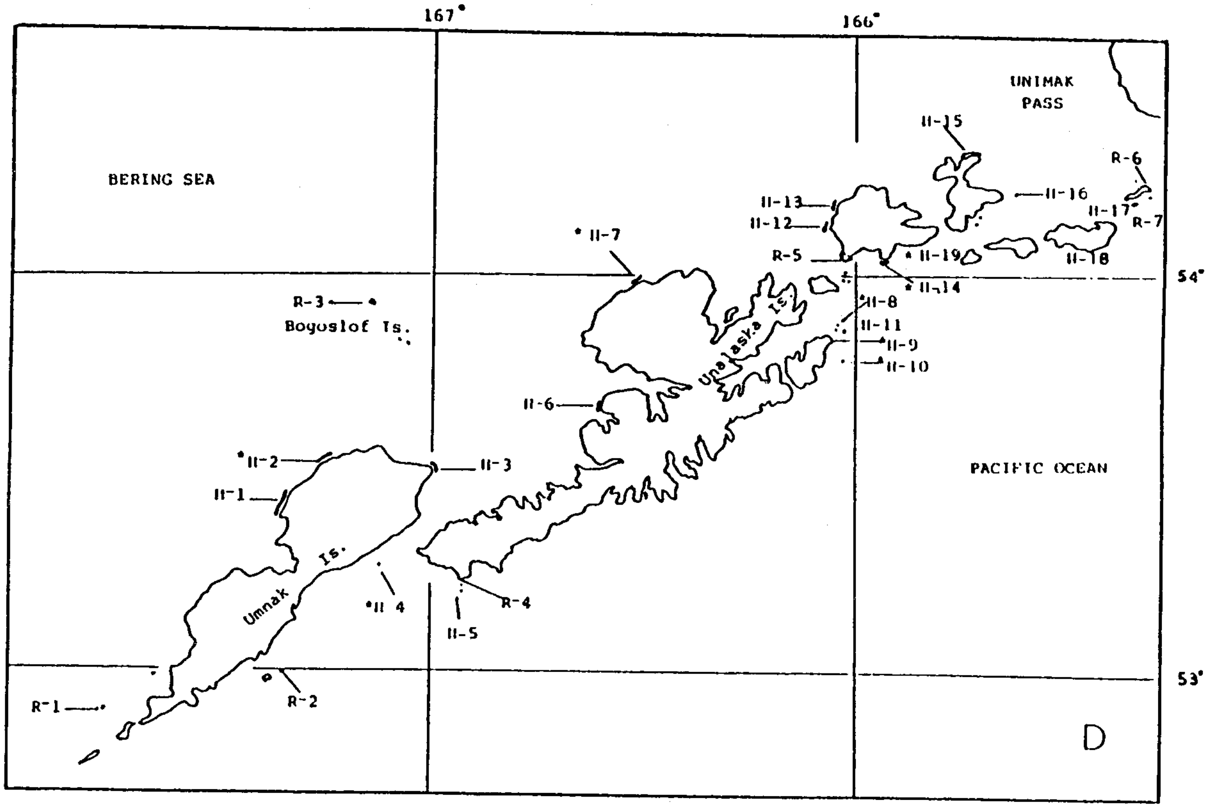


Figure 4A-8. Steller sea lion rookeries (R) and hauling grounds (H) along the eastern Aleutian Islands (Fox Island group) (from Braham et al. 1977). Numbers observed at locations are given in Table 4A-2.

Table 4A-2. Observations of northern sea lions (*Eumetopias jubatus*) from aerial surveys along the Alaska Peninsula, eastern Aleutian Islands, and Bristol Bay. Numbers are based on visual estimates or on counts taken from photographs (*). Dashes indicate areas not surveyed, blank spaces mean no animals were observed. (From Braham et al. 1977). Figure 4A-8 shows locations.

General Location	Map Reference Number	Survey Date				
		June 1975	August 1975	June 1976	August 1976	October 1976
Adugak Is.	R 1	-	1,750*	1,177*	2,000	1,400*
Cape Aslik	H 1	285	1	221*	5	-
Cape Chagak	H 2	20	0	0	0	-
Cape Idak	H 3	-		223*	2	-
Polivnoi Rock	H 4	-	231*	-	0	-
Ogchul Is.	R 2	-	947*	-	1,109*	2,441*
Bogoslof Is.	R 3	-	1,059*	3,308*	1,591*	490*
South Rock	H 5	-	30	48*	8	-
Cape Izigan	R 4	-	547*	737*	1,102*	-
Cape Starichkof	H 6	100	0	78*	0	-
Bishop Pt.	H 7	172*	13	304*	0	136*
Old Man Rocks	H 8	180*	300*	688*	0	-
Cape Sedanka	H 9		200		0	-
Outer Signal	H 10	-		68*	6	-
Sedanka Is.	H 11	-		364*		-
Cape Morgan	R 5	2,794*	3,118*	3,145*	5,924*	2,345*
Reef Bight	H 12	365	182*	874*		58*
Lava Bight	H 13	0	178*	0	300	208*
Battery Pt.	H 14	30				

Table 4A-2. Continued.

General Location	Map Reference Number	Survey Date				
		June 1975	August 1975	June 1976	August 1976	October 1976
Billings Head	H 15	748*	2,641*	1,050*	2,032*	1,130*
Tanginak Is.	H 16	470*	3	358*	20	60*
Rocks, n.e. of Tigalda Is.	H 17	80		274*	22	30*
Tigalda Is.	H 18			314*	19	65
Ugamak Is.	R 6	2,500*	4,630*	4,673*	1,443*[1]	3,765*
Round Is.	R 7	-	175*	246*	134*	158*
Rock, north of Rootok Is.	H 19	118*	46*			66*
Amak Is.	H 20	927*	2,316*	1,777*	1,356*	905*
Sea Lion Rock	R 8	2,006*	2,126*	1,944*	2,331*	1,836*
Unnamed Rock (near Amak Is.)	H 21	108*	234*	132*	355*	110*
The Twins, (Walrus Islands)	H 22	50	30		-	-
Round Is.	H 23	325*	244*	296*	-	-

[1] partial survey

Morgan and Ugamak Island are the largest, accounting for over 50% of the total animals seen on breeding islands or sites (Braham et al. 1977, Braham et al. 1980). Pupping occurs throughout June (Braham et al. 1977).

Fiscus and Baines (1966) reported that sea lions in Unimak Pass foraged 5 to 15 miles away from their haulout areas. Pollock comprise roughly 80% (wet-weight volume) of the sea lion diet. Capelin, herring, Pacific cod, shrimps, and crabs are other dominant prey (Braham et al. 1982, Lowry et al. 1982b). Most studies of Steller sea lion food habits have been made southeast of our area of interest. Fiscus and Baines (1966) reported on a small sample (7) from the Unimak Pass area and found the prey ranking in order of importance to be capelin, sand lance, and sculpins.

Sea lion populations have declined in the eastern Aleutian Islands (Braham et al. 1977, Loughlin et al. 1984) and some other portions of the Bering Sea, including Amak Island (Frost et al. 1982) and the Pribilof Islands, since the late 1970's. For example, counts at the haulout areas on Unimak Island, including Sea Lion Point/Cape Sarichef, Oksenof Point, and Cape Mordvinof, have been as high as 4000 in the past (1960) but were less than 100 in 1975-77. The current status of the sea lion population is unknown, but between 1971 and 1975 the decline was estimated to be 50% (Braham et al. 1982). The causes for these apparent changes are unknown; however, the apparent decline in the eastern Aleutians corresponds to a concurrent increase in commercial groundfish fisheries for preferred sea lion foods (Braham et al. 1980). Fowler (1982) has recently suggested that entanglement with net fragments in areas of intense foreign fishing may be a significant (>5%) source of mortality for fur seals, and the same may be true for sea lions. King (1983) lists the pathogen *Leptospira pomona* as possibly being responsible for the sea lion decline.

Northern Fur Seal (*Callorhinus ursinus*)

Over 70% of the world's population of northern fur seals breeds and pups on the Pribilof Islands (U.S. Dept. Commerce 1985, Braham et al. 1982). From late May through early November, most of these animals are found in the Bering Sea. During the summer, adult females and subadult animals range far from the Pribilof Islands in search of prey. Most of these animals appear to move south toward the shelf break, but others disperse widely over the shelf, including into midshelf waters. Many go as far as Unimak Pass and the eastern Aleutians (Harry and Hartley 1981). An unknown number of adult males may overwinter in Bristol Bay (Braham et al. 1982) and Unimak Pass (Kenyon and Wilke 1953). During winter most seals remain 46 to 93 km offshore. Figure 4A-9 summarizes information on the pelagic distribution of fur seals and indicates that the Bering side of our area of interest is an area of relatively high density of fur seals.

All the eastern Aleutian passes (Wilke and Kenyon 1957), but apparently primarily Unimak (North Pacific Fur Seal Commission 1971, Braham et al. 1982), serve as migration corridors in spring (April-June) and fall (August and November). Fur seal encounters are frequently reported from Akutan Pass (e.g., Kenyon and Wilke 1953, North Pacific Fur Seal Commission 1969). In May, June, and early July pregnant females predominate among seals moving north through the pass. From late July through early October post-partum females are dominant in feeding areas near Unimak Pass. Young seals of both sexes are found in Unimak Pass from July to October. Some post-partum females feed south of Unimak Pass (North Pacific Fur Seal Commission 1971). Young-of-the-year migrate south through the eastern Aleutian passes between mid-November and early December (Fiscus 1978). Whereas Bigg (1985) reports that one-year-old females may still be arriving at the Pribilof Islands during early November it follows that their departure from the Bering Sea, presumably through Unimak Pass, should occur later in the year, perhaps with the young-of-the-year. A small group of northern fur seals, including two females, each with a pup, was found in our area of interest on Bogoslof Island (Lloyd et al. 1981).

Fur seals feed primarily at night and early in the morning. In areas where food species remain in upper water layers, fur seals are known to feed actively throughout the day. Their major foods remain the same each year, changing only in rank of importance. North Pacific Fur Seal Commission (1962) reported pollock and squid as being the principal food in the Bering Sea with capelin and sand lance increasing in importance near islands. Other prey reported in their diet include seal fish (Bathylagus sp.), salmon, and lamprey. In Unimak Pass capelin and Atka

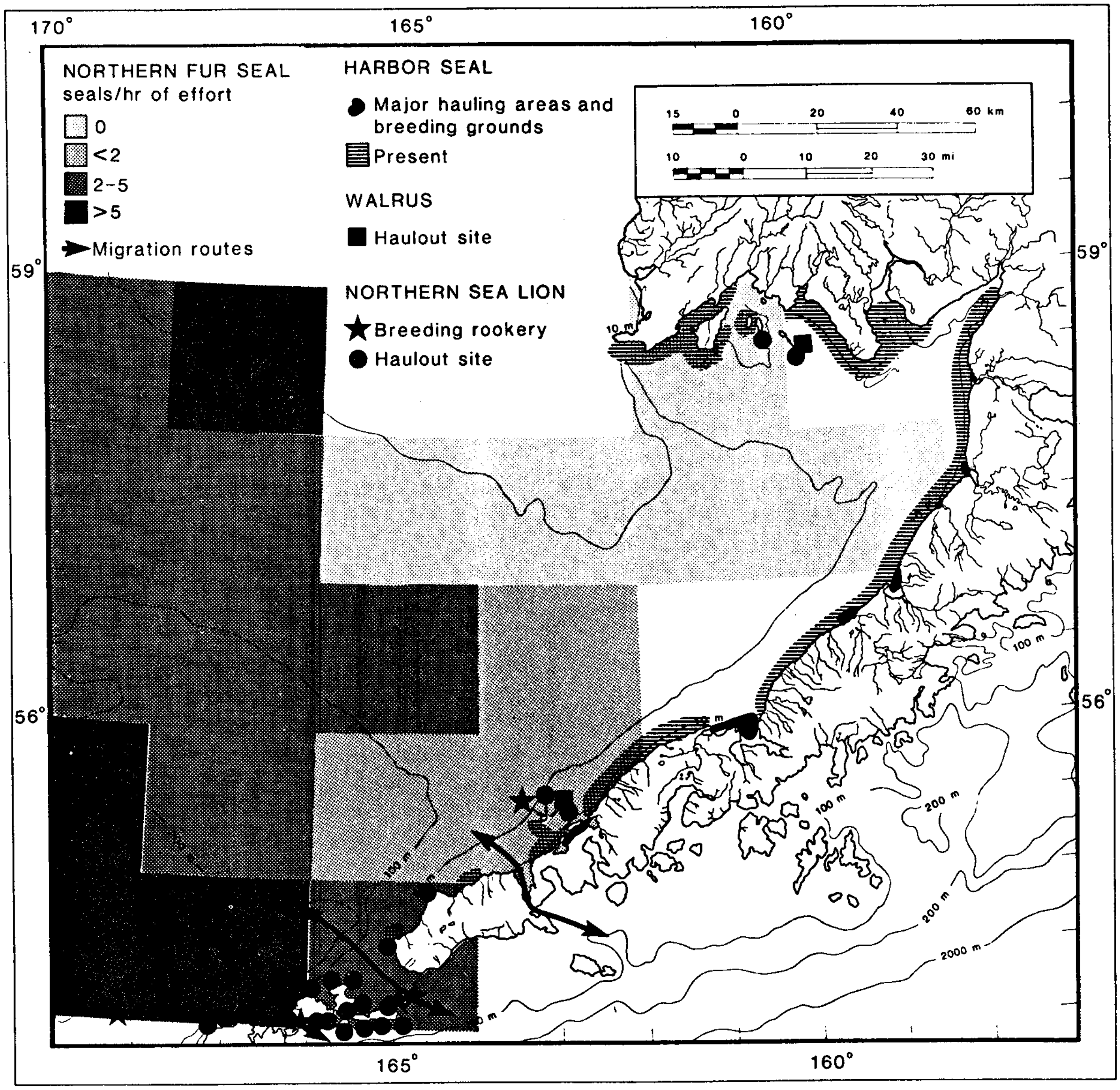


Figure 4A-9. Distribution and abundance of harbor seals and northern fur seals across the southeastern Bering Sea shelf. Haulout areas and breeding sites for seals, sea lions, and walruses are indicated (from Armstrong et al. 1984).

mackerel were listed as the major food items (North Pacific Fur Seal Commission 1971). Prey in the Bering Sea include capelin, walleye pollock, Atka mackerel, deep sea smelt, and gonatid squids (Berryteuthis magister and Gonatopsis borealis).

Fishes of the gadid and osmerid families and gonatid squid make up the most important components in the fur seals' diet in the eastern Bering Sea. The primary species taken are walleye pollock, capelin, and Berryteuthis magister. In Unimak Pass the most important species were capelin, followed by the squid Berryteuthis, pollock, and Atka mackerel (some seasonal variability in diet).

Harbor Seal (Phoca vitulina)

Harbor seals occur in littoral waters throughout the area of interest (Fig. 4A-10, Table 4A-3). Concentrations occur at the Baby Islands, off the northwest end of Tigalda Island, Rootok Island, Inner Signal, Emerald Island, and Samalga Island (Braham et al. 1977, Everitt and Braham 1978). The population throughout the eastern Aleutian Islands is estimated to be approximately 4000 seals (Everitt and Braham 1978, 1980; Braham et al. 1977). With respect to populations on the Alaska Peninsula and elsewhere in the Aleutians, these populations are small. They appear to be resident, breeding on the islands and feeding year-round in adjacent waters.

Haulouts are used for resting, molting, and care of young. Seals haul out on sand bars and other areas exposed by the tides; more animals have been observed hauled out at low than at high tides (Everitt and Branam 1980). Peak use of haulout areas occurs during the molt in June and July and apparently tapers off in September and October when seals spend more time in the water.

As with most other aspects of harbor seal biology in the eastern Aleutian Islands, information on diet is lacking. Harbor seals appear to be largely piscivorous, consuming large quantities of pollock, sand lance, Pacific cod, capelin, smelts, herring, greenling, and cottids (Lowry et al. 1982a, b). These seals are also known to feed on shrimps, Tanner and king crabs, octopus, halibut, and squid. Lowry et al. (1979) reported that seals collected in three different locations in the Aleutian Islands

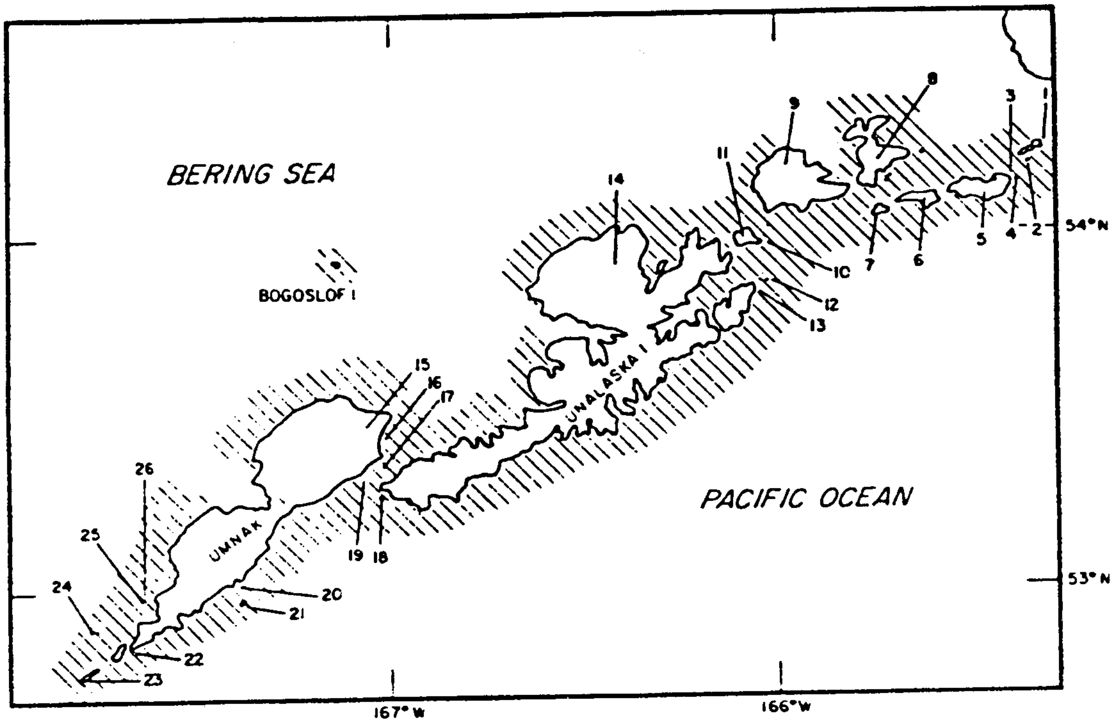


Figure 4A-10. Haulout areas for harbor seals in the eastern Aleutian Islands. Hatched lines indicate presence of harbor seals; numbers refer to the locations listed in Table 4A-3.

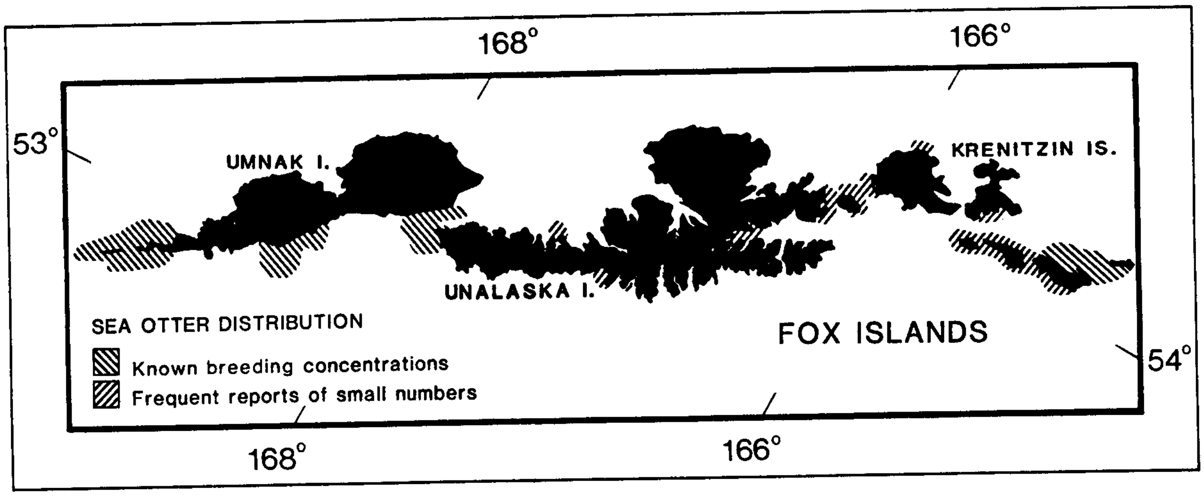


Figure 4A-11. Sea otter distribution around the Fox and Krenitzin islands (from Schneider 1981).

Table 4A-3. Counts of harbor seals by haul and location, observed during aerial surveys in the eastern Aleutian islands, 1975-77 (Everitt and Braham 1980). Numbers are maximum counts for each location by month. Dash (--) means the area was not surveyed.

Ref. no.	Surveyed locations	June 1975	August 1975	June 1976	August 1976	June 1977
1	Ugamak Island	--	30	--	--	0
2	Aiktak Island	50	62	--	100	149
3	Rocks N.E. of Tigalda I.	1	40	4	88	130
4	Kaligagan Island	75	50	--	308	94
5	Tigalda Island	0	76	99	349	0
6	Avatanak Island	44	135	78	107	6
7	Rootok Island	68	131	54	387	101
8	Akun Island	20	146	71	179	35
9	Akutan Island	0	24	57	99	13
10	Baby Islands	178	184	149	430	215
11	Unalga Island	72	37	41	161	32
12	Egg Island	0	80	5	28	0
13	Inner Signal Island	--	50	100	490	290
14	Unalaska Island	612	483	156	173	262
15	Umnak Island	8	148	41	415	199
16	Putsoi Island	12	50	--	40	59
17	Ship Rock	2	0	8	7	4
18	Emerald Island	53	227	15	163	217
19	Black Rock	0	0	0	40	--
20	Kigul Island	--	10	--	25	23
21	Vsevidof Island	0	0	--	71	47
22	Breadloaf Island	--	26	--	28	0
23	Samalga Island	--	178	--	129	84
24	Adugak Island	0	60	0	11	0
25	Annaniulak Island	5	39	0	5	4
26	Pancake Rock	0	13	22	115	2
	Total	1,200	2,279	900	3,948	1,966

had different items in their stomachs. Pollock and cod were found in three stomachs from Unalaska Island. Five seal stomachs from Akun Island contained primarily Pacific cod, octopus, and pollock (Lowry et al. 1982b).

Sea Otter (Enhydra lutris)

Sea otters were formerly widespread and abundant near land throughout the southern Bering Sea, but fur hunting reduced the population to a small colony near Unimak Island and perhaps a few individuals in the Fox Islands. During the past 70 years the number of sea otters has increased remarkably, but large areas of uninhabited or partially repopulated habitat remains (Schneider 1981).

Sea otters are shallow-water animals rarely seen in water deeper than 55 m. Leatherwood et al. (1983) did find "significant" numbers of individuals to depths of 128 m. Distribution and movements within the Bering Sea have been described by Schneider (1981). The area of highest abundance just barely encroaches on our area of interest, extending from mid-Unimak Island east to beyond Izembek Lagoon.

Four separate colonies became established in the Fox Islands during the 1960's. All are growing rapidly, but they amount to only a few hundred animals, and most of the reproductive animals remain concentrated in small areas (Fig. 4A-11) (Kenyon and King 1965, Schneider 1981). Tigalda Island appears to support most of the reproductive portion of the area's sea otter population. Use of our area of interest was no doubt substantially greater in the past than it is today.

Sea otter pups may be born during any month; however, in the Aleutians the majority of young are born in late spring and summer (Kenyon 1978). During summer otters are more widely distributed (less confined to the nearshore) and some are found in the deep water north of the Aleutians (Leatherwood et al. 1983). As winter advances sea otters move to the west and possibly south of the peninsula. If a southward migration occurs, False Pass has been hypothesized to be the primary route (see Armstrong et al. 1984).

Sea otters are highly opportunistic feeders and will exploit and often deplete whatever species might be available. In the western Aleutian Islands, for example, benthic invertebrates (mostly sea urchins) comprised the entire diet of newly established otter populations, but fishes were the major prey of long-established populations, probably due to cnanges in prey availability (Estes 1986).

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 major groups, by volume, to be fishes (50%), mollusks (37%), and echinoderms (11%). In other areas of Alaska sea otters feed on herbivorous epibenthic macroinvertebrates such as sea urchins, limpets, chitons (Simenstad et al. 1978), clams, crabs, and sea stars (Calkins 1978).

The diet of sea otters near or within the study area has not been comprehensively examined. Kenyon (1969) found mainly clams, hermit crabs, and fish (greenling) in stomachs of three otters from north of Unimak Island. Results of studies on the North Aleutian Shelf indicate that bivalves (mussels), crabs, echinoderms (sand dollars), and fish (yellowfin sole) are important (Cimberg et al. 1984, LGL in prep.). Both these latter studies relied on scat analyses, which do not permit an accurate evaluation of the proportion each taxon contributes to the overall diet. For example, sand dollars have much more indigestable material in relation to flesh than do flatfish.

B. BIRDS

by Declan M. Troy

Unimak Pass is one of the major migration corridors for bird populations entering and leaving the Bering Sea (Strauch and Hunt 1982, Thorsteinson 1984). The abundance of birds in the Unimak area is so large and regionally important that potential impacts of ocean transportation in this area are listed as being of concern for developments as far away as the Navarin Basin (Jarvela et al. 1984). An estimate of 1.1 million shearwaters has been recorded in the pass in the fall (see Armstrong et al. 1984). The mean density of all species using the pass in summer was estimated by Strauch and Hunt (1982) to be 224 birds/km^2 or 720,000 birds in the pass area. Hunt et al. (1982) identified the Unimak Pass area as one of the regions in the southeastern Bering Sea with the consistently highest densities of seabirds; for this reason these authors thought the pass area to be very sensitive to potential oil spills.

Two species of endangered birds--Aleutian Canada Goose and Short-tailed Albatross--have been found within the Unimak Pass/eastern Aleutian Islands area. The Short-tailed Albatross occurred regularly in our area of interest before its population was reduced to the brink of extinction. Bones of this species are found in archaeological excavations in our area (e.g. Rauzon 1976, Yesner and Aigner 1976). A juvenile Short-tailed Albatross was reported seen northwest of Akutan Island (at 54°29'N, 166°13'W) as recently as August 1985 (see Gibson 1985). Neither species is known to breed in or regularly use the study area. (It is quite distant from the historical breeding distribution of Short-tailed Albatross.) Aleutian Canada Geese have been encountered during the breeding season on Aiktak Island in 1981 and 1982 but evidence of nesting has not been found (Forsell 1983a,b). An estimated 50 pairs of Canada Geese nest on Chagulak Island just west of our area of interest (Bailey and Trapp 1984). East of Unimak Pass another small isolated population of Canada Geese occurs on Kaliktagik Island (Hatch and Hatch 1983).

An important trophic role for birds in the Bering Sea ecosystem has been inferred by some. Bird consumption of particular resources (e.g., walleye pollock) may be substantial, though only about 0.03% of the mid-shelf primary productivity is funneled into birds (Schneider and Hunt 1982). Armstrong et al. (1984) reasoned that the impact of birds on pelagic prey resources was probably greatest at a few specific areas, one being Unimak Pass.

Seabirds are by far the most important component of the bird fauna in terms of their numbers and biomass. Their abundances in pelagic areas change markedly with season and location. High densities of seabirds, generally resulting from large aggregations, are frequently found in and near Unimak Pass. Seasonal variation is illustrated in Table 4B-1, which summarizes densities recorded during aerial surveys between Cape Mordvinof and Akun Island (LGL 1986). These surveys show that Glaucous-winged Gulls, Crested Auklets, Short-tailed Shearwaters, Common Murres, and Black-legged Kittiwakes are the most abundant birds in the Unimak Pass area.

Abundance of some birds varies markedly with season. For example, kittiwakes and shearwaters peak during summer; Crested Auklets and murres peak during winter. Birds relatively numerous over most of the year are Glaucous-winged Gull, Northern Fulmar, Black-legged Kittiwake, Red-faced Cormorant and auklets.

Table 4B-2 shows seabird densities recorded by shipboard transects as contained in the USFWS pelagic database. These transects were censused opportunistically, often while observers ferried between specific areas, and do not permit rigorous examination of either temporal or spatial trends. They show some important characteristics of the eastern Aleutian area because they include transects between islands and within some smaller passes, sites not well surveyed by other efforts. Of particular interest is the high densities of small alcids, particularly Whiskered Auklets.

Approximately 1.4 million seabirds attend nesting colonies in the Fox Islands. A summary of estimated numbers of birds using colonies in the study area is provided in Table 4B-3; colony locations are shown in Figure 4B-1. The predominant nesting species are Tufted Puffin, Fork-tailed Storm-Petrel, and Leach's Storm-Petrel. This total includes about 50% of the Alaska population of Whiskered Auklet (<u>Aethia pygmaea</u>) and about 45% of the Alaska population of Tufted Puffin (<u>Fratercula cirrhata</u>). The composition of the breeding seabird community in this area differs

Table 4B-1. Densities of marine birds (birds/km^2) in Unimak Pass recorded during North Aleutian Shelf aerial surveys (LGL 1986).

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Red-throated Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Pacific Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Grebe	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Northern Fulmar	0.9	2.2	1.3	0.3		0.2		2.0		5.2	0.0	0.1
Shearwater-dark	0.0	0.0	0.0	0.0		64.5		46.5		0.2	0.0	0.0
Fork-tailed Storm-Petrel	0.0	0.0	0.0	0.0		1.5		0.5		0.2	0.0	0.0
Cormorant	3.2	0.3	0.0	0.2		1.0		2.4		1.5	3.5	0.3
Emperor Goose	0.0	0.0	0.0	0.3		0.0		0.0		0.0	0.0	0.0
Brant	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Mallard	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Eider	0.5	0.2	0.0	0.0		0.0		0.0		0.0	0.0	0.0
King Eider	0.7	3.8	0.2	0.7		0.0		0.0		0.0	0.0	1.2
Steller's Eider	0.1	1.1	0.1	0.0		0.0		0.0		0.1	0.0	0.9
Harlequin Duck	0.0	0.0	0.0	0.1		0.0		0.0		0.0	0.3	0.0
Oldsquaw	0.0	2.3	0.6	0.4		0.0		0.0		0.0	0.0	0.4
Scoter	2.7	1.0	1.8	1.0		0.0		0.0		0.0	0.1	0.3
Red-breasted Merganser	0.0	0.0	0.0	0.0		0.3		0.0		0.0	0.0	0.0
duck	0.0	0.0	0.3	0.0		0.2		0.0		0.0	0.0	0.0
Bald Eagle	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Rock Sandpiper	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
small sandpiper	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Phalarope	0.0	0.0	0.0	0.0		0.0		0.9		1.0	0.0	0.0
shorebird	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Jaeger	0.0	0.0	0.0	0.0		0.0		0.1		0.0	0.0	0.0
Bonaparte's Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Mew Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Herring Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Glaucous-winged Gull	5.5	31.6	18.2	19.8		2.0		75.9		13.8	131.6	3.7
Glaucous Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Black-legged Kittiwake	0.0	0.1	0.4	3.2		5.7		11.7		5.0	0.1	0.1
Sabine's Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Tern	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Murre	0.6	67.3	1.0	14.8		0.1		0.2		0.1	0.1	0.1
Pigeon Guillemot	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Murrelet	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Auklet	71.3	0.0	8.1	80.7		0.2		0.2		0.1	2.8	9.0
Tufted Puffin	0.0	0.0	0.0	0.0		0.6		4.2		0.0	0.0	0.0
Horned Puffin	0.0	0.0	0.0	0.1		0.0		0.0		0.0	0.0	0.0
alcid	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Raven	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Snow Bunting	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
passerine	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
TOTAL	85.7	110.0	32.2	121.6		76.3		144.6		27.2	138.7	16.2

Table 4B-2. Densities of marine birds (birds/km^2) in the eastern Aleutian Islands (FWS pelagic database).

	Umank	Unimak-Krenitzen Islands			
SPECIES/SEASON	mostly summer	April-May	June-Aug	Sept-Oct	Nov-March
loons	0.05				0.05
Laysan Albatross	0.01				
Black-footed Albatross				0.06	
Northern Fulmar	6.42	0.56	4.91	15.43	1.16
total shearwaters		0.19	829.08	418.76	0.38
Leach's Storm-Petrel	0.01				
Fork-tailed Storm-Petrel			1.62	0.77	0.12
total cormorants		1.51	0.77	0.21	1.48
Emperor Goose	0.01				
duck-goose		0.01			0.03
Greater Scaup	0.02				
Oldsquaw		2.99			0.03
Harlequin Duck	0.02				0.13
Black Scoter	0.14				0.05
White-winged Scoter	0.06			0.01	
King Eider	0.02				
eider	0.02	0.36			
Bald Eagle	0.02				
unidentified shorebird	0.21				
unidentified Scolopacid	0.01				
Calidris	0.01				
total phalaropes		2.43	4.39	0.56	0.00
total jaegers			0.18	0.01	
gull	0.01		0.08		0.03
Glaucous Gull			0.01		
Glaucous-winged Gull	1.09	0.94	1.24	3.47	5.70
Thayer's Gull			0.00		
kittiwake	0.13		0.47	0.78	4.64
Black-legged Kittiwake	0.79	0.49	0.52	2.24	0.45
Red-legged Kittiwake	0.02		0.01	0.03	
Sabine's Gull	0.02				
Arctic Tern	0.05		0.00	0.07	
alcid	0.65	1.87	1.35	2.07	3.85
small alcid		0.16	2.32		
small dark alcid	0.27	0.12			
total murres		18.60		2.92	11.74
Pigeon Guillemot	0.15	0.22	0.10		
Ancient Murrelet	0.27	1.36	1.17	0.33	
Cassin's Auklet		0.21	0.06	0.06	
Parakeet Auklet		0.02	0.00	0.31	0.16
auklet	0.01	0.60			
Crested Auklet	0.08	0.18	0.02	0.58	30.63
Least Auklet	0.02	2.60	0.49		0.18
Whiskered Auklet	0.19	11.31	3.27	0.01	
Horned Puffin	0.28	0.10	0.48	0.65	0.47
Tufted Puffin	10.93	25.64	25.28	4.09	0.42
Total	21.99	72.47	877.82	453.42	61.70
Number of Transects	72	67	103	39	24
Area Sampled (sq. km)	86.5	82.3	126.4	220.5	37.9

Table 4B-3. Seabird colonies of the Fox Islands and Unimak Pass. Values listed are the most representative estimates in the FWS Alaska seabird colony database (USFWS 1986). Asterisks denote possible nesting species or unknown population size.

SPECIES/LOCATION	21-004 Kagamil Island	21-005 Adugak Island	21-006 Pancake Rocks	21-007 Nikolski Bay	21-008 Breadloaf Island	21-009 East Cliff Cape Udak	21-010 Black Cape	21-011 Vsevidof Island	21-012 Ogchul Island	21-013 Chuginak Island	22-001 Uliga Island	22-002 Anangulak Island	22-003 Bogoslof Island	22-004 Fire Island	22-005 Kigul Islet #6	22-006 Kigul Islet #3	22-007 Kigul Islet #2	22-008 Kigul Islet #4	22-009 Kigul Islet #5
Northern Fulmar									4										
Fork-tailed Storm Petrel	*	*				*	*	35000	*	*	*	100	500				1000		
Leach's Storm-Petrel	*	*			*	*	*	16000	1200	30		*					1000		
Cormorant															26				
Double-crested Cormorant	26											32						56	
Pelagic Cormorant	34				30			8		150	10	90	4				36	2	
Red-faced Cormorant	90	20	24					76		400			146	40			4	12	
Common Eider			26									143			21	6	32		16
Black Oystercatcher					6			77	2			59			8		10	2	
Glaucous-winged Gull		347	185	*	350		374	*	400	120	20	1500	1696		400	500	240		90
Black-legged Kittiwake													1630	2260					
Red-legged Kittiwake													162	40					
Aleutian Tern				40									32195						
unidentified murre																			
Common Murre	7000												9220	5000					
Thick-billed Murre	27000												*	34300					
Pigeon Guillemot	52	62					6	570	94	130	20	246		*	20	14	8	16	
Ancient Murrelet								3000	1000								*		
Cassin's Auklet								*									*		
Parakeet Auklet								6	10	40				*			*		
Crested Auklet																			
Whiskered Auklet	*	4						20	*	*	*	2					*		
Horned Puffin		44				62	44	1000	86	460	30	25		10	8	12		8	
Tufted Puffin		400				2000	13000	65353	57970	1040	10	21436	5000	300			3600		
TOTAL	34202	677	235	40	386	2062	13424	121110	60766	2370	90	23633	50555	41950	485	532	5930	96	106

Table 4B-3. Continued.

SPECIES/LOCATION	22-010 Kigul Islet #6	22-011 Kigul Island	22-012 Kigul Islet #7	22-013 The Pillars	23-001 Point Izigen	23-002 Unalga Island	23-004 S. Amaknak Island	23-005 Egg Island	23-006 Gargoyle Rocks	23-007 Seacave Point	23-008 Huddle Rocks	23-009 Lion Bight Point	23-010 Ogangen Island	23-011 Islet West of Crow Arm	23-012 Islet N.W. of Reef Point	23-013 Outer West side Usof Bay	23-014 Middle West side Usof Bay	23-015 Triangle Ear
Northern Fulmar					6													
Fork-tailed Storm Petrel	1000	1000	300		15000	*		200000			2500		2000					
Leach's Storm-Petrel	4000	6000	1200		4000	*		70000			7500		*					
Cormorant						52												
Double-crested Cormorant						250		82									36	6
Pelagic Cormorant									4		4		4					2
Red-faced Cormorant						144		488		*			30	50	30			
Common Eider		21	3		2	50				10			29					
Black Oystercatcher	6	44	2		4			14	9		8		8					
Glaucous-winged Gull		900	280		300			1346	*	*	700		904	92		26	55	140
Black-legged Kittiwake																		
Red-legged Kittiwake																		
Aleutian Tern																		
unidentified murre																		
Common Murre																		
Thick-billed Murre				4000														
Pigeon Guillemot		80	6		8	135	*	350	2				82					
Ancient Murrelet	200	300	75		700			5000			2000							
Cassin's Auklet	150	100						2000			1000							
Parakeet Auklet																		
Crested Auklet																		
Whiskered Auklet		6	6		*			10			10							
Horned Puffin	6				50	169	20	*	5	14	16		126					65
Tufted Puffin	16514	800			18850	35		163316		229	8354	150	34450			300		
TOTAL	21876	9251	1872	4000	38920	855	20	442606	20	253	22092	150	37633	142	30	326	91	213

Table 4B-3. Continued.

SPECIES/LOCATION	23-016 Three Island Bay Islands	23-0017 Cape Yanaliuk	23-018 West Hive Bay	23-019 East Hive Bay	23-020 S.W. Udagak	23-021 Emerald Island	23-022 Ship Rock	23-023 Pustoi Island	23-024 Paso Point	23-025 Peacock Point	23-026 West Point	23-027 Chernofs Harbor	23-028 Hemming Point	23-029 Island at Sedanka Pt	23-030 Pumicestone Bay	23-031 South Skan Bay Islet	23-032 East Skan Bay	23-033 Peter Island	23-034 Greg Island
Northern Fulmar																			
Fork-tailed Storm Petrel						43530	3000	4000											
Leach's Storm-Petrel						80652	300	9500						*					
Cormorant												80							
Double-crested Cormorant		36							66		32							60	
Pelagic Cormorant		2		8	*					24	14								
Red-faced Cormorant		8		6	18						34								
Common Eider														50					
Black Oystercatcher						28	1	19						10				12	18
Glaucous-winged Gull	304					314	60	404		60	34			4	60	20		66	20
Black-legged Kittiwake																			
Red-legged Kittiwake																			
Aleutian Tern																			
unidentified murre							6500												
Common Murre							*												
Thick-billed Murre																			
Pigeon Guillemot	9				*		80	110				77		30				24	180
Ancient Murrelet						3000	*	550						6					
Cassin's Auklet						3000		400											
Parakeet Auklet							595												
Crested Auklet														*					
Whiskered Auklet						6								*					
Horned Puffin	50													38			65	14	44
Tufted Puffin	1000		130		270	31863	66	14140					120	459				2879	
TOTAL	1363	46	130	14	288	162593	10602	29123	66	84	114	157	120	597	60	20	65	3055	262

Table 4B-3. Continued.

SPECIES/LOCATION	23-035 Portage Bay	23-036 Cathedral Rocks	23-037 Makushin Point Islets	23-038 Point Kadin	23-039 Koriga Point	23-040 Irishman's Hat	23-041 Wislow Island	23-042 Cape Cheerful	23-043 Elder Point	23-045 Hog Island	23-046 Tanaskan Bay Island	23-047 Dushkot Island	23-048 Round Island	23-049 Islet at N Sedanka Is.	23-050 Old Man Rock	23-051 Cape Morgan	23-052 Reef Point	23-053 Lava Point	23-054 Kiliuik Bay & Nest Rock
Northern Fulmar																			
Fork-tailed Storm Petrel							40												
Leach's Storm-Petrel							200												
Cormorant																			
Double-crested Cormorant								2						72		46	8		
Pelagic Cormorant	42	16						14						6					
Red-faced Cormorant								308	30					*	2	784	1036	1408	
Common Eider																			
Black Oystercatcher		4					3				21	7	4						7
Glaucous-winged Gull								50		200	180	800					4	6	32
Black-legged Kittiwake												32							
Red-legged Kittiwake																			
Aleutian Tern																			
unidentified murre																			
Common Murre																			
Thick-billed Murre																			
Pigeon Guillemot		6								142	198	96	86			20	34		4
Ancient Murrelet							3000												
Cassin's Auklet																			
Parakeet Auklet																			
Crested Auklet																			
Whiskered Auklet							20												
Horned Puffin		26								54						4	6	32	
Tufted Puffin			140	100	100	60	10000				3106	3645	11504	130		1000			
TOTAL	42	52	140	100	100	60	13263	374	30	396	3505	4580	11594	208	2	1854	1088	1446	43

Table 4B-3. Continued.

SPECIES/LOCATION	23-055 Kisselen Bay	23-056 Eriskine Bay	23-057 McIver Bight Is.	23-058 Mist Triangle	23-059 Auket Island	23-060 Tangagm Island	23-061 Excelsior Island	23-062 Adokt Island	23-063 Koschekt Island	23-064 Pt. opposite Staraya Bay	24-001 Rootok Island	24-003 Mt. Gilbert Akun Is	24-004 2.5 mi N. Sennet Pt	24-005 Scotch Cap Rock	24-006 Sealion Point	24-007 Cave Point	24-008 Cape Mordvinof	24-009 Derbin Island	24-010 Tigalda Island
Northern Fulmar																			
Fork-tailed Storm Petrel					200	1500	2000	1000	2500		*							600	*
Leach's Storm-Petrel					300	1500	2500	1000	2500		*							600	*
Cormorant																	*		
Double-crested Cormorant											20	6			*			106	
Pelagic Cormorant				42											50				
Red-faced Cormorant						*	96	142			68	150	30	200	560	1000	*		164
Common Eider																			10
Black Oystercatcher	17	5			6	16	12	26	26			2						12	*
Glaucous-winged Gull	150	16					30	60	130	96	20	200						1318	100
Black-legged Kittiwake	28																*		
Red-legged Kittiwake																			
Aleutian Tern																	*		
unidentified murre																			
Common Murre							12											23	
Thick-billed Murre																			
Pigeon Guillemot		42			30	150	115	70	34	*	8							34	270
Ancient Murrelet					200	600	400	700	300									100	
Cassin's Auklet					3500		2000	40											
Parakeet Auklet																			
Crested Auklet																			
Whiskered Auklet						2	4	*	2									4	*
Horned Puffin		36			*			40	*	*	74						*	6	304
Tufted Puffin	112	100	40		41696	27331	40201	25492	10998						30		*	9485	*
TOTAL	307	199	40	42	45932	31099	47372	26572	16490	96	190	358	30	200	640	1000	0	12490	848

Table 4B-3. Continued.

SPECIES/LOCATION	24-011 Ugamak Island	24-012 Kaligagan Island	24-013 Cape Luke	24-014 Sflce Island	24-015 Derbin Str Islets	24-016 Tanginak Island	24-017 Tangik Island	24-018 Puffin Island	24-019 Poa Island	24-020 Jackass Point	24-021 South Is, Akun Str	24-022 North Is, Akun Str	24-023 Surf Bay Islets	24-024 Akun Head	24-025 Pinnacle by Little Bay	24-026 Kaligagan Islets #2	24-027 Kaligagan Islets #3	24-028 Kaligagan Islets #6	24-029 Kaligagan Islets #4	24-030 Kaligagan Islets #1
Northern Fulmar																				
Fork-tailed Storm Petrel		7500		*		*	4500	800	5000	*		200				600		*		36
Leach's Storm-Petrel		5500		*		*	300	100	700	*		*				300		*		40
Cormorant																				
Double-crested Cormorant						8				214				24						
Pelagic Cormorant						245														
Red-faced Cormorant		280	60			455	38			98		10	4	210	12			8		
Common Eider													*							
Black Oystercatcher	4						16	6	15	*		10	2			14	1		2	8
Glaucous-winged Gull		2000				182	350		1060	163			90	15	27	44	54	167	30	
Black-legged Kittiwake						346														
Red-legged Kittiwake																				
Aleutian Tern													*							
unidentified murre																				
Common Murre		300				880														
Thick-billed Murre						220														
Pigeon Guillemot	142	328			122	12	18	45	15			162	4			30	40		50	132
Ancient Murrelet		1000					350	200	1000			400				500		*		*
Cassin's Auklet		50										*				300		*		100
Parakeet Auklet												*								
Crested Auklet																				
Whiskered Auklet		18		*		*	10	10	25		4	4	*			10		*		6
Horned Puffin	268	20	*	*		4						6	*					2		6
Tufted Puffin	130	111082	*	260	130		20228	35374	33484	340		53372		306	196	15198		668		5508
TOTAL	544	128078	60	260	252	2352	25810	36535	41299	815	4	54166	100	555	235	16996	95	845	82	5832

Table 4B-3. Continued.

SPECIES/LOCATION	24-031 Kaligagan Islets #5	24-032 Aiktak Island	24-033 Round Island	24-034 Don Pinnacle -Ugamak	24-035 Battery Point	24-036 Talus Point	24-037 Akutan Harbor Islets	24-038 Akutan Point	24-039 North Head	24-040 Pt 2 km east of Lt.	24-041 Light	TOTAL
Northern Fulmar												6
Fork-tailed Storm Petrel		15000	*	*								311506
Leach's Storm-Petrel		8500		*								196392
Cormorant										*	*	132
Double-crested Cormorant		64			30			4				1194
Pelagic Cormorant		62						4				543
Red-faced Cormorant	28	1588			192	108		636	90			10605
Common Eider					*							151
Black Oystercatcher		49				*						428
Glaucous-winged Gull	60	2750	126		60		44					15525
Black-legged Kittiwake												406
Red-legged Kittiwake												
Aleutian Tern												0
unidentified murre												
Common Murre	55	12600			22							13892
Thick-billed Murre		2400										2620
Pigeon Guillemot	12	68			*	*	58					3664
Ancient Murrelet		1000										21006
Cassin's Auklet		*										12390
Parakeet Auklet												595
Crested Auklet												
Whiskered Auklet		6	*	*				2				155
Horned Puffin		32			130	65	24	66				1897
Tufted Puffin	260	102428	262	1000			40	2500				844667
												0
TOTAL	415	146567	388	1000	434	173	166	3212	90	0	0	1444274

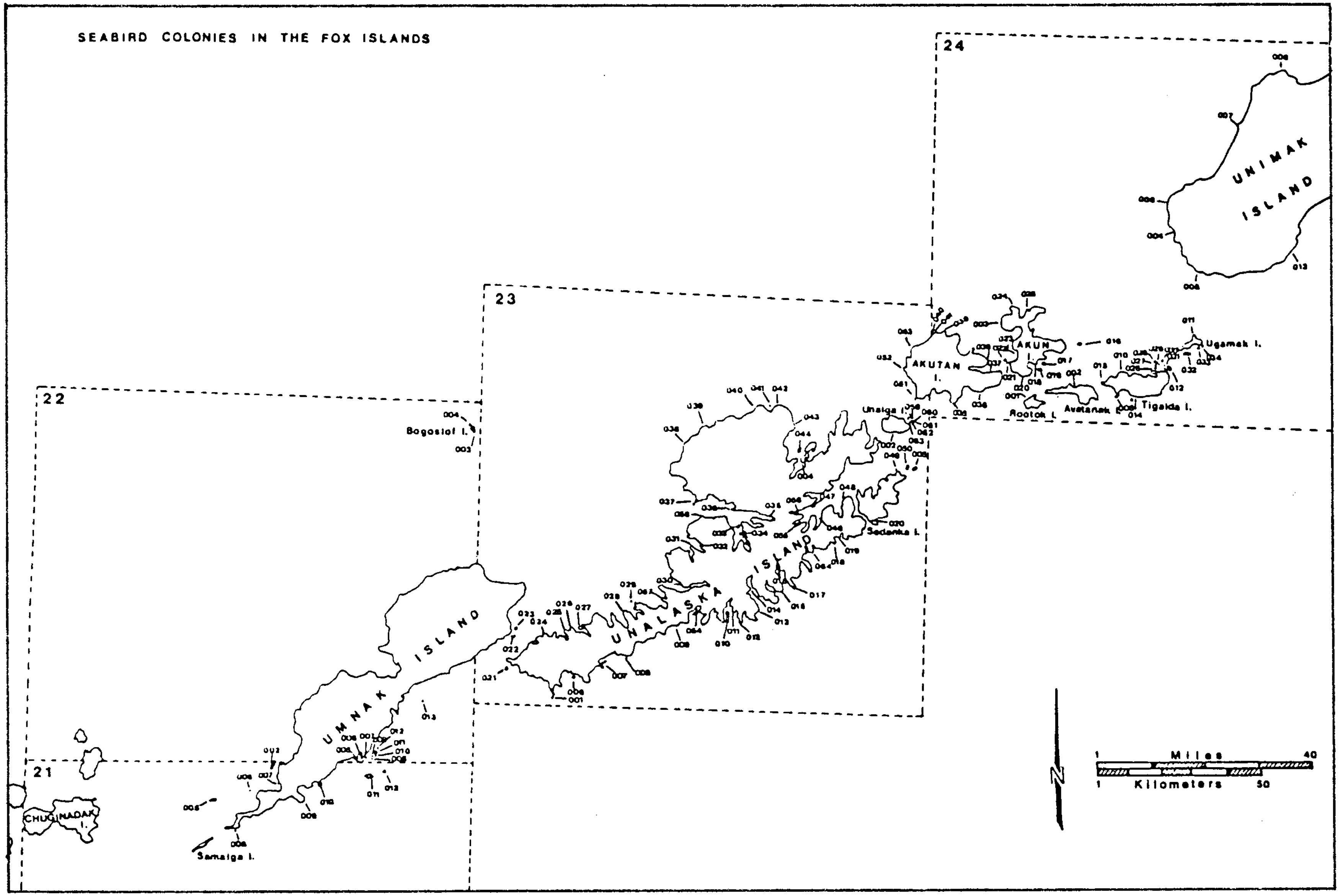


Figure 4B-1. Locations of seabird colonies listed in Table 4B-3 (from USFWS seabird colony database).

markedly from that of many areas in other parts of the Bering Sea and Alaska, in that murres and kittiwakes are a minor component and burrowing seabirds and notably nocturnal species (storm-petrels, Ancient Murrelet, Cassin's Auklet) are numerous.

Detailed work on the breeding biology of birds in this area is lacking; however, seabirds are probably present on the colonies from at least April through November (see Fig. 4B-2). Egg laying probably commences during May and hatch commences in late June. Fledging of Leach's Storm-Petrel (*Oceanodroma leucorhoa*) and Tufted Puffin may occur as late as October or November.

The waters around the eastern Aleutians are especially important to nesting birds. In this area seabirds have short flying times to a variety of marine environments, including a broad continental shelf, a precipitous shelf break, and deep oceanic expanses. In addition, the eastern Aleutians have many deep and protected bays and inlets, and a tidal flow which creates rip tides within an abundance of straits and passes.

Sources of Information

Regional summaries of seabirds in or near the area of interest have been compiled as follows: North Aleutian Shelf (Armstrong et al. 1984), St. George Basin (Strauch and Hunt 1982). The most comprehensive study of breeding seabirds in the area is that of Nysewander et al. (1982). Summaries of the status of breeding colonies in the area were obtained from the USFWS seabird colony database (provided by Art Sowls). Similarly, current summaries of pelagic seabird surveys were obtained from the pelagic seabird database (provided by Doug Forsell). Additional unpublished data were obtained from the North Aleutian Shelf Ecological Process Study (LGL 1986). Much of the life history information for seabirds in the Bering Sea was summarized from Lewbel (1983).

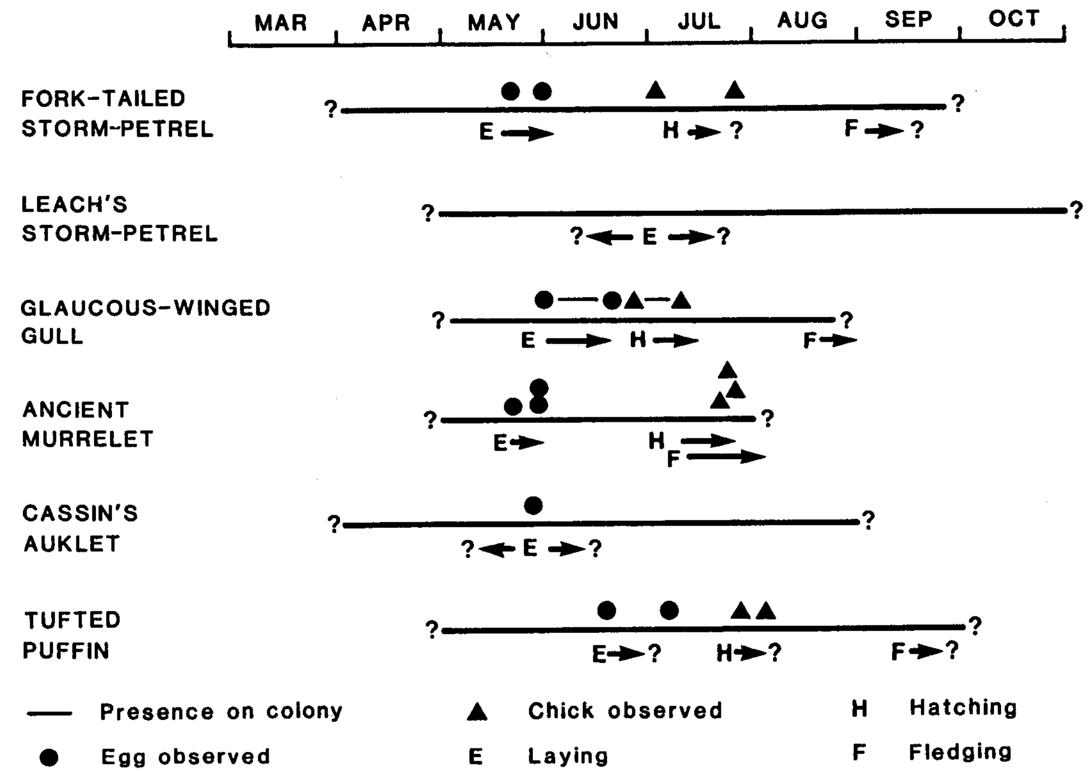


Figure 4B-2. Estimated phenologies of seabirds on the Fox Islands (from Strauch and Hunt 1982).

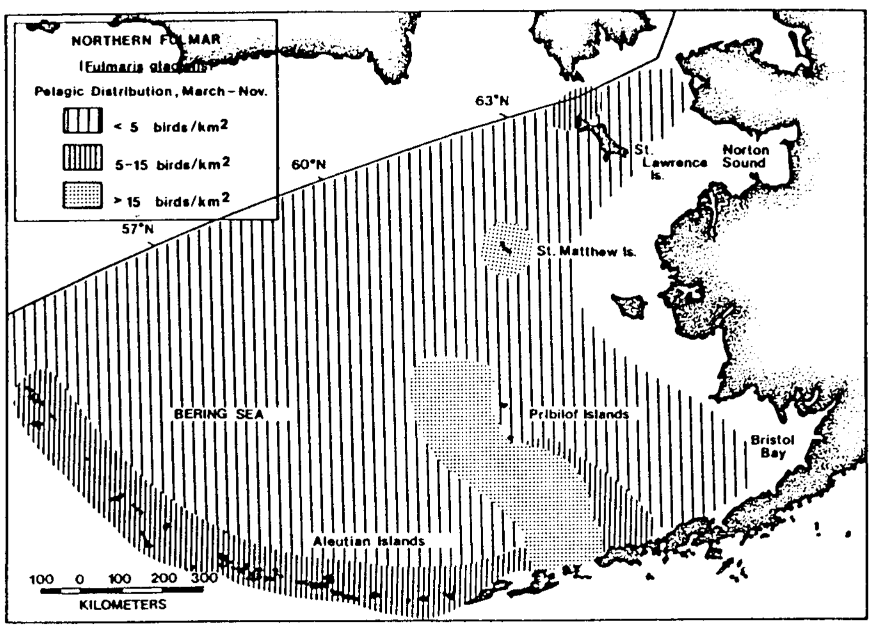


Figure 4B-3. Pelagic distribution of Northern Fulmars in the Bering Sea, March-November (from Lewbel 1983).

Northern Fulmar (Fulmarus glacialis)

The Northern Fulmar occurs year-round in the Unimak Pass area. The eastern Bering Sea population is estimated to be near one million and is highly concentrated at a few breeding locations (Sowls et al. 1978). All but a few thousand breed in three areas: on Chagulak Island in the Aleutians, on the Pribilof Islands, and on St. Matthew/Hall islands. Insignificant numbers (six) of fulmars nest in the Fox Islands.

Fulmars at sea during the summer are concentrated along the shelf break and outer shelf near the Pribilof Islands and south to Unimak Pass (Fig. 4B-3), often in close association with fishing fleets. They are markedly less common in the shallow waters of Bristol Bay and the inner shelf (Hunt et al. 1981d). In winter, most fulmars leave the Bering Sea for the North Pacific; however, some are still present in ice-free waters north and west of the Pribilof Islands and between the Pribilofs and Unimak Pass. Birds from many areas, particularly northern colonies, use the pass as a migration corridor. Fulmar numbers are generally lower in the pass area than in the shelf break waters to the northwest and southeast. Murie (1959) suggested that fulmars in the Aleutian Islands are most abundant in rip tide areas and offshore of their breeding colonies. Cahn (1947) also mentioned congregations of fulmars within the passes of the eastern Aleutians, especially during late summer and winter. Densities may reach up to 17 birds/km^2 in Unimak Pass waters in the fall (Gould 1982).

Fulmars feed by surface-seizing (Ashmole 1971). They prey on cephalopods, crustaceans and fish. Fulmars have become habituated to scavenging fish offal from fishing vessels as a major food source (Hunt et al. 1981d).

Short-tailed Shearwater (Puffinus tenuirostris) and Sooty Shearwater (P. griseus)

Both of these species occur in the study area. Unfortunately, they are not consistently differentiated during pelagic surveys and thus specific areas of abundance of each species are difficult to delineate. In general it appears that Sooty Shearwaters are most abundant in the Gulf of Alaska whereas mostly Short-tailed Shearwaters occur within the Bering Sea. There is a zone of overlap in the southern Bering Sea; both species probably occur in our area of interest.

From June through September the Short-tailed Shearwater is the most abundant species in the Bering Sea. Large aggregations (over 10,000) have been found in Unimak Pass from mid-May through late October (Jaques 1930, Gould 1982). These birds are typically found over the continental shelf, with only moderate numbers occurring over the shelf break. They are concentrated near and within the 50-m isobath. Concentrations of over 1,000,000 shearwaters have been recorded feeding in Unimak Pass in July. Large movements have been recorded through Unimak Pass, Baby Pass and Derbin Strait (Trapp 1975) (Fig. 4B-4). Passage of Short-tailed Shearwaters between the Pacific Ocean and Bering Sea is widespread; however, the area between Akutan Pass and Amak Island (including Unimak Pass itself) appears to be the most heavily visited region in Alaskan waters (Guzman 1981, Guzman and Myres 1982). Really high numbers of Short-tailed Shearwaters (up to 1,000,000) have been reported only from Unimak Pass and the waters northeast of Unimak Island (Byrd 1973, Guzman and Myres 1982). Late summer concentrations occur in northeastern Unimak Pass/Akun Bay. During 1986 large rafts of Short-tailed Shearwaters were present in this area from at least mid-July through late August, but the adjacent North Aleutian Shelf was largely deserted (LGL 1986). Northern Unimak Pass was also found to harbor large numbers of shearwaters on 20 October 1981, with estimates ranging from 8-84 million (USFWS memorandum, 12 January 1982).

Shearwaters feed mainly by pursuit-diving but also by surface-seizing (Hunt et al. 1981a). They probably feed entirely within the upper 5 m of the water column (Sanger 1972). While on the North Aleutian Shelf Short-tailed Shearwaters appear to prey primarily on euphausiids during spring/early summer, and shift to fish (predominantly sand lance) during the remainder of the year (July and September) (LGL 1986). In the Kodiak Island area, Short-tailed Shearwaters feed mostly on euphausiids, fish (capelin and osmerids), and squid (Sanger et al. 1978). In the Bering Sea euphausiids are important prey in summer, while in fall the amphipod

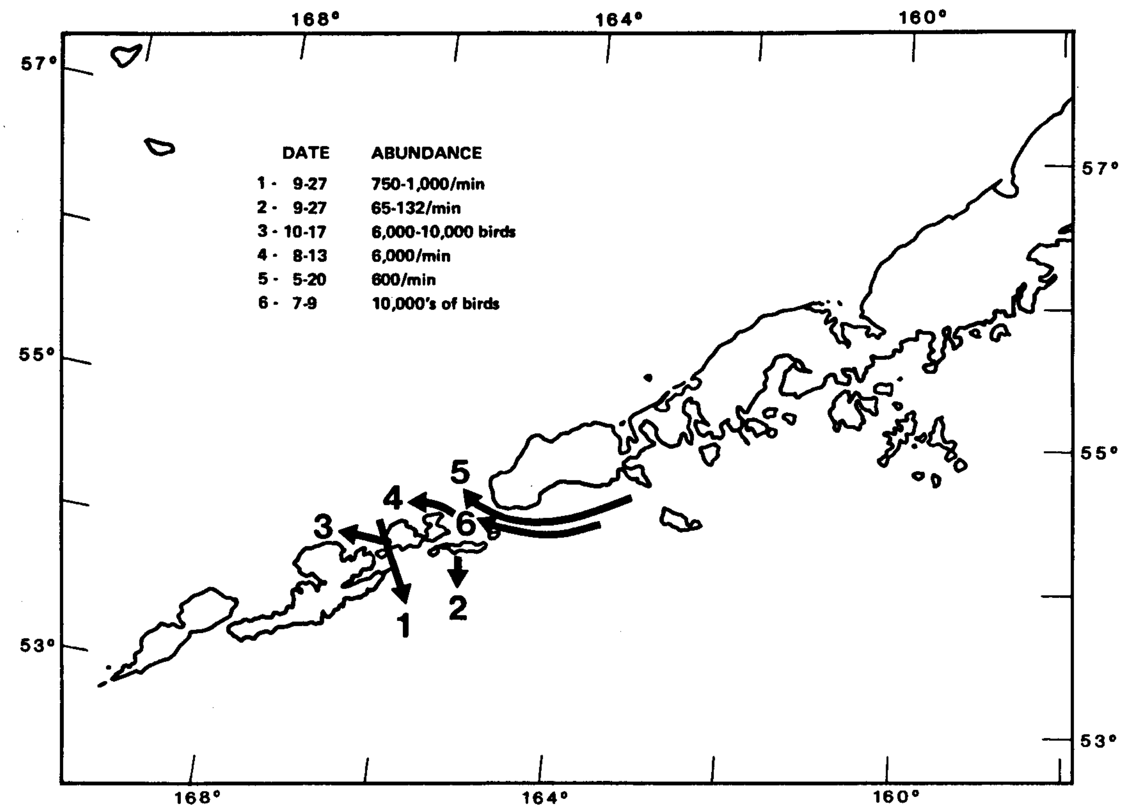


Figure 4B-4. Distribution of flying flocks of 10,000 or more shearwaters in the eastern Aleutian Islands (from Strauch and Hunt 1982).

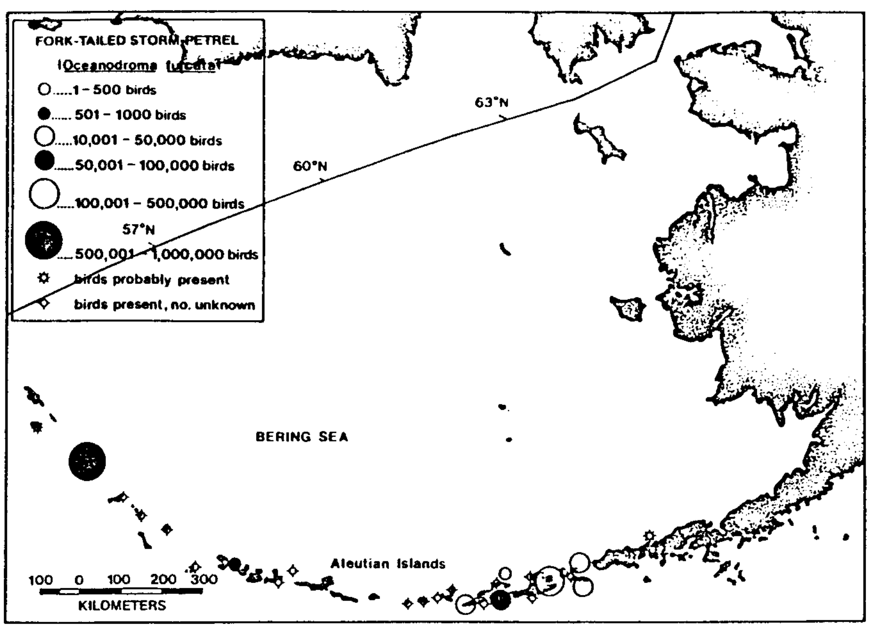


Figure 4B-5. Breeding distribution of Fork-tailed Storm-petrels in the Bering Sea (from Lewbel 1983).

Parathemisto libellula is taken extensively, with cephalopods and fish used both seasons (Hunt et al. 1981a). Sooty Shearwaters in Alaska appear to depend more heavily on fish and squid at all times than do Short-tailed Shearwaters (Sanger et al. 1978).

Fork-tailed Storm-Petrel (Oceanodroma furcata) and Leach's Storm-Petrel (O. leucorhoa)

Both the Fork-tailed Storm-Petrel and the Leach's Storm-Petrel nest in the Aleutians in large numbers, but are not known to nest elsewhere in the eastern Bering Sea (Sowls et al. 1978). Leach's Storm-Petrel breeds south to Baja California and southern Japan in the Pacific, and there is also an Atlantic breeding population (Palmer 1962). Leach's Storm-Petrels are rarely seen in the Bering Sea except at the breeding colonies; they apparently forage to the south of the Aleutian chain in deep oceanic waters of the North Pacific (Hunt et al. 1981d). Over 200,000 were estimated to nest in the Fox Islands (Nysewander et al. 1982). The other large known concentration in the Aleutians is at Buldir Island, where an estimated 800,000 nest (Sowls et al. 1978). Fork-tailed Storm-Petrels are restricted to the Pacific Ocean. They breed from the Kurile Islands through the Aleutians, along the southern and southeastern coasts of Alaska, and south to northern California.

Because of their nocturnal habits, storm-petrels are difficult to census and are easily overlooked on their breeding grounds; thus, there is considerable uncertainty in population estimates. Nesting populations in the Aleutians may be on the order of three million birds, based on the estimate by Sowls et al. (1978); however, the currently documented breeding population is only 875,000. Fork-tailed Storm-Petrels are quite commonly sighted in Bering Sea waters. Aerial and shipboard surveys by Gould et al. (1982) suggest a summer population on the order of three to six million storm-petrels feeding in the eastern Bering Sea.

Because the Fork-tailed Storm-Petrel is the only common pelagic storm-petrel in the eastern Bering Sea, the remainder of this account will refer specifically to that species. The breeding distribution is illustrated in Fig. 4B-5. The pelagic distribution during the summer is depicted in Fig. 4B-6. Storm-petrels are rarely found north of 58°N (Hunt

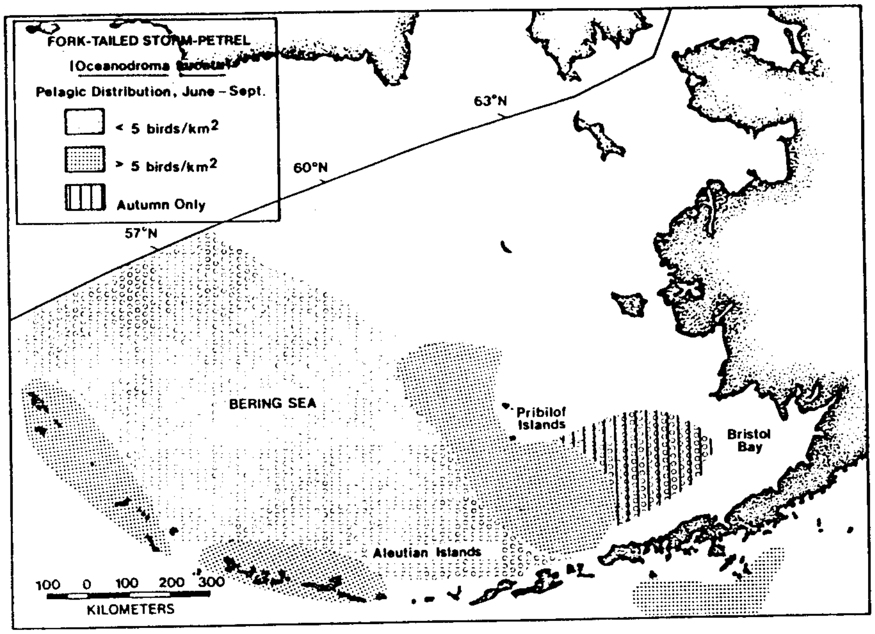


Figure 4B-6. Pelagic distribution of Fork-tailed Storm-petrels in the Bering Sea, June-September (from Lewbel 1983).

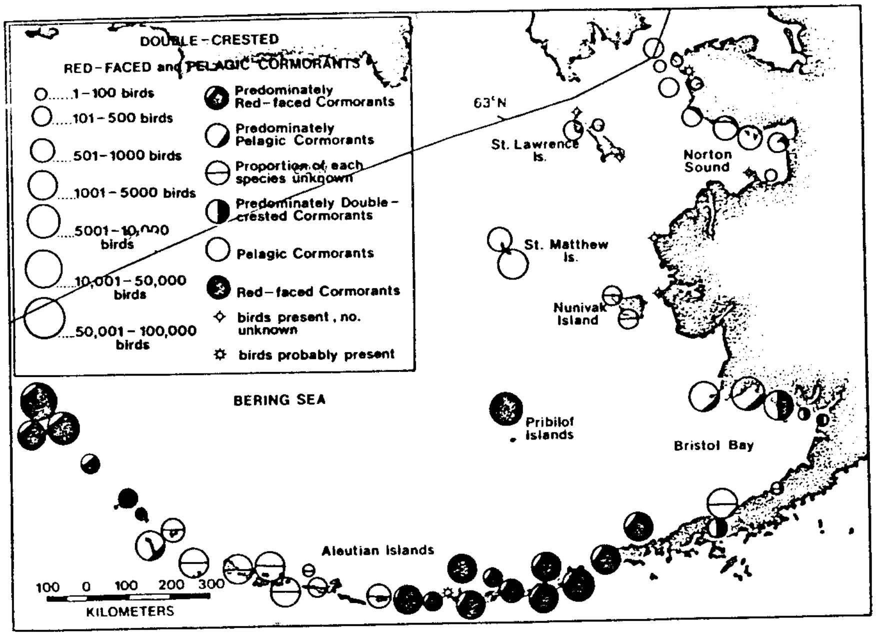


Figure 4B-7. Breeding distribution of cormorants in the Bering Sea (from Lewbel 1983).

et al. 1981d) and are most numerous at the shelf break and on the outer shelf (Hunt et al. 1982). Although their absolute densities over deep oceanic waters are lower than in shelf and shelf break waters, they are among the most numerous birds in deep water areas. In a winter survey in the southeastern Bering Sea, Fork-tailed Storm-Petrels were seen only over deep waters (Hunt et al. 1981d).

Fork-tailed Storm-Petrels feed by surface-seizing or by pattering on the surface (Hunt et al. 1981d) and probably feed at night, at least during the breeding season. Food habits are poorly known, but squid, fish, euphausiids and fish offal are eaten by adults (Day 1980, Hunt et al. 1981a). Invertebrates brought to chicks by adult storm-petrels at Wooded Islands included calanoid copepods, euphausiids, gammarid amphipods, cephalopods and shrimp (Quinlan 1979). Fish found in these food loads included cottids, gadids, myctophids and Scorpaeniformes.

Red-faced Cormorants (*Phalacrocorax urile*)

Red-faced Cormorants, Pelagic Cormorants (*P. pelagicus*), and Double-crested Cormorants (*P. auritus*) all occur in the area of interest, but Red-faced Cormorants predominate (Fig. 4B-7). Nelson (1976) estimated that these three species occurred in a 6:2:1 ratio at Unimak Island during the fall but their abundance as breeding birds in the area of interest is roughly 20:1:2 (Table 4B-3). Red-faced Cormorants nest on cliffs, and in the Pribilofs they are restricted to portions of cliffs less than 200 ft high (Hickey 1976, Troy and Baker 1985). Nests are constructed at least partially of seaweed.

Red-faced Cormorants are probably year-round residents through most of their range, although some movement is evident in the Aleutian Islands because their population levels are lower in the winter than during the breeding season (Byrd et al. 1974). A southward movement of cormorants, predominantly Red-faced, was recorded through Unimak Pass from 7 April to 26 May 1976 (Nelson and Taber, FWS, unpubl. data). Gill et al. (1979) thought it unlikely that this was the result of cormorants wintering in the Bering Sea, but other surveys (LGL 1986) suggest that cormorant densities in northern Unimak Pass do in fact peak during winter (Table 4B-1).

Cormorants feed nearshore and are seldom seen more than a few km from their breeding colonies during the nesting season. A few are seen in small numbers in the open ocean during spring and fall (Hunt et al. 1981d, LGL 1986). Their feeding method is pursuit-diving (Ashmole 1971). Fish are the primary prey, but decapods (shrimps and crabs) and amphipods are also eaten. Sculpins appear to be the most frequently taken fish. Cormorants appear to be restricted to foraging close to land near the bottom (Hunt et al. 1981a).

Glaucous-winged Gull (Larus glaucescens)

The Glaucous-winged Gull is in many respects an overlooked seabird. Most regional species accounts tend to omit this species. The summaries in Tables 4B-1 and 4B-2 show this bird to be consistently among the most abundant of the species encountered. Their abundance varies seasonally; peak densities occur in summer and fall, at least in coastal areas.

Glaucous-winged Gulls are omnivorous and are opportunistic foragers. Their diet includes a variety of intertidal organisms, fish, garbage, offal, and other prey. Most foraging occurs in nearshore habitats, especially during the breeding season, but sometimes these birds are found far offshore. Because of its opportunistic foraging behavior, the Glaucous-winged Gull is prone to great geographic variability in its diet. In the western Aleutians, Trapp (1979) found it to specialize on whatever species was abundant and vulnerable; food selection varied from invertebrates (sea urchins) to fish to seabirds depending on the feeding location and (presumably in the case of seabirds) the season. Interestingly, Trapp noted that the relative use of fish and invertebrates was partially dependent on the presence of large sea otter populations which reduce macroinvertebrate numbers such that they are unavailable to the gulls. In the eastern Aleutians, invertebrates are important in gull diets, presumably because sea otter populations are low. Storm-petrels and young murrelets are probably preyed upon when available during the breeding season. Murie (1959) found Glaucous-winged Gulls on Bogoslof Island to specialize on murre eggs and chicks.

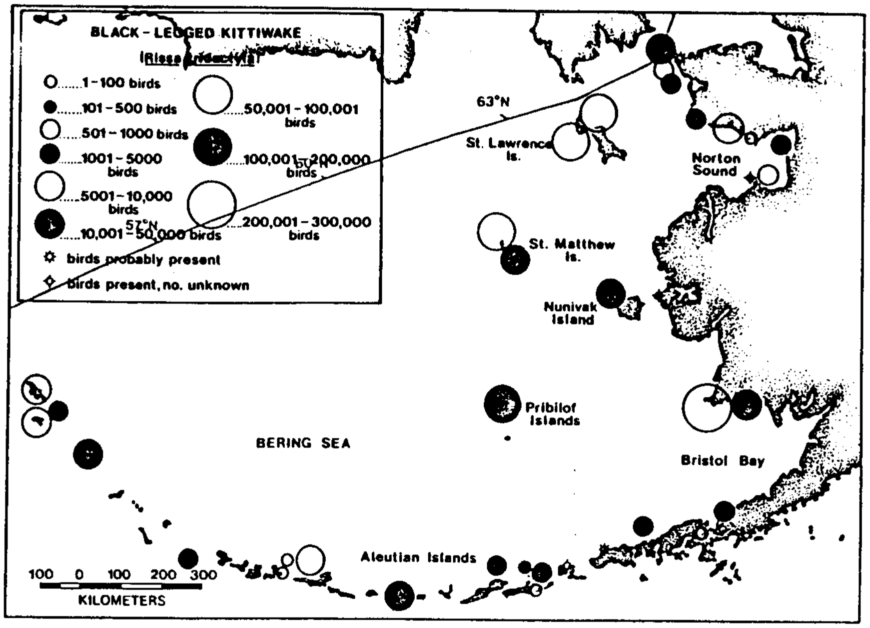


Figure 4B-8. Breeding distribution of Black-legged Kittiwakes in the Bering Sea (from Lewbel 1983).

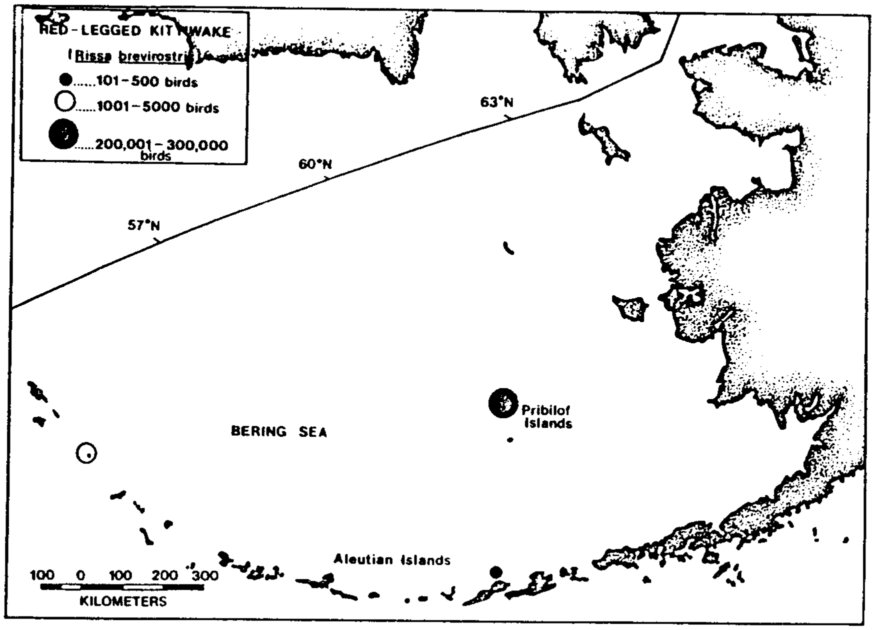


Figure 4B-9. Breeding distribution of Red-legged Kittiwakes in the Bering Sea (from Lewbel 1983).

area, euphausiids were heavily preyed upon during early summer (May) (LGL 1986).

Red-legged Kittiwake (Rissa brevirostris)

Red-legged Kittiwakes are endemic to the Pribilof, Komandorskiye, and Aleutian Islands. Only very low numbers breed in the eastern Aleutian Islands, and most of these nest on Bogoslof Island (Fig. 4B-9). Nesting by this species on Bogoslof Island was unknown prior to 1973, when approximately 100 nests were found (Byrd 1973, Byrd et al. 1980).

The pelagic distribution of Red-legged Kittiwakes is shown in Fig 4B-10. In summer, the birds are concentrated on the shelf break near (predominantly south and west of) the Pribilofs; few are sighted in water shallower than 100 m and very few are recorded north of 59°N or east of 165°W (Hunt et al. 1981d). Birds from Bogoslof probably forage in deep waters to the north of Bogoslof Island, though some birds have been noted in western Unimak Pass during mid-summer (LGL 1986).

Little is known of the winter distribution of this species. Many, if not most, Red-legged Kittiwakes probably leave the Bering Sea. Records from the Gulf of Alaska in fall and winter (Kessel and Gibson 1978) support this suggestion.

Feeding is primarily by dipping, but surface-seizing or plunging may also be used (Ashmole 1971). Hunt et al. (1981a) found myctophids (lantern fishes) to be an important food item at the Pribilof Islands, and reliance on this group may explain pelagic concentrations of Red-legged Kittiwakes along the shelf break. Foraging activity occurs primarily at night, probably because myctophids come to the surface at night. Pollock were also taken at the Pribilofs, and cephalopods were the most important item other than fish. In the Aleutians, Red-legged Kittiwakes feed primarily on fish and crustaceans and secondarily on cephalopods (Day 1980).

Common Murre (Uria algae) and Thick-billed Murre (U. lomvia)

Both species of murre are abundant and widespread in the southeastern Bering Sea. The species differ in many aspects of their biology and

Black-legged Kittiwake (*Rissa tridactyla*)

Black-legged Kittiwakes are circumpolar in distribution and are numerous in the eastern Bering Sea, where there is a minimum breeding population estimated at 750,000 (Sowls et al. 1978). Population indices derived from aerial and shipboard censuses indicate the presence of 1-3 million kittiwakes in summer and 3-4.5 million in fall in the eastern Bering Sea (Gould et al. 1982).

The breeding distribution of Black-legged Kittiwakes in the Bering Sea is depicted in Fig. 4B-8. The pelagic distribution during all seasons may be characterized as low-density and dispersed in the southern sector of the Bering Sea. Hunt et al. (1982) described a tendency for higher densities to occur between the 100-m isobath and deeper waters of the shelf break, and for lower densities to occur between the 50- and 100-m isobaths.

In winter, most Black-legged Kittiwakes leave the Bering Sea, although they still occur in low densities north of the Aleutians, on the shelf break, and in oceanic waters north of the Pribilofs. Kenyon (1949) reported few wintering in the Gulf of Alaska and northeastern Pacific; however, they are more common along the California coast and over a broad zone of deep oceanic water south of the Aleutians. Gould et al. (1982) described kittiwakes as virtually absent from shallow waters of Bristol Bay in winter, but present in "fair numbers" over shelf break and oceanic waters. Probably most of the kittiwakes breeding in colonies in the Bering Sea concentrate in the western portion of their major wintering area south of the Aleutians.

Northward displacement begins in mid-March with intensive movements occurring through straits of the eastern Aleutian ridge in April. Fall migration through Unimak Pass occurs from the middle of September into late October (Nelson 1976). For the eastern Bering Sea population there is a broad and gradual movement from breeding colonies to wintering areas south of the Aleutians.

The feeding method of kittiwakes is primarily dipping; however, surface-seizing and occasionally shallow pursuit-diving is employed (Hunt et al. 1981a). Fish are the primary prey, but crustaceans (euphausiids, amphipods) and cephalopods are also consumed. In the North Aleutian Shelf

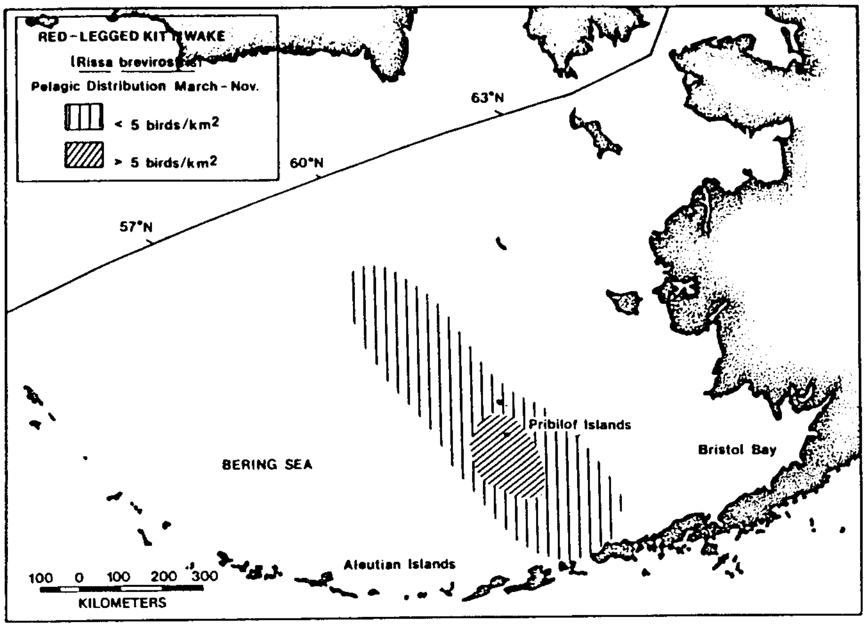


Figure 4B-10. Pelagic distribution of Red-legged Kittiwakes in the Bering Sea, March-November (from Lewbel 1983).

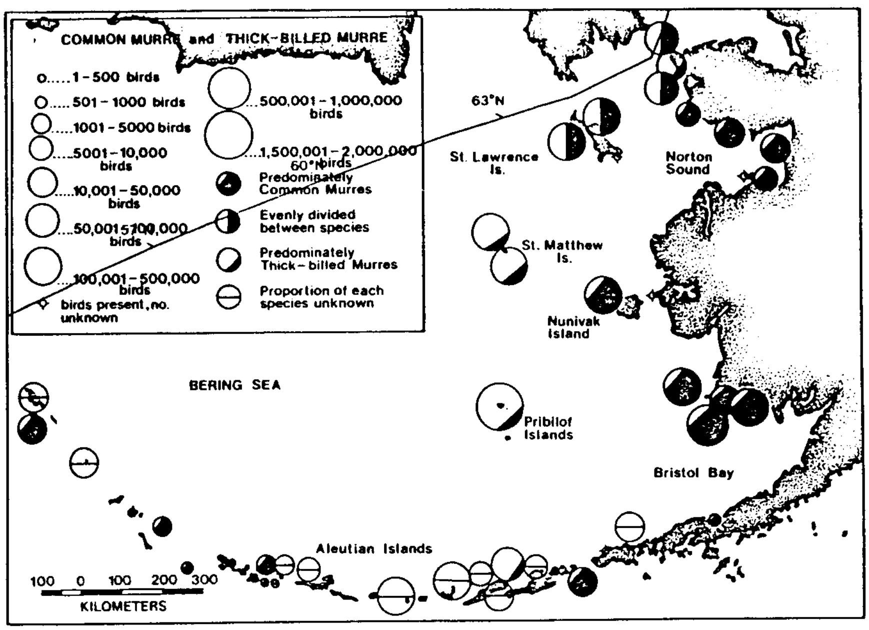


Figure 4B-11. Breeding distribution of Common Murres and Thick-billed Murres in the Bering Sea (from Lewbel 1983).

distribution, but a great many studies could not, or did not, use methods that would distinguish between them. Because of this, we have to treat them as a group in this discussion.

The eastern Bering Sea supports a minimum of 5.3 million breeding murres (Sowls et al. 1978). In general Common Murres predominate at the mainland colonies of the Bering Sea, and Thick-billed Murres predominate in the Aleutian, Pribilof and other offshore Islands (Fig. 4B-11). The eastern Aleutian Islands do not harbor any major murre colonies; there are only about 17,000 birds total and these appear to be predominantly Common Murres (Table 4B-3). Murres begin to aggregate on waters near the colonies in late March and April (Hunt et al. 1981b).

Murres are most commonly found over the continental shelf. In the spring they occur throughout areas of open water. In the summer they are concentrated around the major breeding colonies. In the fall they again disperse over the continental shelf. They are the most abundant seabird wintering in the Bering Sea.

Murres are distributed in fall over shelf waters from the Gulf of Anadyr to Bristol Bay. They may remain in northerly areas of the Bering Sea until forced south by advancing ice. Murre numbers appear to increase in the eastern Aleutians and Unimak Pass during the fall. The pelagic distribution of murres in winter is shown in Figure 4B-12.

A substantial number of the Bering Sea breeders migrates through Unimak Pass in spring and fall between the Bering Sea and wintering areas in the Gulf of Alaska (Nelson 1976). The spring migration through Unimak Pass into the Bering Sea commences in late March, peaks in late April, and continues into May. Phillips (1976) estimated 20,000 murres swimming in Unimak Pass off Cape Sarichef on 14 May. Gould (1982) reports mean at-sea densities of murres of 10-28 birds/km^2 in Unimak Pass during spring.

Autumn migration through Unimak Pass is also quite protracted, extending from late July through October. Peak movements have been recorded during the last week of August and again during October (Nelson 1976).

Aerial survey data taken during North Aleutian Shelf surveys (Table 4B-1) (LGL 1986) showed peak numbers of murres to occur in Unimak Pass during late winter and spring. Numbers were rather variable and suggested considerable movement between months. During February 1986 murres were

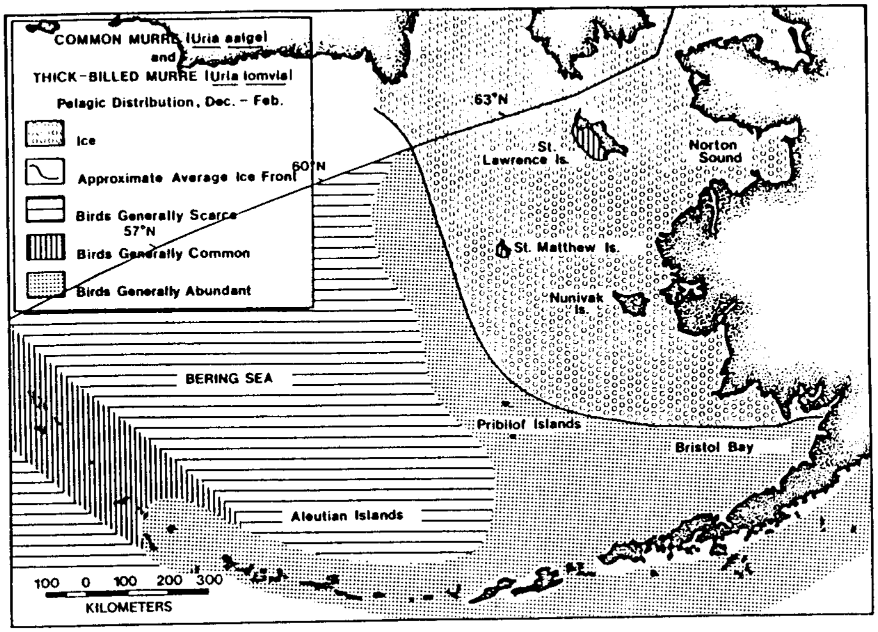


Figure 4B-12. Pelagic distribution of Common Murres and Thick-billed Murres in the Bering Sea, December-February (from Lewbel 1983).

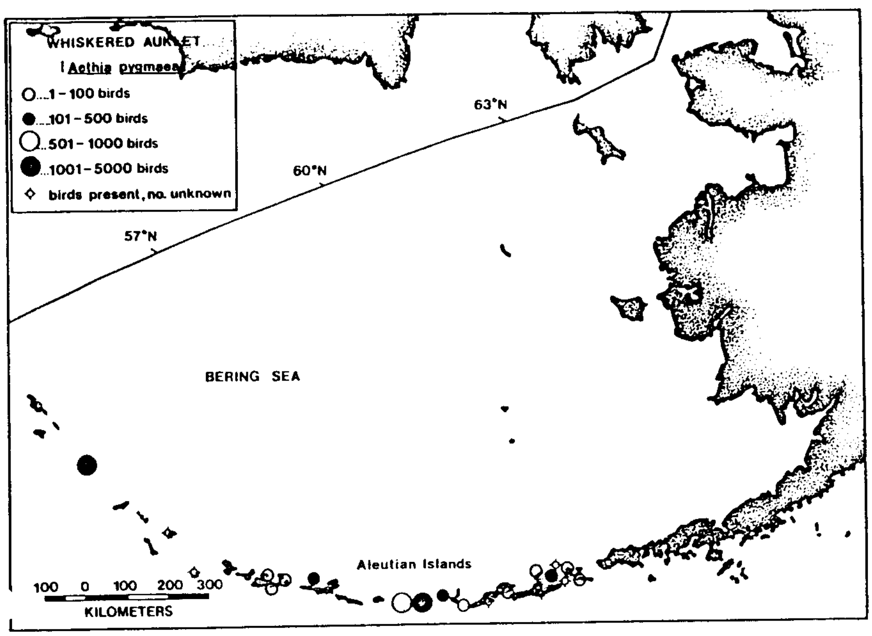


Figure 4B-13. Breeding distribution of Whiskered Auklets in the Bering Sea (from Lewbel 1983).

the most numerous species in the Unimak Pass area. Their distribution on occasion appeared to parallel (on western parts of the North Aleutian Shelf) the distribution of Crested Auklets. During the January 1985 cruise an estimated 100,000 murres were estimated at one location in this region.

Both species of murre feed by diving, often attaining depths of 110-130 m (Forsell and Gould 1980). Fish are the principal prey, but invertebrates are often an important constituent of the diet. Common Murres tend to feed within a few km of shore in water 50 m or less in depth, whereas Thick-billed Murres may feed tens of kilometers to sea in deep water (Roseneau and Springer 1982). Thick-billed Murres also take a greater variety of prey (with a greater proportion of invertebrates in the diet) than Common Murres. Common Murres are dependent on nearshore mid-water fishes, whereas Thick-billed Murres use demersal fishes.

Common Murres in the Bering Sea feed on a variety of fish including cod, sand lance, capelin and pricklebacks (Stichaeidae); the latter is used principally as food for the chicks. Thick-billed Murres frequently prey on all the above fish (except pricklebacks) and also take sculpins, which occur near the sea bottom (Roseneau and Springer 1982). Invertebrates consumed by both species include, in approximate order of importance, shrimps, amphipods, euphausiids, cephalopods and polychaetes (Roseneau and Springer 1982). There is considerable regional variability in diet; murres on the Pribilof Islands take walleye pollock extensively (Bradstreet 1985), whereas murres in Norton Sound are dependent on sand lance and arctic cod (Hunt et al. 1981). In the North Aleutian Shelf both species preyed primarily on fish, with sand lance and pollock predominating (LGL 1986).

Whiskered Auklet (Aethia pygmaea)

The Whiskered Auklet is known to nest only on some 40 islands in the Aleutian chain (all but 9 in the Fox group); the total population is estimated to be at least 25,000 (Byrd and Gibson 1980), although colony censuses have documented breeding sites of only 6800 birds (Sowls et al. 1978, Nysewander et al. 1982). This species is particularly difficult to census and it is likely that additional breeding sites will be found.

The breeding distribution of the Whiskered Auklet is depicted in Figure 4B-13. Whiskered Auklets are less colonial than other Aethia auklets, having widely scattered nest sites (Nysewander et al. 1982).

Whiskered Auklets have been seen in large flocks along the Aleutian chain. The spring distribution tends to be more clumped than the summer distribution. In the Andreanof Islands of the Aleutian Chain, Byrd and Gibson (1980) found a greater number of Whiskered Auklets in spring than during the breeding season. Large flocks (up to 10,000) may be found in tide-rip areas (Byrd and Gibson 1980). Areas in the Aleutian chain where concentrations have been noted include Tigalda Island to Baby Pass (particularly Baby Pass, Umnak Pass, and Avatanak Strait [Nysewander et al. 1982]), Unimak Pass, Herbert Island to Yunaska Island, near Seguam and Great Sitkin islands, near Segula Island, and at Buldir Island (Fig. 4B-14). Byrd (1973) found 7000 Whiskered Auklets within Baby Pass and in rip tides northwest of the Baby Islands on 3 July 1973.

In winter, Whiskered Auklets are presumed to be distributed near the breeding areas. During November 1964, approximately 1100 Whiskered Auklets collided with a ship among the islands of the Four Mountains (Dick and Donaldson 1978).

Whiskered Auklets feed by pursuit-diving (Ashmole 1971), and feeding concentrations are nearly always restricted to tide-rip areas (Byrd and Gibson 1980, Nysewander et al. 1982). Little is known of food habits, but limited data suggest that this species feeds primarily on crustaceans such as copepods, amphipods, larval crabs, and isopods. Mollusk eggs and fish have also been reported as food items (see Day 1980).

Crested Auklet (Aethia cristatella)

The Crested Auklet has its population center in the Bering Sea where an estimated two million nest in Alaskan waters. This species is not known to nest in our area of interest although large colonies are found to the west in the Aleutian chain.

Insufficient data are available to accurately describe the wintering distribution of this species. Most small auklets may leave the Bering Sea in fall, wintering along the Aleutian chain and in the North Pacific. Kodiak Island is a known wintering area for Crested Auklets (Gould et al.

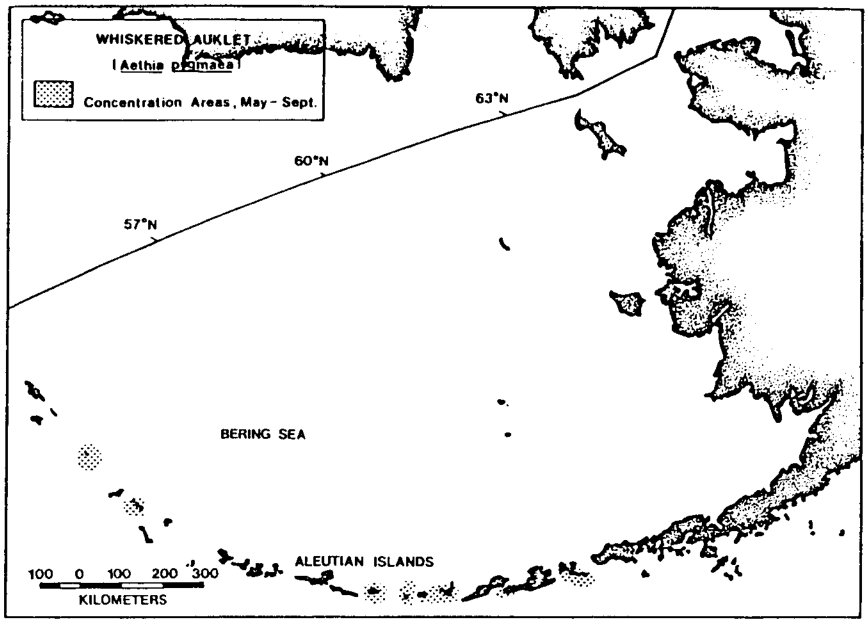


Figure 4B-14. Areas of observed concentrations of Whiskered Auklets in the Bering Sea (from Lewbel 1983).

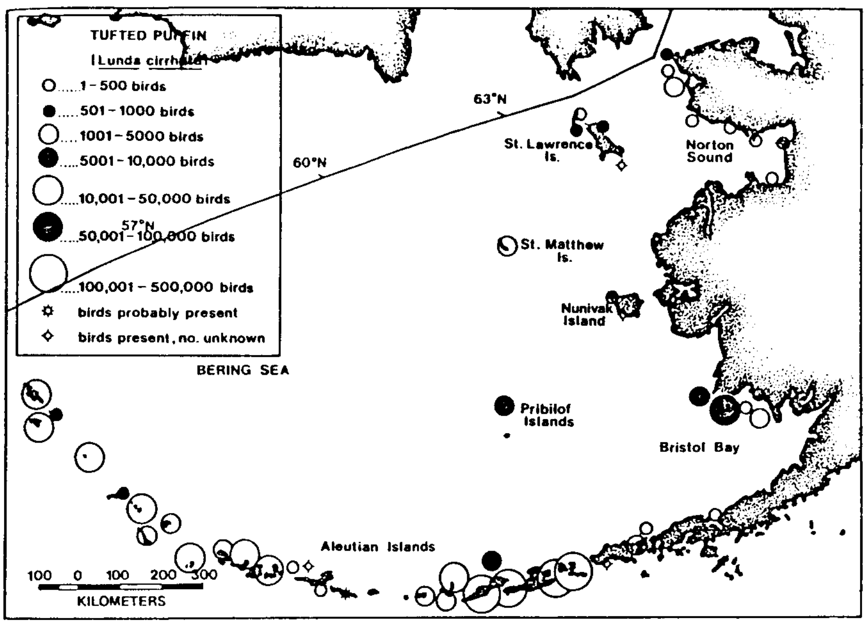


Figure 4B-15. Breeding distribution of Tufted Puffins in the Bering Sea (from Lewbel 1983).

1982). As part of the NAS investigations, LGL (1986) found a large concentration of Crested Auklets in a restricted area in the northeastern corner of the study area. Population estimates have yet to be made but appear to be on the order of 300,000. The size of this population between December and March is sufficient to make the area-wide average winter density greater than that of any other species. Arneson (1977) reports rafts of this species during winter in both Unimak and Akutan passes. Akutan Pass was also identified as supporting large numbers (72,000 estimated) of mixed Crested and Whiskered Auklets on 2 November 1981 (USFWS memorandum 11 January 1982). The pass between Poa and Tangik Island (south of Akun Island) harbored an additional 25,000 auklets.

Crested Auklets feed by pursuit-diving (Ashmole 1971) and specialize in preying on zooplankton at moderate depths (Hunt et al. 1981d). At the Pribilof Islands Crested Auklets take mostly euphausiids, with secondary reliance on copepods and amphipods (Hunt et al. 1981d). Searing (1977) indicated that Crested Auklets at St. Lawrence Island were foraging almost completely on calanoid copepods, at least as food for their young. No auklets were collected as part of the NAS investigations (LGL 1986) to determine their winter diet in this area.

Tufted Puffin (<u>Fratercula cirrhata</u>)

About 25% of the world's 6.3-8 million Tufted Puffins nest in the eastern Bering Sea. The eastern Aleutian Islands are the center of abundance for this species in Alaska (Fig. 4B-15) and the world. These birds are ubiquitous in the area; they are the predominant breeding birds and may reach mean densities of 11-122 birds/km^2 in Unimak Pass during the summer. An estimated 800,000 breeding puffins nest on 55 islands in the Fox Islands group (Nysewander et al. 1982); there are six colonies of over 100,000 birds, together accounting for about 40% of all known breeding Tufted Puffins in Alaska. Largest numbers of puffins in pelagic waters occur near the breeding islands. The birds occur also in the tide-rip areas of all major passes and straits, for example in Unalga Pass and between Rootok and Akun islands (Gould 1982), sometimes in locations well removed from the nesting colonies.

During nesting, the birds feed over the continental shelf, seldom straying beyond (Harrison 1977, Gould 1977). Occasional large concentrations have been sighted in tide-rip areas in Aleutian passes (Hunt et al. 1981d, Gould et al. 1982). Following breeding, birds immediately resume a pelagic existence and do not linger over inshore waters near the colonies. The population disperses over the open ocean, usually off the continental shelf. By November birds are seldom found over the continental shelf and most have left the Bering Sea.

Puffins feed by pursuit-diving, mostly within 15 m of the surface. Generally, fish are the most important component of their diet although in some areas squid have been found to be important. Crustaceans are consumed in lesser amounts. Sand lance and capelin are the most common prey fed to nestling puffins, and growth rates of young are the greatest when these fish predominate in food loads brought to nestlings. When these primary prey species are not available, Tufted Puffins tend to prey mainly on cephalopods, or on cod, sculpin and greenlings.

Waterfowl and Shorebirds

Surprisingly few data are available documenting the distributions and abundances of waterfowl and shorebird species in the study area. The only document evaluating waterfowl use of this area is by Arneson (1980) and is based on a single winter survey. The North Aleutian Shelf data (LGL 1986) summarized in Table 4B-1 includes waterfowl sighted along Unimak Island. The available data suggest that the eastern Aleutians study area may support reasonably high populations of wintering waterfowl. Unimak Pass itself provides a migration corridor for several species of waterfowl (Fig. 4B-16) and phalaropes.

During a winter survey of coastal areas in the Fox Islands, Arneson (1980) found a mean density of 94 birds/km^2, mostly waterfowl and shorebirds. The highest density (3240 birds/km^2), mostly waterfowl, was found around Samalga Island (Table 4B-4 and Fig. 4B-17). The most abundant species or species groups at this latter location were Emperor Goose (Chen canagica) (1435 birds/km^2), sea ducks (416 birds/km^2), and shorebirds (1240 birds/km^2). The principal wintering area for Emperor

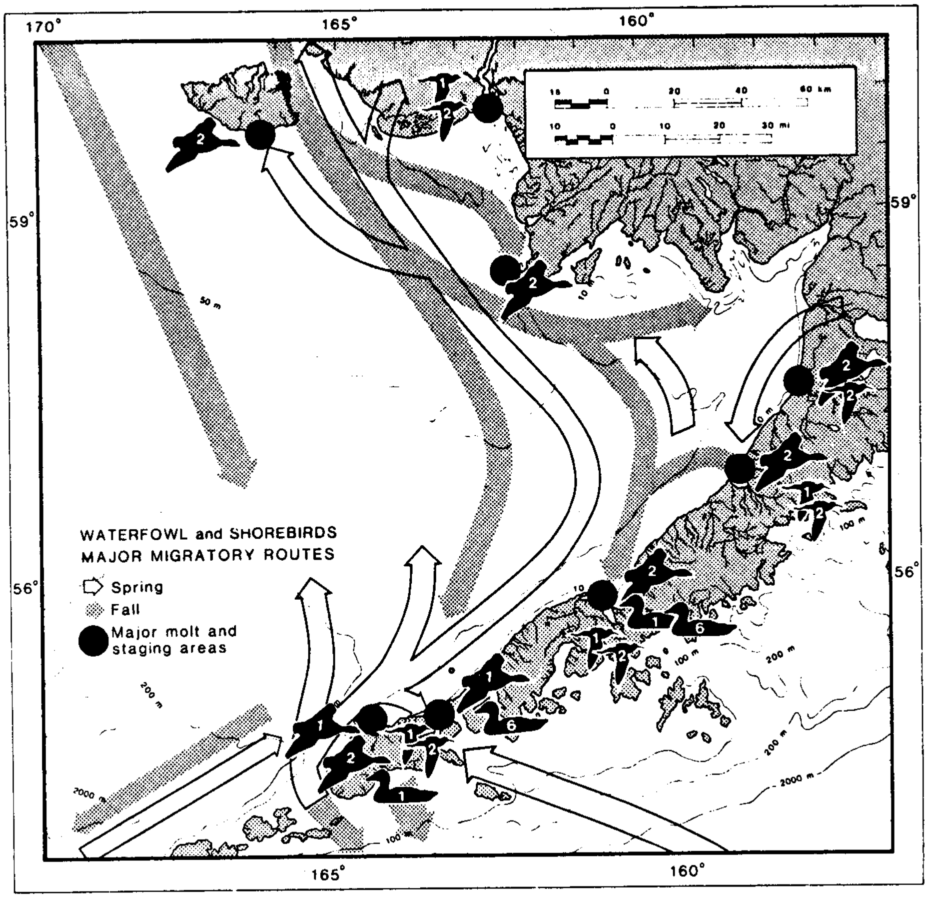


Figure 4B-16. Major migratory routes and feeding areas of waterfowl and shorebirds in the southeastern Bering Sea (from Strauch and Hunt 1982).

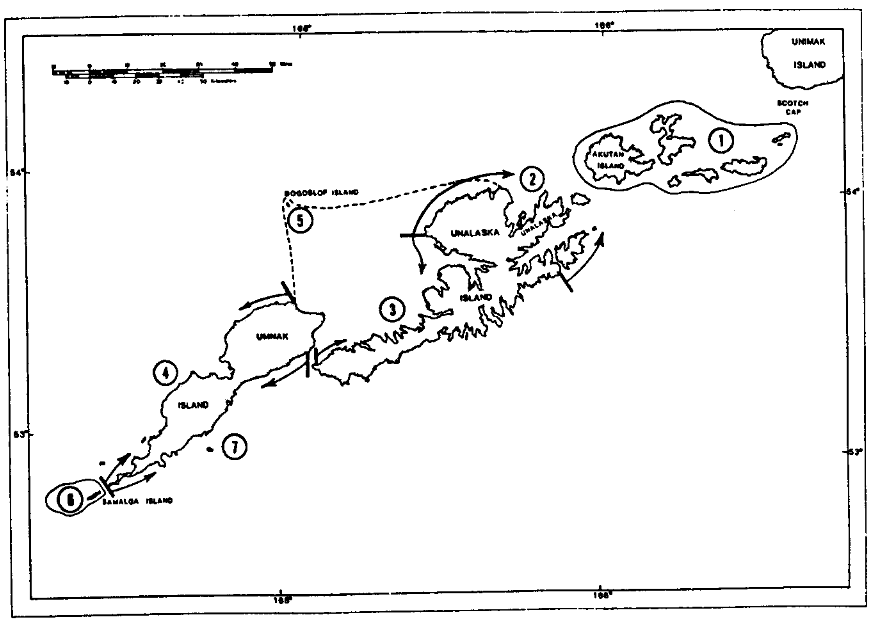


Figure 4B-17. Subdivisions of the Fox Islands for bird density analysis. Each numbered section contains several survey stations (from Arneson 1980). See Table 4B-4 for density estimates.

Table 4B-4. Bird density by section of coastline in Aleutian Shelf, winter 1978 (Arneson 1980). Figure 4B-17 shows section boundaries. (T = trace.)

	Winter Densities (birds/km^2)							
	Section of Coastline							
Bird Group	1	2	3	4	5	6	7	Total
Loon	T	T	T	T				T
Grebe	T	T	T			T		T
Tubenose					1			T
Cormorant	6	4	4	2	T		2	4
Goose and Swan	6	9	23	8		1435	10	17
Dabbler	T	T		2		30	1	1
Diver	T	1	1	T		20	1	1
Sea Duck	50	41	51	30	T	416	57	43
Merganser	T	T	T			T	T	T
Raptor	T	T	T	T			T	T
Crane								0
Shorebird	1	1	1	1		1240	48	13
Gull and Jaeger	7	14	10	11	12	99	9	11
Tern								0
Alcid	4	8	10	T	T			5
Corvid	T	1	T	T			T	T
Other Passerine		T	T				1	T
Other Bird		T	2				T	T
TOTAL	75	80	103	54	13	3240	129	94

Geese includes the northwestern Alaska Peninsula, eastern Aleutian Islands, and the entire Kodiak Basin; included is our area of interest.

Unimak Pass is shown to be an important migration corridor for Steller's Eider (Polysticta stelleri) by Gill et al. (1979). Steller's Eiders winter primarily along the south side of the Alaska Peninsula from Unimak Pass to Kodiak Island. Common Eiders migrate in large numbers from the Gulf of Alaska into the Bering Sea but there are few records from Unimak Pass. Presumably most of these birds pass directly over the Alaska Peninsula (Gill et al. 1979).

Most of the western Canadian breeders of King Eiders (Somateria spectabilis), an unknown portion of the Siberian breeders, and all of the Alaskan breeding populations are thought to winter along the Alaska Peninsula and Aleutian Islands (Bellrose 1976). The birds tend to congregate in the eastern Aleutians and off the major lagoons along the western Alaska Peninsula during winter. During normal ice years numbers of birds usually do not begin to increase along the Alaska Peninsula until after November. They are not reported to arrive in the eastern Aleutians until early December (Cahn 1947).

Concentrations of wintering Black Scoters (Melanitta nigra) occur along the Alaska Peninsula and throughout the Aleutian Islands (Bellrose 1976).

C. FISH

by Peter Craig

The productive waters of the southern Bering Sea and North Pacific Ocean are among the world's richest fishing grounds. These waters support an abundant and diverse fish fauna--over 300 fish species occur there, about 20 of which are of major commercial importance. In this section, four major groups of fishes are reviewed:

1. Salmon - primarily pink salmon
2. Forage Fish - herring, capelin, sand lance
3. Groundfish - pollock, Pacific cod, halibut, sablefish, others
4. Inshore Fish - an abundant and diverse group

Sources of Information

The eastern Bering Sea has long been the focus of fisheries studies and a vast body of information has accumulated. Many studies conducted there are relevant to the present project because they include some sampling stations near the eastern Aleutian Islands, or they provide pertinent information about species and populations which also occur in the study area. Such studies include comprehensive research programs and publication series by OCSEAP (Outer Continental Shelf Environmental Assessment Program), NMFS/NWAFC (National Marine Fisheries Service, Northwest and Alaska Fisheries Center), ADFG (Alaska Department of Fish and Game), PROBES (Processes and Resources of the Bering Sea Shelf), INPFC (International North Pacific Fisheries Commission), IPHC (International Pacific Halibut Commission), and the Soviet Fisheries Investigations in the Northeastern Pacific (Moiseev 1963). In addition, Bering Sea fish resources are monitored annually by state and federal agencies (ADFG, NMFS/NWAFC). We have examined the available studies according to whether they provided (1) directly pertinent data within about 20 km of the eastern Aleutians (Unimak Pass to 170° W longitude), or (2) background information about fishes in adjacent waterbodies (Bering Sea and Gulf of Alaska). About 45 references comprise the former group--these are emphasized in this report and have been annotated (see Part II, Annotated Bibliography).

Salmon

Both local and non-local salmon are an important feature of the eastern Aleutian environment. Background information about salmon in the study area includes stock assessments and commercial harvest levels (Holmes 1982; ADFG 1983, 1985a; Shaul et al. 1984; Shaul 1985), migration studies (Atkinson 1955, Hartt 1962, Thorsteinson and Merrell 1964, Brannian 1984), and subsistence use (Veltre and Veltre 1982). Numerous other reports contribute to an understanding of juvenile and adult salmon movements in the eastern Bering Sea and Gulf of Alaska (e.g., French and Bakkala 1974, Fujii 1975, Godfrey et al. 1975, Neave et al. 1976, French et al. 1976, Major et al. 1978, Hartt 1980, Takagi et al. 1981, Straty 1981, Isakson et al. 1986).

Distribution In and Use of Study Area

Local Stocks. Salmon have been found on most of the Aleutian Islands surveyed, but populations are small compared with those of other salmon fisheries in Alaska (Holmes 1982). Salmon occur in approximately 86 drainages on Unalaska Island and 25 on Umnak Island, which FWS (1986) describes as follows (after Holmes 1982):

> Unalaska Island. This island supports the largest production of salmon on the Aleutian chain. The best pink salmon streams are on the southwestern panhandle. The largest run, estimated at 243,000 pinks in 1982, occurs in the Nateekin River. Two other streams support runs of over 100,000 pinks, and eight streams support runs of between 50,000 and 100,000 pinks. The largest run of sockeye occurs in the Kashega Lake system--8000 in East Lake and 16,000 in West Lake. There are no major runs of chum salmon on the island.

Umnak Island. Almost all of the anadromous fish streams occur on the southern half of the island. Streams in the northern half seem to be capable of supporting salmon but it has been suggested that the drainage from Okmok Volcano restricts usage. The largest producer is on Okee Bay (44,000 pinks) and the second largest is on Geyser Bight (40,000 pinks). Lakes in the vicinity of Nikolski Village support fair sockeye runs. Salmon are an important resource to village residents.

Akutan Island. A stream flowing into Akutan Harbor supports pink salmon. Other streams, although not surveyed, seem to have little potential for salmon.

Pink salmon are by far the most abundant species of salmon in the study area (Table 4C-1); they accounted for over 97% of all stream escapements in 1982 although other species may have been underestimated due to the timing of the survey. Pinks also accounted for about 97% of the commercial harvest in the study area although the annual variation in harvest levels and composition is high (Table 4C-2). For example, in 1982 escapement counts (over 1.5 million) and harvests (1.5 million) plummeted the following year to only 0.1 million and 0.001 million, respectively. Much of this decline was to be expected because pink salmon runs in the Aleutians are cyclic, with even-year runs being much higher than odd-year runs. The commercial fishery for these salmon operates primarily on the north side of Unalaska Island (Fig. 4C-1).

Local salmon stocks are present in coastal waters of the study area for about half of the year, mid-March through early October as follows (ADFG 1985a):

	Juveniles Enter Ocean	Adults Enter Streams
Pink	Mid-March - Mid-May	Early July - Late August
Sockeye	Early May - Early August	Early June - Mid-August
Chum	No Data	Early July - Late August
Coho	No Data	Late August - Early October

Table 4C-1. Escapement counts of salmon spawners, 1982 (Holmes 1982).

Island	Escapement Count of Spawners				
	Pinks	Sockeye[a]	Chum[a]	Coho[a]	King
Akutan	10,500[b]	-	-	-	-
Unalaska	1,541,317	44,995	100	300	0
Umnak	295,385	805	0	143	0

[a]Counts may be underestimates due to survey timing.

[b]Only one stream was surveyed (Harbor Creek).

Table 4C-2. Commercial salmon harvest at Unalaska, 1980-85 (Shaul 1985).

Year	Commercial Catch (x 1000)[a]				
	Pink	Chum	Sockeye	Coho	King
1980	2598	4.9	9.2	0	0
1981	303	6.6	5.4	0.2	0
1982	1448	6.1	2.7	0	0
1983	1	10.0	3.0	0	0
1984	2310	33.9	67.2	0	0
1985	0.3	14.0	2.0	0	0
MEAN (%)	1110 (97.6)	13 (1.1)	15 (1.3)	0 (0)	0 (0)

[a]Some variation may be due to annual changes in fishing effort.

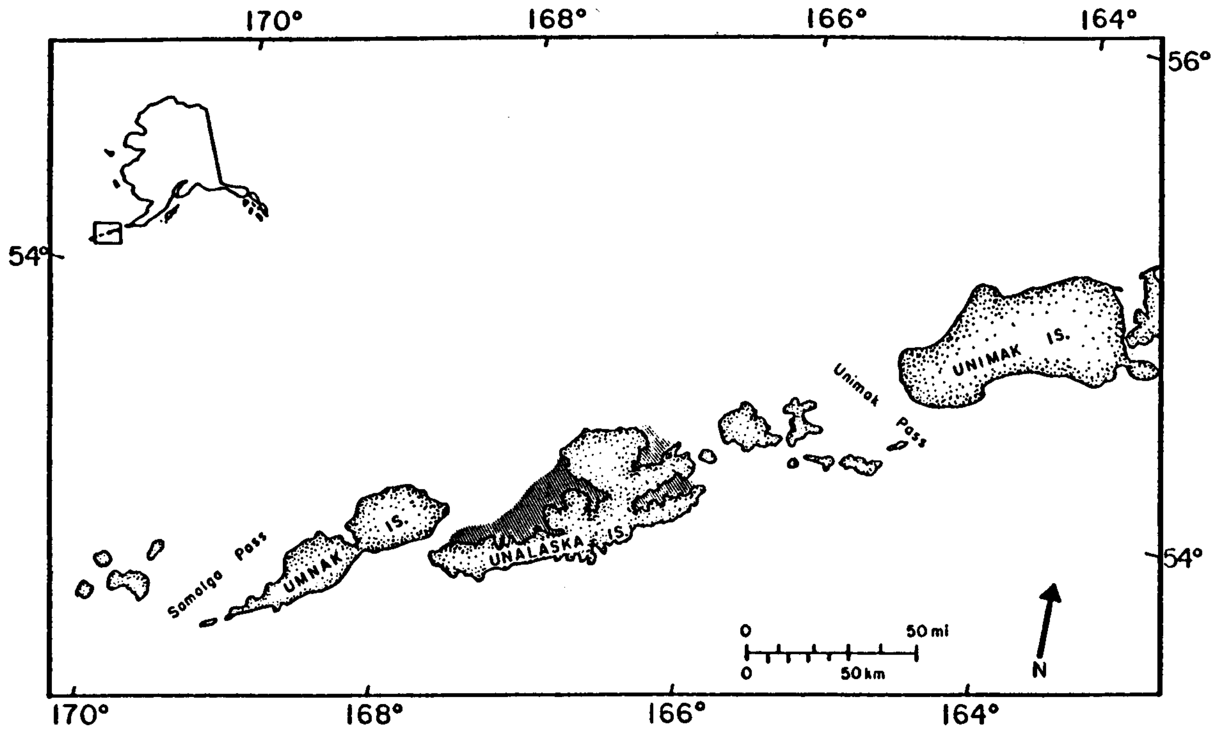


Figure 4C-1. Commercial fishing areas for salmon at Unalaska Island (shaded areas) (from ADFG 1985a, Shaul pers. comm.).

The timing of adult returns to nearshore waters of the study area differs among species (Fig. 4C-2). In Unalaska Bay the pink salmon runs usually occur from about 20 July to 25 August, with peak numbers from about 25 July to 10 August (Shaul et al. 1984); however, these dates can vary--in 1983 the run was nine days later than the average date of return (ADFG 1983). Sockeye are most abundant in coastal waters from late July to early August, and chum from mid-July to mid-August. Local stocks of coho are most abundant in coastal waters in September (A. Shaul, ADFG, pers. comm.). The extent of ADFG escapement surveys in this region consists of annual fall surveys (weather permitting) of streams on the north side of Unalaska Island and the eastern half of Unimak Island, and occasional surveys elsewhere (A. Shaul, ADFG, pers. comm.).

Local salmon stocks use the study area in two ways. First, newly smolted salmon juveniles feed in nearshore waters for days or weeks prior to migrating offshore. These rearing areas are basically the same as those where the commercial salmon fishery occurs (Fig. 4C-1). Second, adult salmon gather in nearshore waters prior to commencing their spawning runs up Aleutian rivers.

Non-Local Stocks. The oceanic migrations of salmon stocks from Asia and North America are complex and variable, and may at times include movements in the vicinity of the eastern Aleutian Islands. There are two general components to such movements: (1) an emigration of salmon juveniles from Bering Sea streams into the North Pacific Ocean, and (2) the return migrations of ocean-dwelling adults back to their spawning streams.

Hartt (1980) has summarized the movements of juvenile salmon during their first year at sea (Fig. 4C-3). There tends to be a westward movement of these fish during summer followed by presumed fall and winter migrations to the south. The timing of these movements is not specifically known nor is the use by migrating salmon of island passes in the eastern Aleutians. Multiple migrations through the Aleutian chain may occur (Fig. 4C-4). Bax (1985) provides a detailed review of sockeye salmon migrations in the Bristol Bay area.

After spending months or years feeding in the North Pacific, many western salmon stocks begin their return to spawning streams by migrating

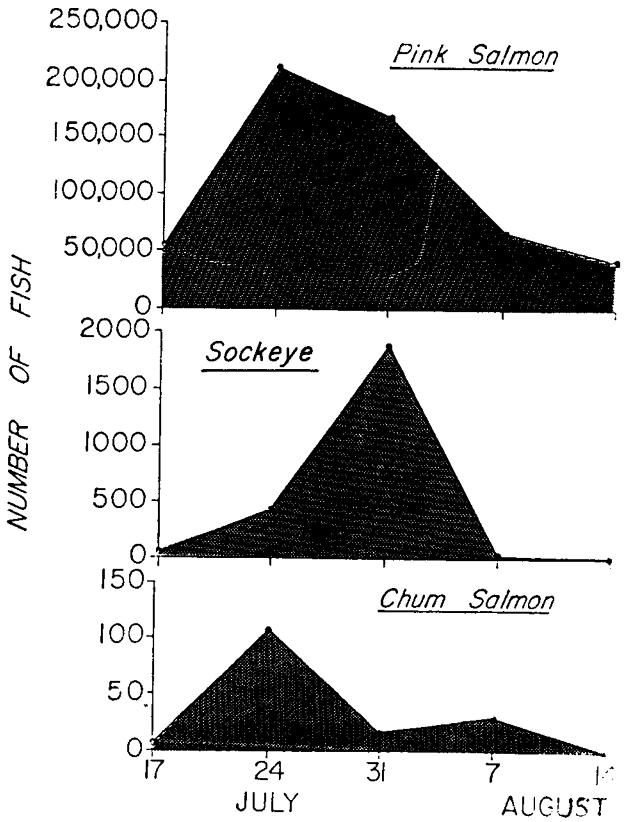


Figure 4C-2. Seasonal abundance of salmon in the Unalaska area, 1954 (from Atkinson 1955).

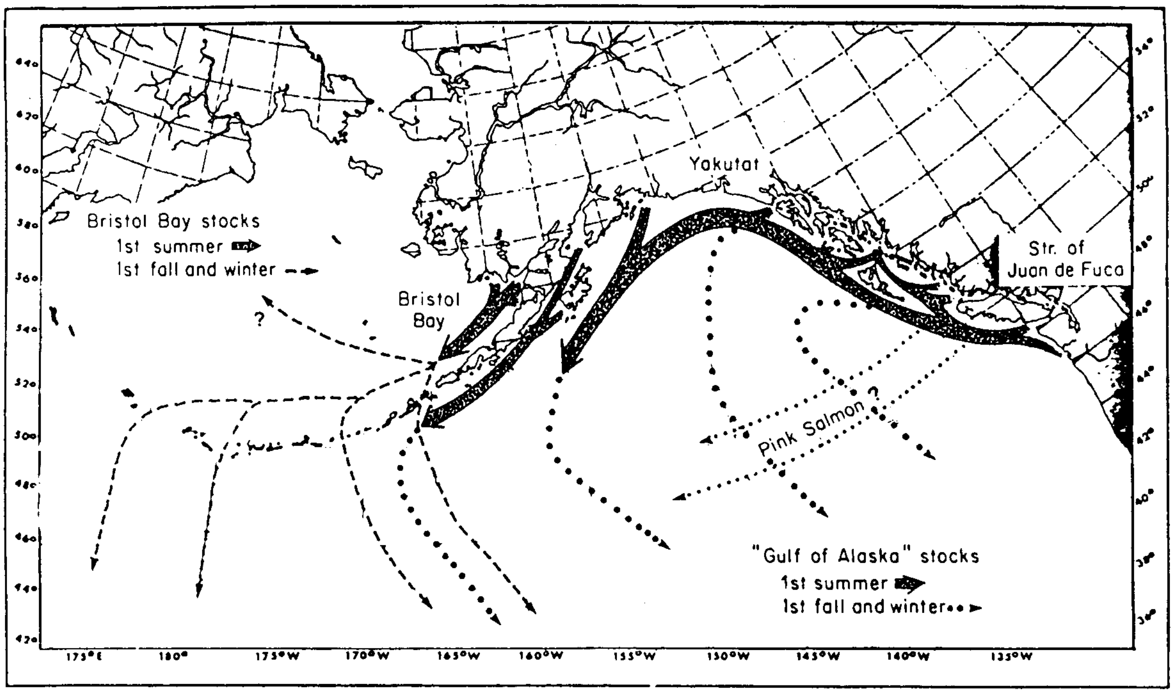


Figure 4C-3. Oceanic migration patterns of some major stocks of North American sockeye, chum, and pink salmon during their first summer at sea, and probable migrations during their first fall and winter (from Hartt 1980).

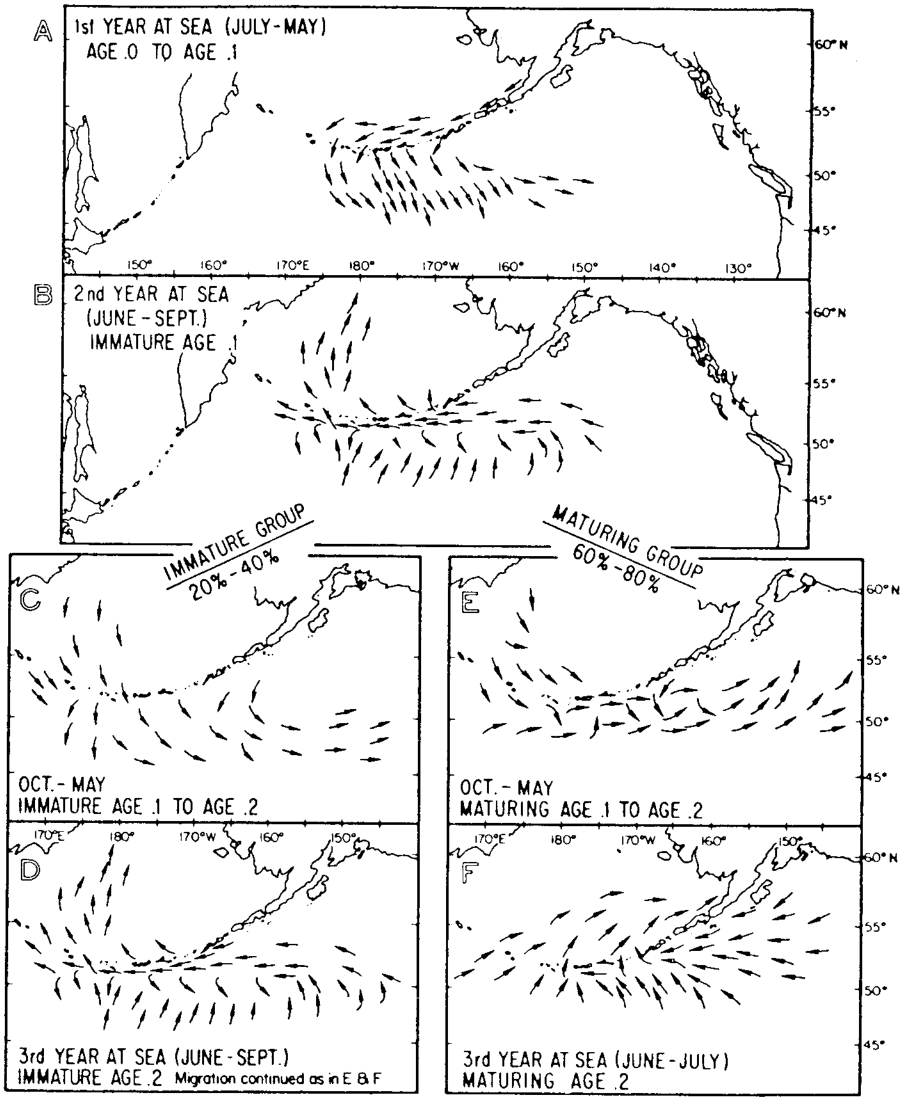


Figure 4C-4. Migration model for sockeye salmon in western Alaska (from French et al. 1976).

westward along the southern side of the Aleutian Islands (e.g., Hartt 1962). The width of this westward-moving band of fish is not well-defined, but it is presumably at least tens of kilometers wide. Probably only a small portion of the band lies within 10 km of the eastern Aleutian Islands. In some years, however, island passes in the study area may be a principal route by which the returning adults enter the Bering Sea (Fig. 4C-5).

The origin of the adult salmon that migrate along the south side of the Aleutians is currently a contentious issue. ADFG (1986) notes that several tagging studies conducted during the period 1956-1963 showed that a substantial portion of the sockeye and chum salmon available to nearby fisheries (south Unimak and Shumagin Island areas) were not of local origin. For chum salmon, the pattern of tag recoveries indicated that these fisheries were intercepting fish primarily from western Alaska although tags were also recovered from widely dispersed areas throughout the Alaska Peninsula, Japan, Russia, British Columbia, and Puget Sound. Most sockeye intercepted by these fisheries were from Bristol Bay with minor interceptions of sockeye bound for north Alaska Peninsula streams. ADFG (1986) plans to sponsor another tagging program in 1987 to further investigate these migration patterns.

Tagging data also indicate that the timing of adults migrating along the south side of the eastern Aleutians differs somewhat according to the destination of each stock. For chum salmon, migration times are May-early June (for the summer run of Yukon River chum), June (Norton Sound and Kotzebue chum), mid- to late June (Bristol Bay and the fall run of Yukon River chum), and mid- June to early July (Kotzebue chum) (Brannian 1984).

Feeding Habits

There are three principal groups of feeding salmon in the study area: (1) recently smolted pink salmon fry, (2) larger juveniles of all species, and (3) pre-spawning adults. Pink salmon fry enter coastal waters soon after emerging from stream gravels in springtime. In nearshore waters, they consume small crustaceans (e.g., copepods, euphausiids, amphipods, ostracods), larvae of decapods, cirripedes, tunicates and dipteran insects (Neave 1966, ADFG 1985a).

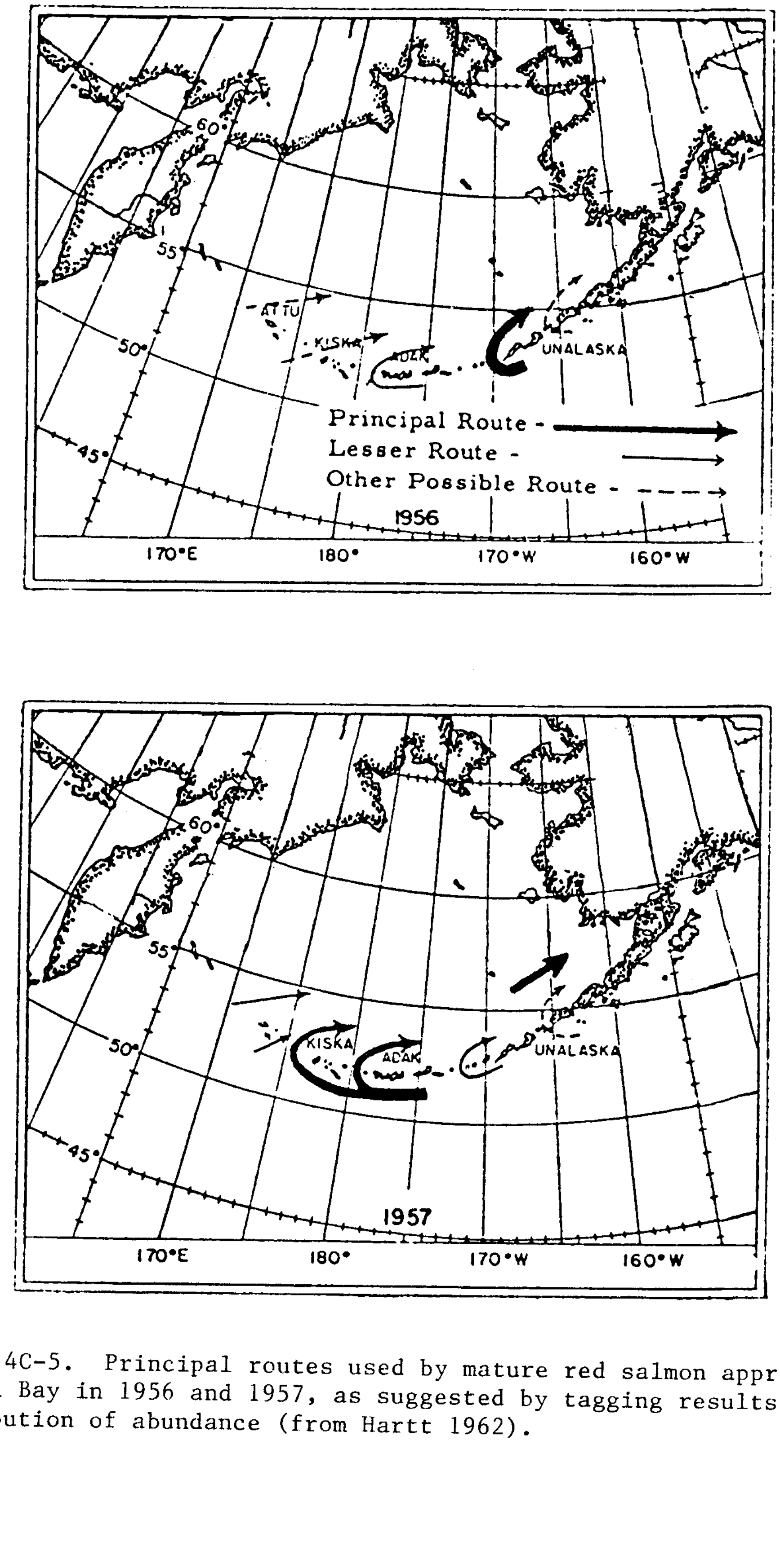


Figure 4C-5. Principal routes used by mature red salmon approaching Bristol Bay in 1956 and 1957, as suggested by tagging results and by distribution of abundance (from Hartt 1962).

Juveniles from Bristol Bay streams are about 100-200 mm in length by the time they leave outer Bristol Bay and arrive in the vicinity of the eastern Aleutian Islands. Their foods include sand lance, euphausiids, amphipods, decapod larvae, mysids and copepods (Neave 1966, Straty 1974, LGL 1985b). Adult salmon in the eastern Bering Sea consume euphausiids, fish, amphipods, crab zoea and pteropods (Kanno and Hamai 1971, Nishiyama 1974, LGL 1986).

Factors Affecting Distribution and Abundance

Several environmental factors affect the number of salmon in the study area, among which are (1) the amount of spawning habitat available to salmon in Aleutian rivers, (2) survival of eggs and juveniles, and (3) the water temperature/salinity structure. First, streams in the eastern Aleutian Islands have a limited potential for salmon--the streams are relatively small and occasionally obstructed by debris at their mouths (ADFG 1985a). Some streams on the northern half of Umnak Island appear to be "essentially sterile for salmon" due, perhaps, to some adverse factor associated with drainage from the Okmok Volcano (Holmes 1982).

Second, a variety of biotic and abiotic factors may affect the spawning success and subsequent survival of salmon fry and juveniles. For example, factors such as the impacts of weather conditions on egg survival, the availability of prey when smolts enter marine waters, predation, and commercial harvest all affect the numbers of salmon that will ultimately return to spawn.

Third, the abundance of salmon in coastal waters is likely affected by their preferences for particular water temperature and salinity regimes. The study area is situated in a region of complex water origins and mixtures, including flow through passes and upwelling. It would seem likely that, in this region of diverse and changing water structure, fish demonstrating a temperature/salinity preference would not be distributed evenly throughout the region. Fujii (1975) discusses some of the hydrologic conditions along the Aleutian Islands under which sockeye will and will not migrate through the island passes.

Forage Fish

The term "forage fish" refers to species that are abundant, small in size, and significant in the diets of other consumers. Important forage species in the eastern Aleutians include herring, capelin and sand lance. Available information is limited for herring and generally lacking for the other two species.

Herring

Pacific herring are distributed nearly continuously around Alaska, excluding northernmost regions. In the eastern Bering Sea, herring are a significant component of the food web and form the basis of an important commercial fishery. Spawning populations in the eastern Aleutian Islands are a relatively small part of the overall herring biomass in the eastern Bering Sea, but the study area is an important feeding area for herring, including stocks spawned elsewhere in the eastern Bering Sea. Scale-pattern analyses indicate that about 80% of the herring harvested at Unalaska Island are from Bristol Bay (Togiak stock) with 10% from farther north (Nelson Island) and 10% from Port Moller (Walker and Schnepf 1982, Libida et al. 1984, Rogers and Schnepf 1985). Herring stocks south of the Alaska Peninsula, however, apparently do not mix with Bering Sea stocks (Grant and Utter 1984, Rogers and Schnepf 1985).

The following description of herring in the eastern Aleutians is based largely on recent reports by Malloy (1985) and ADFG (1985a), and is supported by more general reviews (Wespestad 1978, Macy et al. 1978, Barton and Wespestad 1980, Barton and Steinhoff 1980, Wespestad and Barton 1981, Warner and Shafford 1981, Wespestad and Fried 1983, Lewbel 1983, Gilmer 1984, LGL 1985b, Schwarz 1985, Fried and Wespestad 1985).

<u>Distribution and Use of the Study Area</u>. Patterns of habitat usage differ between local and non-local herring stocks.

<u>Local stocks</u> - Small stocks occur at several locations, the principal one being Unalaska Bay but also Makushin and Akutan bays, and possibly in Beaver Inlet (Fig. 4C-6A). Spawning sites within Unalaska Bay

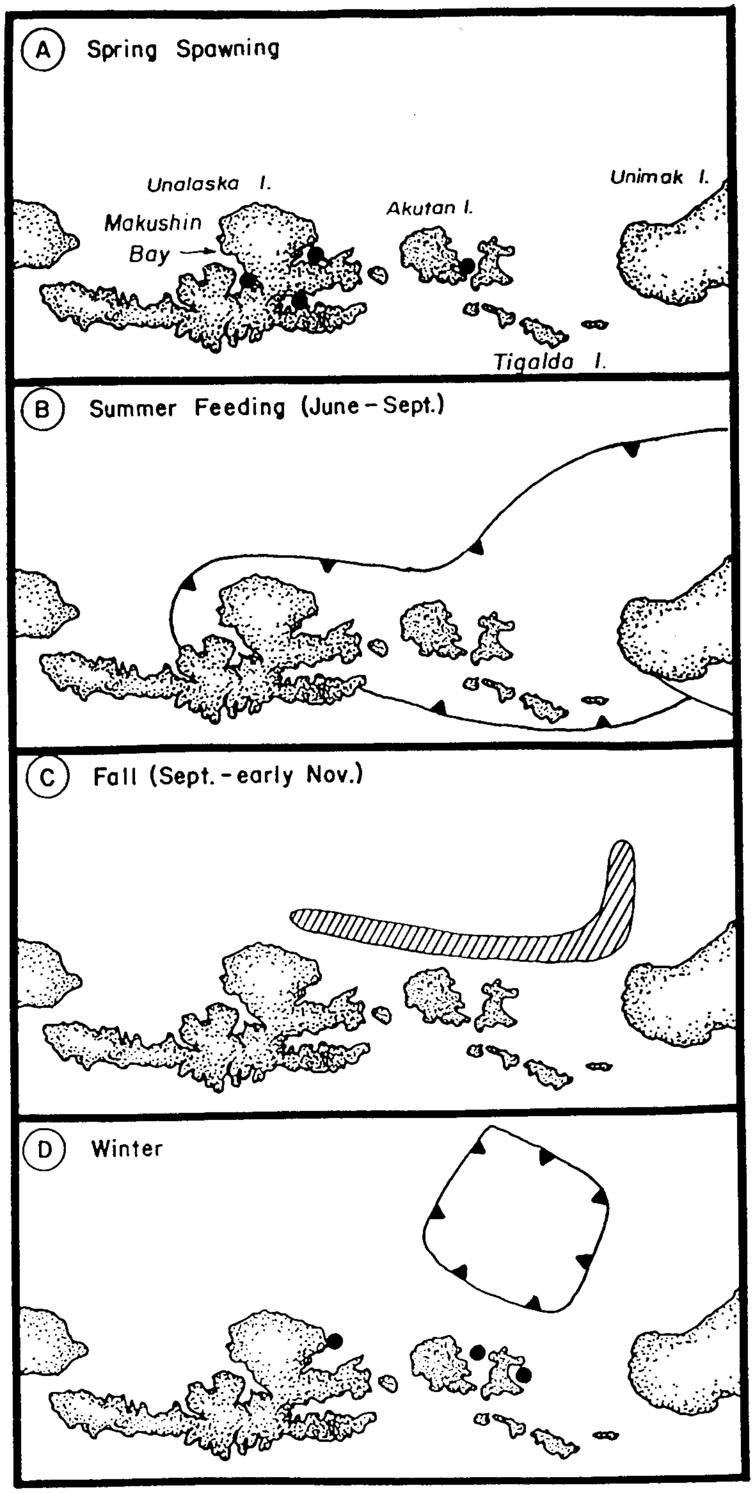


Figure 4C-6. Pacific herring in the eastern Aleutian Islands (from Macy et al. 1978, ADFG 1985a, Malloy pers. comm.).

are reported at Nateekin Bay, Captains Harbor and Wide Bay (McCullough 1984). Spawning elsewhere in the study area is likely but undocumented.

Herring spawn in the Aleutians from late April to mid-July (ADFG 1985a). Their eggs are deposited both intertidally and subtidally on aquatic vegetation. After the eggs hatch, the larvae remain in nearshore areas (Fig. 4C-6B) until summer and fall when they move offshore. Local stocks may reside in the eastern Aleutian Islands year-round, but their distribution is not clear due to the large influx of non-local stocks in summer (discussed later). In summer, herring are distributed throughout much of the study area (Fig. 4C-6B), including the straits and passes of the Four Island group at the western end of the study area (ADFG 1985a). Some remain through fall (Fig. 4C-6C) and winter (Fig. 4C-6D). This winter concentration is small compared to winter concentrations of herring near the Pribilof Islands, and it is not clear that the Unimak Pass area is used regularly by herring during the winter months (Wespestad 1978); however, it seems probable that at least the winter concentrations of herring in Unalaska, Akutan and Akun bays are of local stock origin because herring in other areas of Alaska are known to overwinter close to their spawning sites (e.g., Carlson 1980).

Non-local stocks - The dominant stocks of herring in the eastern Bering Sea undertake extensive annual migrations among wintering, spawning and feeding areas, and the eastern Aleutian Islands lie along one of their migratory routes (Fig. 4C-7). The largest wintering concentration of these fish occurs northwest of the Pribilof Islands, more than 700 km from their major spawning area in northern Bristol Bay (Shaboneev 1965, Rumyantsev and Darda 1970, Wespestad and Barton 1981). After spawning, many of these fish migrate westward along the Alaska Peninsula as far as Unalaska Island where they feed in summer. These herring are harvested in a food/bait fishery (3200 mt total harvest) which operates over an approximate 90-mi distance between Tigalda Island and Makushin Bay, although most fishing occurs within about a 5-mi radius of shore-based processing facilities in Unalaska and Akutan bays (Malloy 1985).

Malloy (1985) notes that early accounts of herring in the Unalaska area described both an early summer run (late June to late July) and a late summer run (late August to early September), but in current years

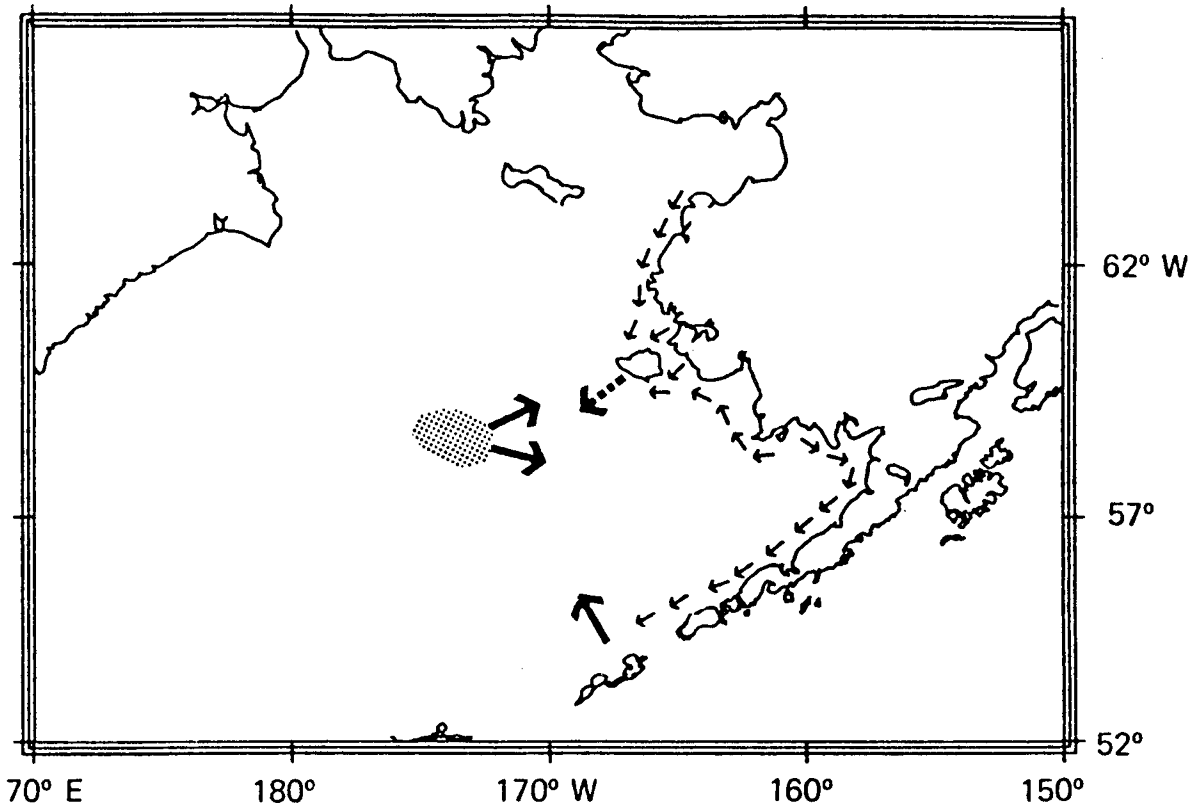


Figure 4C-7. Conceptualized migration routes of herring from (1) offshore wintering grounds (stippled area) to coastal areas in spring, and (2) return routes in summer and fall. Redrawn from Wespestad and Barton (1981) and Wespestad and Fried (1983), as modified by ADFG (1985a) to include Unalaska data.

there seems to be a steady harvest of herring from mid-July through mid-September. During this period, however, the availability of herring is not entirely dependable--weather conditions seem to determine daily herring movements and behavior patterns and hence the herring are periodically not available in "traditional" harvest locations (Malloy 1985).

Trophic Relationships. Herring are an important component of the eastern Bering Sea food web--they are the prey of many seabirds, marine mammals and other fishes (Pace 1984). Of the potentially harvestable population, Lavaestu and Favorite (1978) estimated that 95% of the herring stock is needed by these consumers and that only 5% is available to the commercial fishery.

Herring feeding habits in the study area have not been examined but are presumably similar to those occurring at other locations. ADFG (1985a) provides the following summary:

1. Larvae and postlarvae feed on ostracods, small copepods and nauplii, small fish larvae, and diatoms (Hart 1973). The first food eaten by larval herring may be limited to relatively small, microscopic plankton organisms that the larvae must nearly collide with to notice and capture. Early food items may be comprised of more than 50% microscopic eggs (Wespestad and Barton 1981).
2. Juveniles consume mostly crustaceans such as copepods, amphipods, cladocerans, decapods, barnacle larvae, and euphausiids. Consumption of some small fish, marine worms, and larval clams has also been documented (Hart 1973). In the western Bering Sea and Kamchatka area in November and December, the diet of juveniles has consisted of chaetognaths, mysids, copepods, and tunicates (Kachina and Akinova 1972).
3. Adults in the eastern Bering Sea in August ate 84% euphausiids, 8% fish fry, 6% calanoid copepods, 2% gammarid amphipods; fish fry, in order of importance were walleye pollock, sandlance, capelin, and smelt. During spring

months, food items were mainly *Themisto* (amphipoda) and *Sagitta* (chaetognath). After spawning (eastern Bering Sea), adults preferred euphausiids, copepods (*Calanus* spp.), and arrow worms (*Sagitta* spp.) (Dudnik and Usoltsev 1964). In demersal areas, stomach contents of herring included polychaete worms, bivalve molluscs, amphipods, copepods, juvenile fish, and detritus (Kachina and Akinova 1972). Barton (1979) found cladocerans, flatworms (Platyhelminthes), copepods, and cirripeds in herring captured during spring months. Rather than exhibiting a preference for certain food items, adult herring feed opportunistically on any large organisms predominating among the plankton in a given area (Kaganovskii 1955).

Important Physical Habitat Factors. Spawning areas provide the best examples of important physical parameters of habitat for herring. In the Bering Sea, spawning occurs in the intertidal or subtidal zone on rocky headlands or in shallow lagoons and bays (Barton 1979, Warner and Schafford 1981). Preferred spawning substrates are aquatic vegetation, particularly rockweed (*Fucus*), kelp (*Laminaria*) and eelgrass (*Zostera*). As previously mentioned, spawning areas have been located at only three sites in the study area (Fig. 4C-6a), but others probably exist.

Population Limiting Factors. Herring stocks in the eastern Bering Sea have undergone large fluctuations in abundance over the past 20 years (Fig. 4C-8). Year-class strengths of herring were particularly high in 1957; there were lesser peaks in 1962, 1968, 1974 and 1977 (Fig. 4C-9). The 1977 year class has constituted a large portion of the annual commercial harvest of herring in the food/bait fishery at Unalaska Island (Fig. 4C-10). The apparent absence of younger fish in this fishery would seem to suggest that harvests may decline in the near future. Wespestad and Fried (1983) note that many explanations and hypotheses have been offered concerning the causes of recruitment variability, but most recognize that environmental factors, rather than harvest levels, may be most important in controlling year-class strength unless spawning stocks have fallen below a critical threshold level.

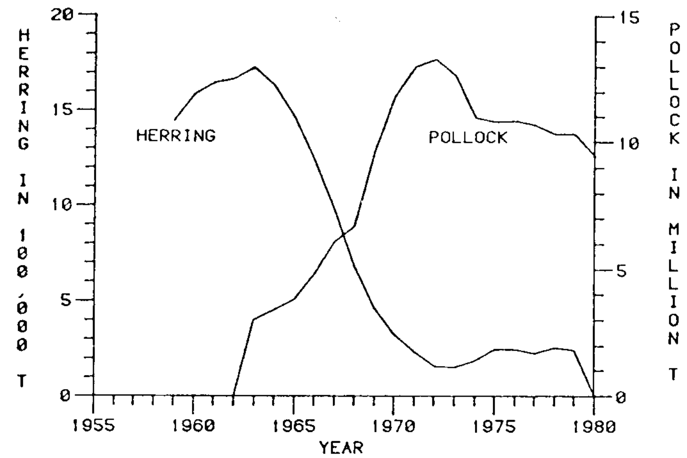


Figure 4C-8. Relationship between pollock and herring abundance in the eastern Bering Sea (from Wespestad and Fried 1983).

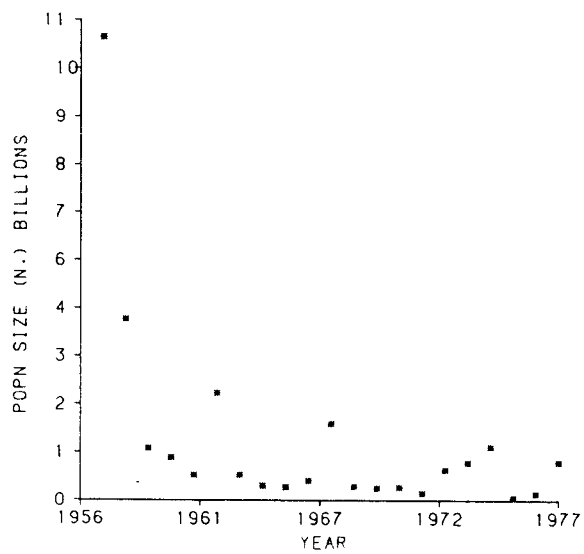


Figure 4C-9. Estimated numbers of age 1 herring in the eastern Bering Sea by year-class, 1957-77 (from Wespestad and Fried 1983).

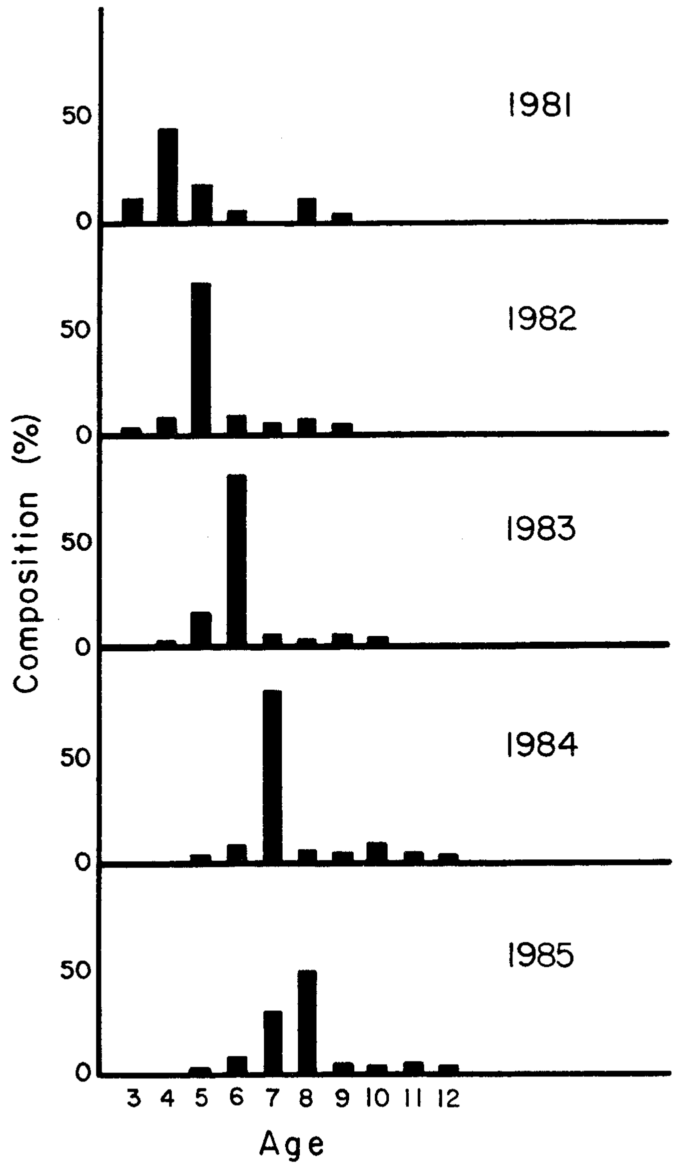


Figure 4C-10. Age composition of herring harvested in the food/bait fishery near Unalaska Island (from Malloy 1985).

It is generally believed that most variation in year-class strength is determined during early life history, and water temperature is probably an important factor (Wespestad and Fried 1983)--there is some correlation between the occurrence of warmer waters and increased survival of herring (e.g., Pearcy 1983). Other factors such as predation and availability of suitable spawning habitat could also be contributing factors. Pearcy (1983) concludes that:

> Environmental variables that affect year-class success of herring probably range from single, short-term events such as a storm or freshet that affect the survival of cohorts in an isolated inlet to large-scale events that affect the productivity and circulation of large areas of the northeastern Pacific for a year or more. The synchrony of strong year classes in distant stocks during El Ninos supports the idea that large-scale ocean events are important. But we lack information on interannual differences in oceanographic conditions in the northern North Pacific, as well as on specific mechanisms on how varying ocean conditions modify year-class success of herring.

Capelin

Capelin range throughout the Bering Sea (Warner and Shafford 1979) and are abundant in the study area at various times of year (Fig. 4C-11). A hundred years ago Turner (1886) remarked "Among the Aleutian Islands these fish abound in incredible numbers."

Capelin are generally found in large schools offshore, except during the breeding season when they migrate shoreward to spawn (Macy et al. 1978, Paulke 1985). Spawning occurs in northern Bristol Bay and along the north side of the Alaska Peninsula, but the eastern Aleutians have not been surveyed for this purpose. Along the Alaska Peninsula, schools of spawners are most abundant in mid-May to mid-June where they spawn on pebble-covered beaches and shallow shoals (Barton 1979). Their sticky eggs adhere to the substrate until they hatch, whereupon the larvae move

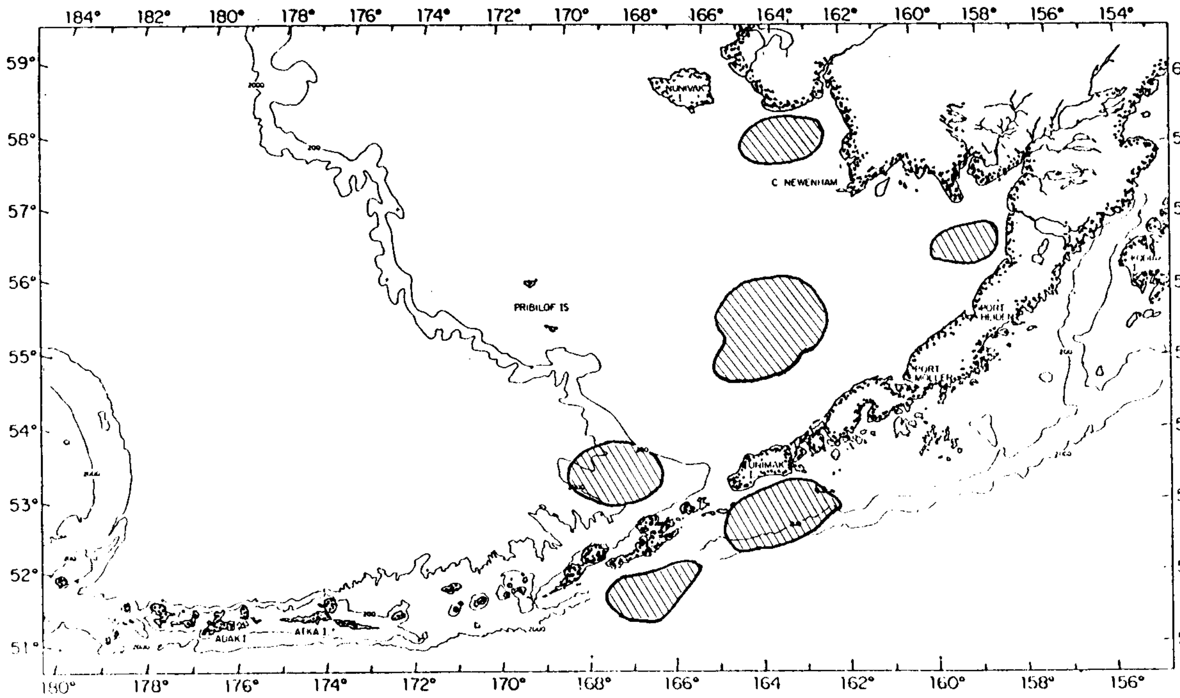


Figure 4C-11. Generalized areas in which capelin larvae or juveniles were caught by seines in spring and summer, eastern Bering Sea and western Gulf of Alaska (from Macy et al. 1978).

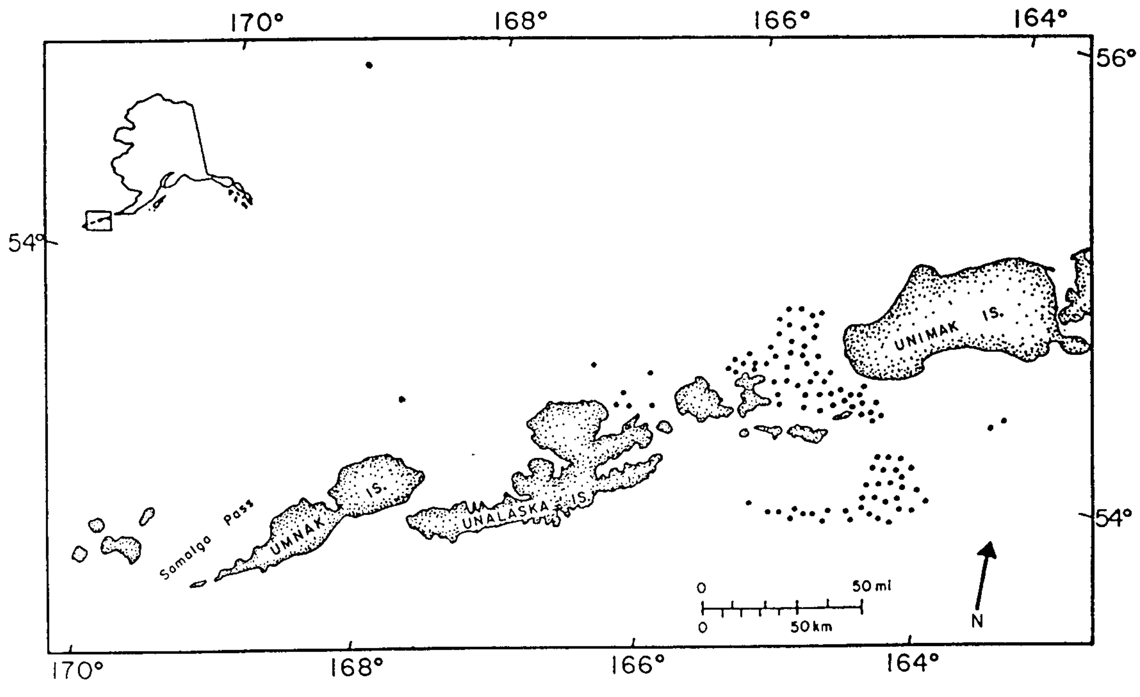


Figure 4C-12. Locations where capelin were present in fur seal stomachs (redrawn from Fiscus et al. 1964).

offshore in late summer and fall. The nearshore zone thus serves as a breeding habitat for adults and as a feeding ground for larvae and fry.

Capelin feed primarily on small crustaceans such as copepods, euphausiids, amphipods and decapod larvae, and small fish. Capelin are eaten by salmon, cod, marine mammals and seabirds (Hart 1973, Macy et al. 1978, Vesin et al. 1981). Fiscus et al. (1964) found that the Unimak Pass area was a favored summer feeding ground for fur seals which consumed vast quantities of capelin that had congregated there (Fig. 4C-12).

Sand Lance

Pacific sand lance is one of the most abundant forage fishes in the eastern Bering Sea, including the eastern Aleutian area (Fig. 4C-13). Information about this species is limited and has been reviewed by Trumble (1973) and Macy et al. (1978). More recent studies have examined sand lance on the north side of the Alaska Peninsula (LGL 1986, Isakson et al. 1986) and near Kodiak (Dick and Warner 1982).

Along the Alaska Peninsula, sand lance were most abundant during mid- to late summer (July-September) in nearshore waters less than 35 m deep. Their distribution was very patchy--they sometimes formed dense schools in shallow water while at other times they were found partially buried in unconsolidated sediment (Hart 1973, Macy et al. 1978, Dick and Warner 1982). LGL (1986) reports that sand lance consumed a variety of prey in May (euphausiids, copepods, amphipods, mysids, polychaetes and eggs) but less of a variety in September (copepods).

Sand lance in the study area probably spawn in late fall or winter (Macy et al. 1978, Dick and Warner 1982). They may spawn intertidally (Dick and Warner 1982) or at depths of 25-100 m in areas having strong currents (Trumble 1973). These fish require particular substrate compositions for burrowing and presumably spawning. Their adhesive eggs probably hatch in about three months depending on water temperatures. After hatching the larvae become pelagic and widely distributed in the Bering Sea (Fig. 4C-13).

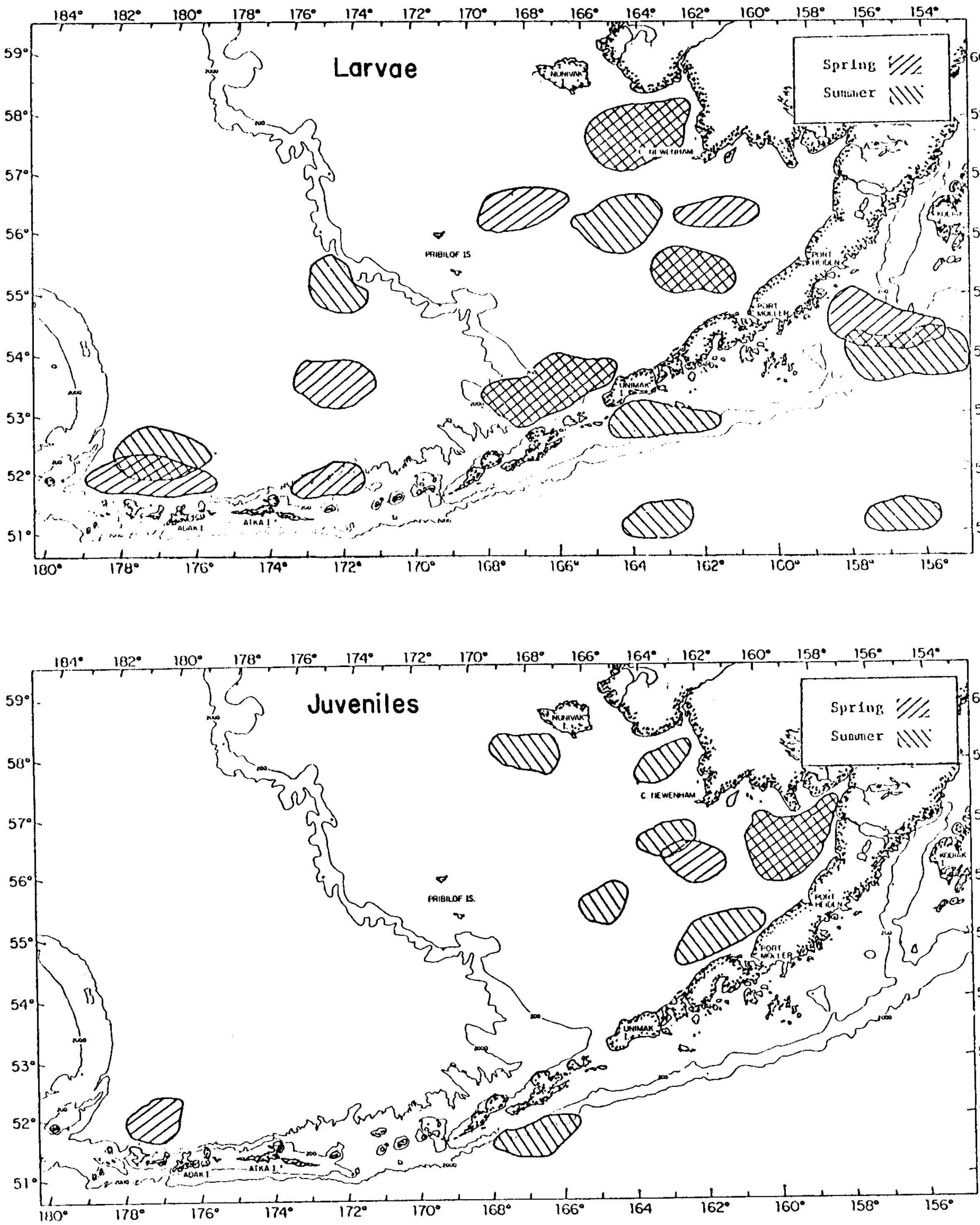


Figure 4C-13. Generalized areas in which sand lance larvae (top) and juveniles (bottom) were caught by plankton nets, seine nets, and bongo nets in spring and summer (from Macy et al. 1978).

Groundfish

The term "groundfish" refers to a diverse group of fishes which usually inhabit near-bottom offshore waters. It is a term of convenience for it encompasses not only flatfishes living directly on the seabottom but also species like pollock which often dwell near the bottom but may be pelagic as well. In addition, many groundfish species have pelagic egg and larval stages.

The Bering Sea is well known for its abundance of groundfish (summarized by Hood and Calder 1981, Lewbel 1983, ADFG 1985a, and others). Much of the commercial catch occurs along the continental shelf break adjacent to Unimak Pass (Fig. 4C-14) and just south of Unimak Pass (Fig. 4C-15). The region of highest catches in Figure 4C-14 is popularly known as the "Golden Triangle" (between Unimak Pass, the Pribilof Islands, and Amutka Pass). Because of the commercial value of this resource, a vast amount of information describing groundfish in the Bering Sea and western Gulf of Alaska has accumulated. Commercial harvests are monitored by state and federal agencies, and NMFS anually surveys groundfish over a large area adjacent to the current study area (Fig. 4C-16). Over 125 reports describing groundfish resources were examined during the present literature review. As previously mentioned, these sources provide useful backgound information, but relatively few describe groundfish resources specifically within the current study area.

Several sources of information are directly pertinent to the present project. In 1980 NMFS and Japan conducted a joint survey of groundfish resources in Aleutian Island waters (Fig. 4C-17) (Ronholt et al. 1982, Wilderbuer et al. 1985, Ronholt et al. 1986). NMFS (1975-81) also surveyed shrimp (and fish) resources in the bays around Unalaska Island (Fig. 4C-18). Other information sources include the composition of fishes in commercial fisheries north of Unimak Pass (Fig. 4C-18) and surveys conducted south of Unimak Pass by NMFS (Fig. 4C-19) and IPHC (Fig. 4C-20).

The surveys above were selected to provide the best coverage of the study area, with emphasis on the more recent sampling efforts. For completeness, the reader should note that data from additional surveys are

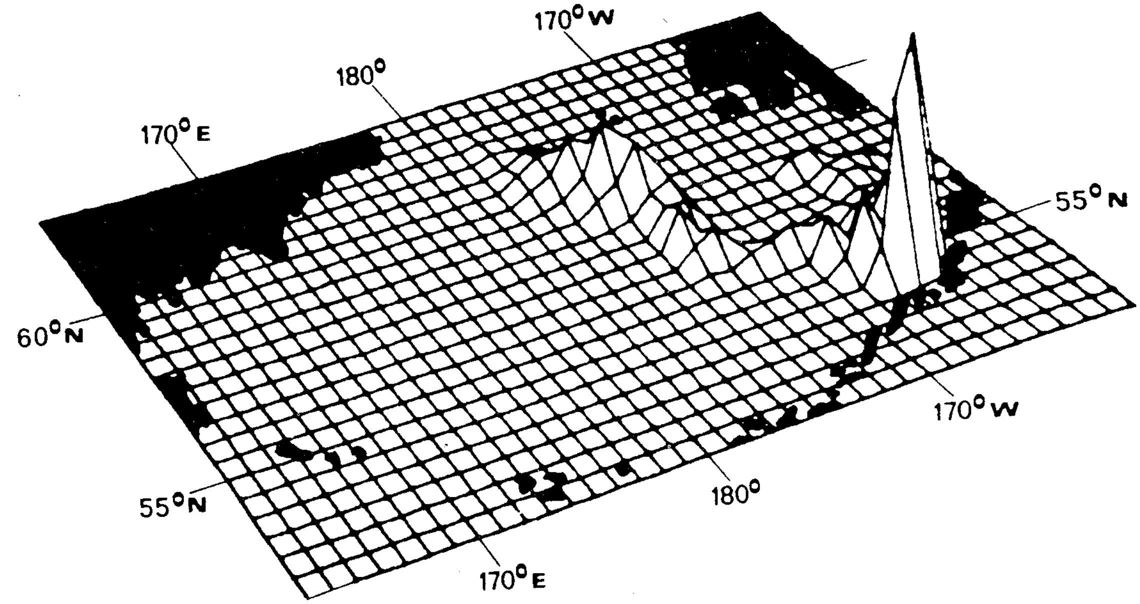


Figure 4C-14. General catch distribution of groundfish in the Bering Sea (from Low 1976).

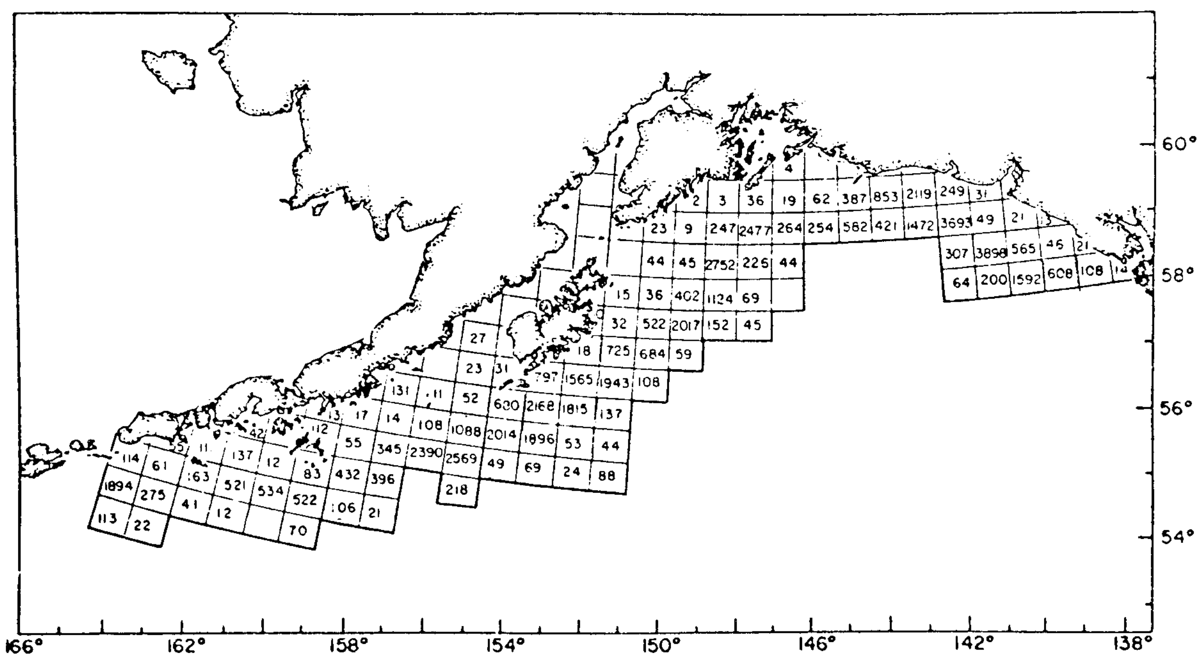


Figure 4C-15. Annual harvest (mt) of groundfish by the Japanese fishery, 1964-74 (from Ronholt et al. 1978).

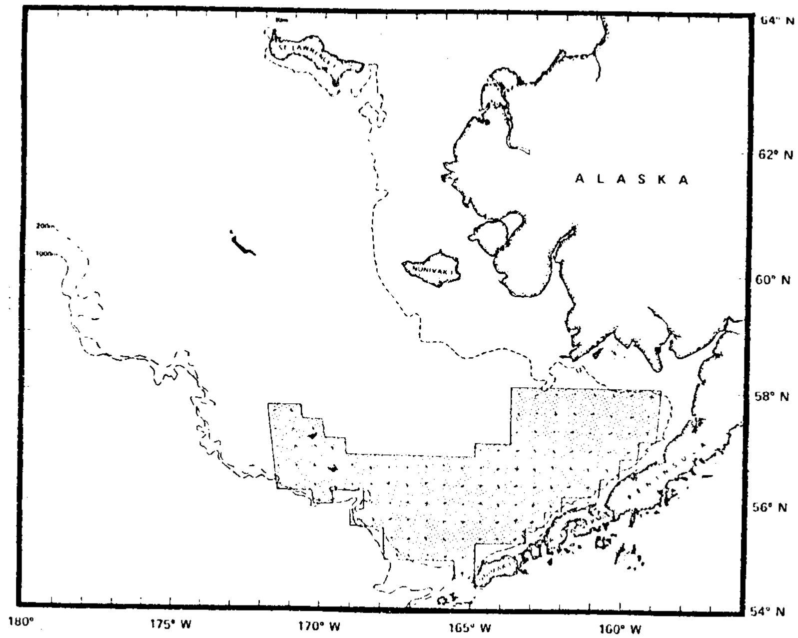


Figure 4C-16. Annual survey area (shaded) for groundfish and crabs conducted by NMFS/NWAFC. See Bakkala (1984) for annual differences in the area surveyed.

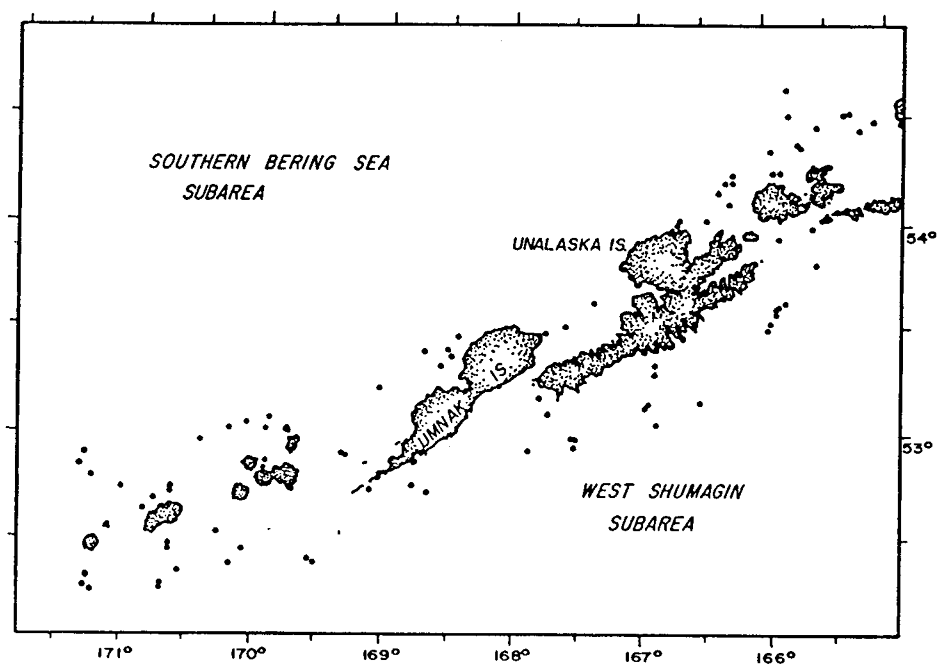


Figure 4C-17. Location of the sampling stations in the western Shumagin subarea (Pacific side of the Aleutian Islands) and southern Bering Sea subarea (Bering Sea side of the Aleutian Islands) during the 1980 cooperative U.S.-Japan Aleutian Islands groundfish trawl survey (from Ronholt et al. 1986).

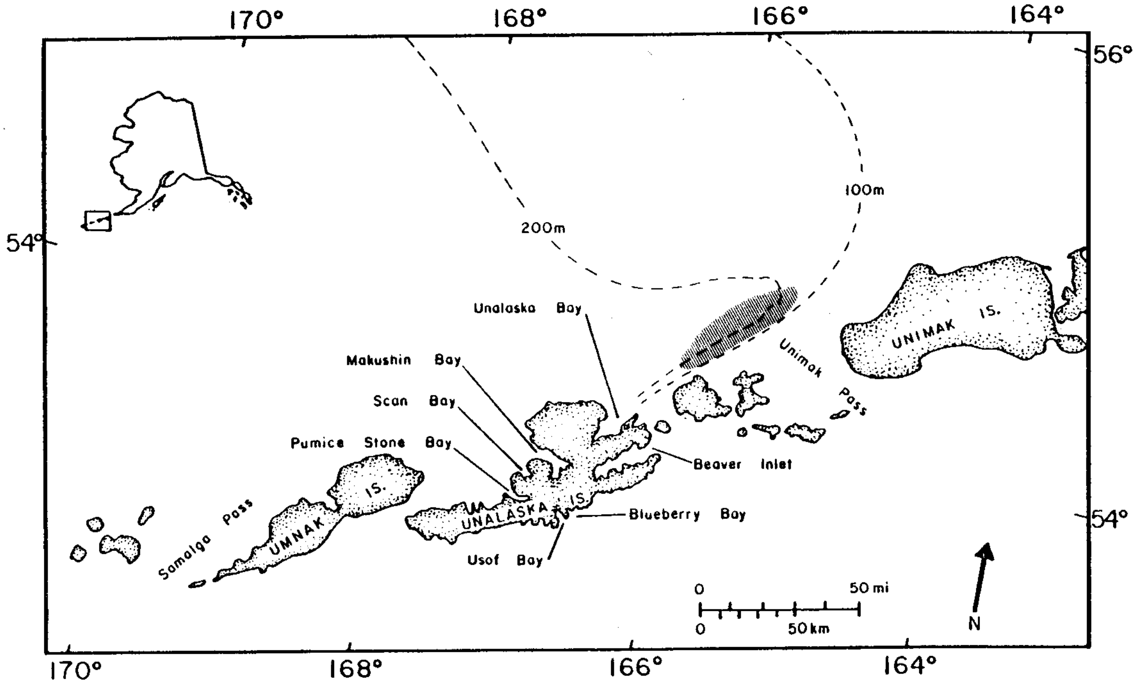


Figure 4C-18. Unalaska bays sampled by shrimp trawl, 1975-81 (NMFS 1975-81); and approximate area where a domestic trawl fishery was monitored in February and March 1980, indicated by crosshatching (Blackburn et al. 1980).

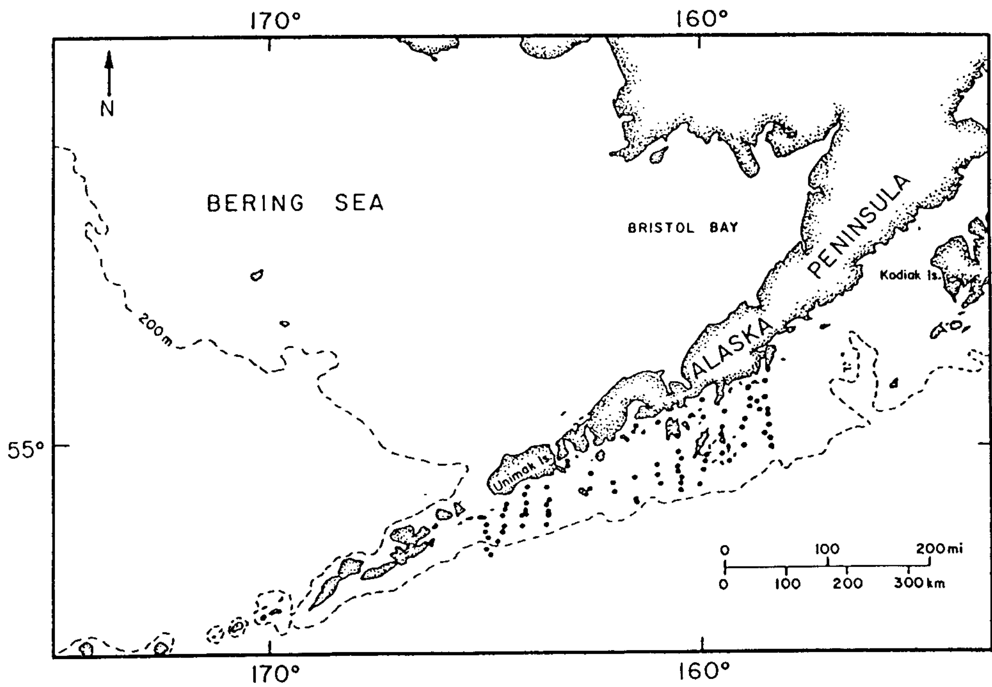


Figure 4C-19. Sampling stations for NMFS Cruise 619; Cruises 618 and 744 also sampled south of Unimak Pass (from Ronholt et al. 1978).

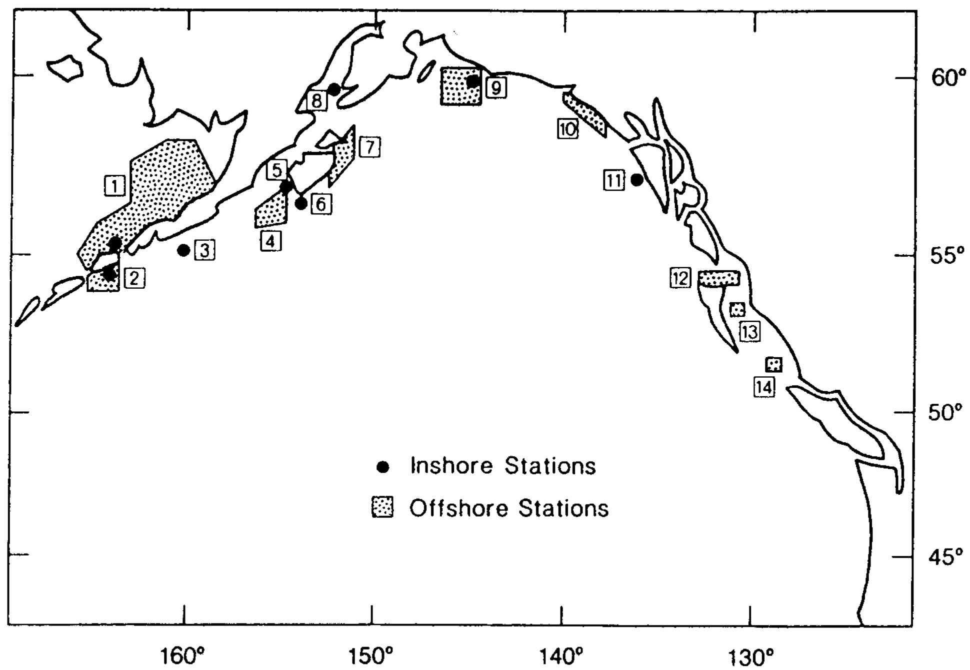


Figure 4C-20. Areas surveyed for juvenile halibut by the International Pacific Halibut Commission (IPHC 1980-85, Best and Hardmen 1982). Results from Area 2, Unimak Bight, are described in this report.

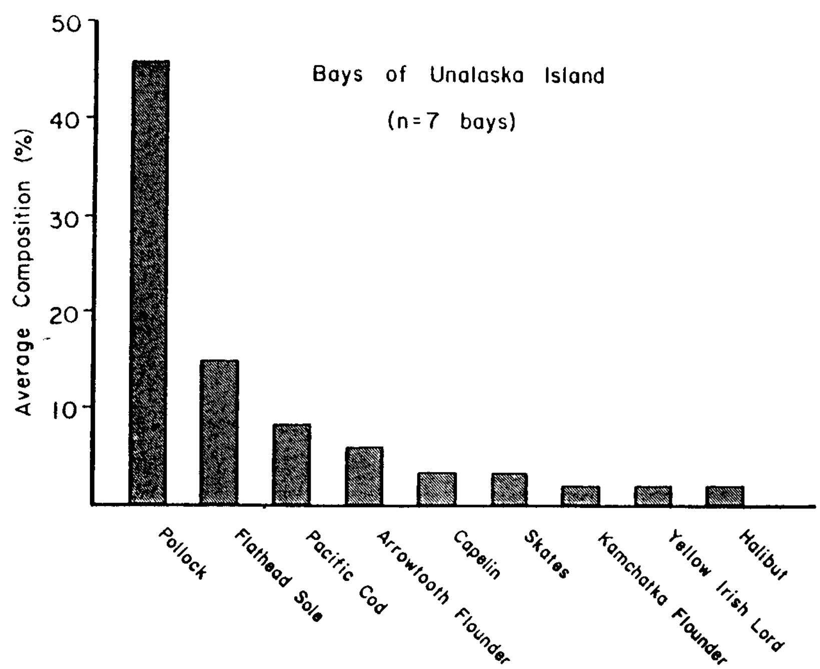


Figure 4C-21. Species composition of fishes in seven bays of Unalaska Island: Makushin (n = 25 trawls), Unalaska (16), Beaver Inlet (16), Scan (5), Blueberry (4), Pumicestone (3). Data presented are the grand averages of species compositions in each bay, 1975-81. Depth of samples, 55-275 m. (Calculated from NMFS 1975-81.)

available as follows, but are not analyzed herein because time and space do not permit in-depth comparisons:

A. The extensive groundfish surveys conducted annually in the southeastern Bering Sea (see Fig. 4C-16) are described in a series of reports (e.g., Bakkala and Low 1983, 1984 and 1985; Bakkala et al. 1985).

B. NMFS Cruises 618 (May-Oct. 1961), 619 (Sept.-Nov. 1961), and 744 (Apr.-Oct. 1973-76) are summarized by Ronholt et al. 1978. Figure 4C-19 shows the approximate sampling area.

C. Joint US-Japan surveys along the Aleutians in 1983-84 (see Fig. 4C-17) are not yet available in report form; additional surveys are scheduled in 1986-87 (L. Ronholt, pers. comm.).

D. Early IPHC surveys included the Unimak Bight area (IPHC 1964). Figure 4C-20 shows the approximate sampling area.

E. Aleutian Islands from Unimak Pass to Atka Island--NMFS/NWAFC trawl survey, Feb.-Mar. 1982. Data for Pacific cod are listed by Bakkala et al. 1983; catches of other species are apparently not available in report form.

F. Gulf of Alaska trawl surveys by NMFS/NWAFC (e.g., Major 1985, Walters et al. 1985).

Distribution In and Use of the Study Area

The broad array of sampling stations illustrated in Figures 4C-16 to 4C-20 shows that a considerable sampling effort has occurred for groundfish in and around the study area. The list of species caught is long, but if we focus on the major species (arbitrarily designated as those species accounting for 10% or more by weight of each study's catch), it becomes apparent that two species clearly dominate the groundfish community in the eastern Aleutian Islands: walleye pollock and Pacific cod. Pollock were abundant in all regions surveyed on the north and south sides of the eastern Aleutians (NMFS 1975-81, Blackburn et al. 1980, IPHC 1980-85, Ronholt et al. 1986) and Pacific cod were abundant in most of these regions. Five additional fishes were a dominant species in at

Table 4C-3. Species composition of dominant fishes (> 25 lb/n. mile) in bays of Unalaska Island, 15 August-16 October 1975-81. Depth of samples, 55-175 m. Calculated from NMFS (1975-81).

	Trawl Catch (lbs/nautical mile)						
Fish	Unalaska Bay	Makushin Bay	Beaver Inlet	Blueberry Bay	Pumicestone Bay	Usof Bay	Scan Bay
Pollock	670	250	170	50	210	50	990
Flathead sole	140	110	170	50	40		40
Pacific cod	240	30	100	30			
Arrowtooth flounder	120	40	50				
Shortfin eelpout	120						
Yellow Irish Lord	60						
Great sculpin	50						
Spinyhead sculpin	30						
Capelin		30		30			
Sablefish		40					
Longsnout prickleback		40					
Skates				40			
Others	70	80	80	50	60	110	100
TOTALS	1500	620	570	250	310	160	1130
NO. TRAWLS	16	25	16	4	3	5	5

[a]Data are estimates which have not been corrected for generally small changes in duration of trawls. Data collected during different years have been combined. Samples were collected with a 61 ft high-opening shrimp trawl towed for 30 min (approximately 1 n. mile). Single trawl samples in Three Island Bay and Chernofski Harbor are not included.

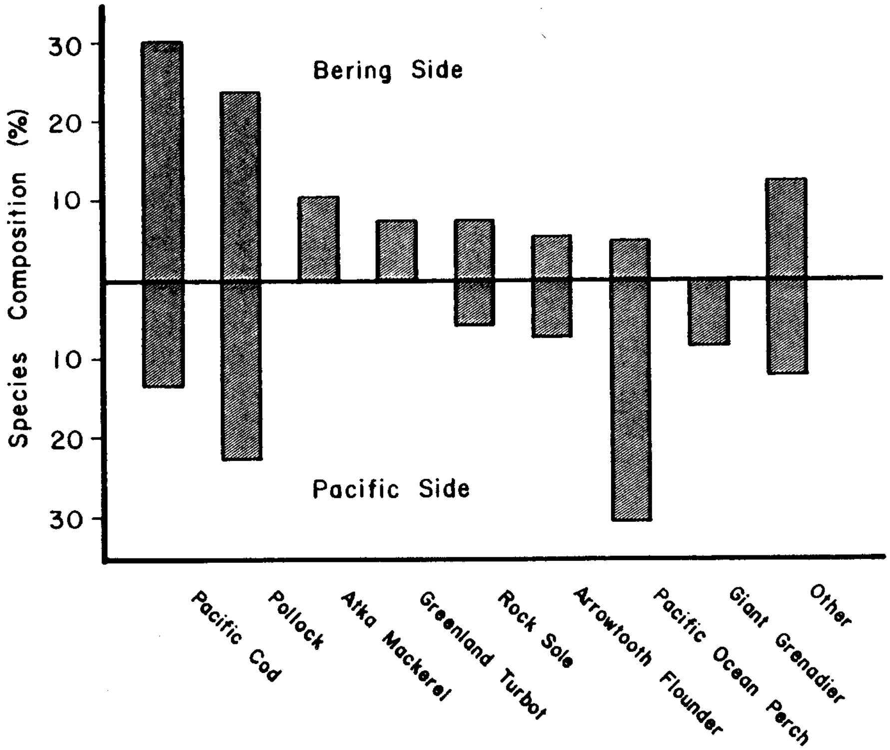


Figure 4C-22. Species composition of groundfish on the Bering and Pacific sides of the eastern Aleutian Islands (from Ronholt et al. 1986).

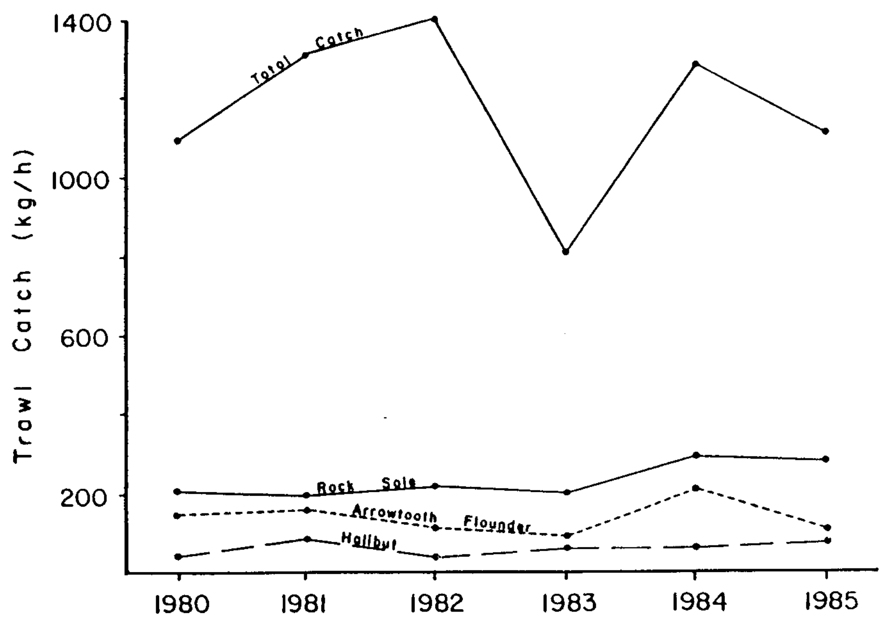


Figure 4C-23. Annual groundfish catch at Unimak Bight located south of Unimak Island (from IPHC 1980-85). See text concerning the relative efficiencies of the IPHC gear in capturing flatfish versus semipelagic species such as pollock and Pacific cod.

Table 4C-4. The most abundant groundfishes caught on the north and south sides of the eastern Aleutian Islands: NMFS survey, June-November 1980 (Ronhold et al. 1986); commercial catch, February-March 1980 (Blackburn et al. 1980). Note that the surveys used different sampling gear.

	NMFS Summer Survey				Winter Commercial Catch	
	Bering Sea Side[a]		Pacific Side[b]		Bering Sea Side	
Species	CPUE[c]	%	CPUE[c]	%	CPUE[d]	%
Pacific cod	52	30	33	14	2216	81
Pollock	42	24	56	23	274	10
Atka mackeral	19	11	*		60	2
Greenland turbot	13	7	*			
Rock sole	12	7	12	5	68	3
Sablefish	7	4	3	1		
Arrowtooth flounder	7	4	15	6	7	*
Pacific ocean perch	6	3	72	30		
Great sculpin	4	2	1			
Irish Lords	3	2	3	1		
Sculpin					83	3
Halibut	2	1	2	1	24	1
Giant grenadier	1		18	8		
Shortspine thornyhead	1		4	2		
Rex sole	1		4	2		
Dover sole	*		7	3		
Others	7	4	4	2	6	*
TOTAL FISH	177		234		2738	

[a]Southern Bering Sea subarea (n = 36 trawls)

[b]West Shumagin subarea (n = 27 trawls)

[c]kg/ha

[d]kg/h

*<0.5

least one of the regions surveyed: rock sole, flathead sole, arrowtooth flounder, Atka mackerel, and Pacific ocean perch.

Beyond this regional summation, numerous temporal and spatial differences are exhibited by groundfish species in the study area. But before proceeding to species accounts, four groundfish surveys are briefly summarized below because each describes a different portion of the groundfish community in the study area.

Survey 1: Bays of Unalaska Island (NMFS 1975-81)

Small-mesh trawl surveys were conducted over a several-year period in several bays around Unalaska Island (Fig. 4C-18). Pollock, mostly juveniles, were by far the most abundant fish present (Fig. 4C-21); the occurrence of other common species differed among bays (Table 4C-3).

Highest catches were recorded in Unalaska and Scan bays, largely due to high catches of pollock. If pollock are excluded, catches in the largest bays (Unalaska, Makushin, Beaver Inlet) were about four times greater than in the remaining smaller bays.

Survey 2: Eastern Aleutian Islands (Ronholt et al. 1986).

A trawl survey was conducted on both the Bering and Pacific sides of the eastern Aleutian Islands, June-November 1980 (Fig. 4C-17). Trawl depths averaged 230m (range 31-725m). Pollock and Pacific cod were abundant on both sides of the islands, but differences among the other species were noted north and south of the Aleutians (Fig. 4C-22, Table 4C-4). Pacific ocean perch and giant grenadier were generally restricted to the Pacific side, whereas Atka mackeral and Greenland turbot occurred on the Bering side.

Survey 3: Domestic trawl fishery, north Unimak Pass (Blackburn et al. 1980)

This fishery occurred in winter (February-March 1980), generally along the 100 fathom contour north of Unimak Pass and Akun Island (Fig. 4C-18). Pacific cod accounted for 81% of the catch (Table 4C-4). The sampling gear used in this survey and in Survey 2 differed, which probably accounts for the differences in catch compositions obtained in these surveys.

Survey 4: Unimak Bight survey (IPHC 1980-85)

Trawl surveys in Unimak Bight located south of Unimak Island are conducted almost annually by IPHC (Fig. 4C-20). Trawl depths in this area are typically 27-110m. Although the Unimak Bight area extends beyond our immediate study area, the data are particularly useful because they illustrate annual variability in the catches of groundfish.

In these surveys, four species accounted for 67% of the catch, averaged over the period 1980-85: rock sole, Pacific cod, arrowtooth flounder, and pollock (Table 4C-5). These results differ considerably from those mentioned above (Survey 2) where Pacific ocean perch accounted for 30% of the sample on the Pacific side of the study area. At least part of this difference is due to the sampling gear used. IPHC trawls are rigged to catch flatfish (i.e., the trawl hugs the seafloor and has a vertical opening of only 4-5 feet--G. St-Pierre, pers. comm.), whereas the NMFS trawls have a much higher opening (20 feet) and thus would catch more "semi-demersal" fish. In the IPHC trawls, semi-demersal fish would be caught on more of a "hit or miss" basis.

The annual variability recorded in IPHC surveys was high, even though all surveys were generally similar in sampling time, location and gear. Total catches varied from 806-1401 kg/h, largely due to fluctuations of pollock and Pacific cod which, as mentioned above, were probably not sampled consistently by the IPHC trawls. Catches of flatfishes were less variable during this period (Fig. 4C-23).

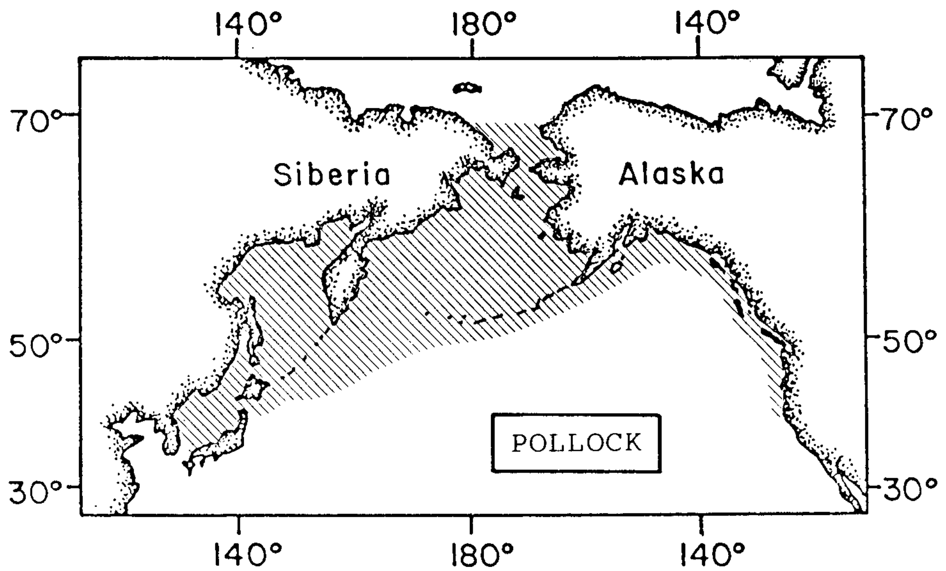
Pollock

Pollock are widely distributed throughout the Bering Sea and the eastern Aleutian Islands (Fig. 4C-24). They are very abundant,

Table 4C-5. Annual groundfish catch at Unimak Bight, south of Unimak Island (IPHC 1980-85).

Fish	Trawl Catch (kg/h)							
	1980	1981	1982	1983	1984	1985	Mean	%
Rock sole	222	210	238	231	310	291	250	22
Pacific cod	212	338	386	103	207	222	245	21
Arrowtooth flounder	150	181	133	95	225	118	150	13
Pollock	118	66	318	26	123	91	124	11
Flathead sole	80	136	91	59	120	87	96	8
Yellowfin sole	61	87	73	97	56	48	70	6
Halibut	43	100	59	72	73	92	73	6
Sculpins	139	50	46	25	29	32	54	5
Butter sole	24	55	30	57	29	16	35	3
Skates	4	25	1	18	62	29	23	2
Rex sole	20	16	8	12	15	20	15	1
Starry flounder	5	1	13	4	15	32	12	1
Wolf eel	2	32	*	4	1	0	7	0.6
Sablefish	9	13	0	*	0	1	4	0.3
TOTAL FISH	1113	1312	1401	806	1286	1087		
NO. TRAWLS	25	25	25	25	50	25		

*<0.5 kg/h.



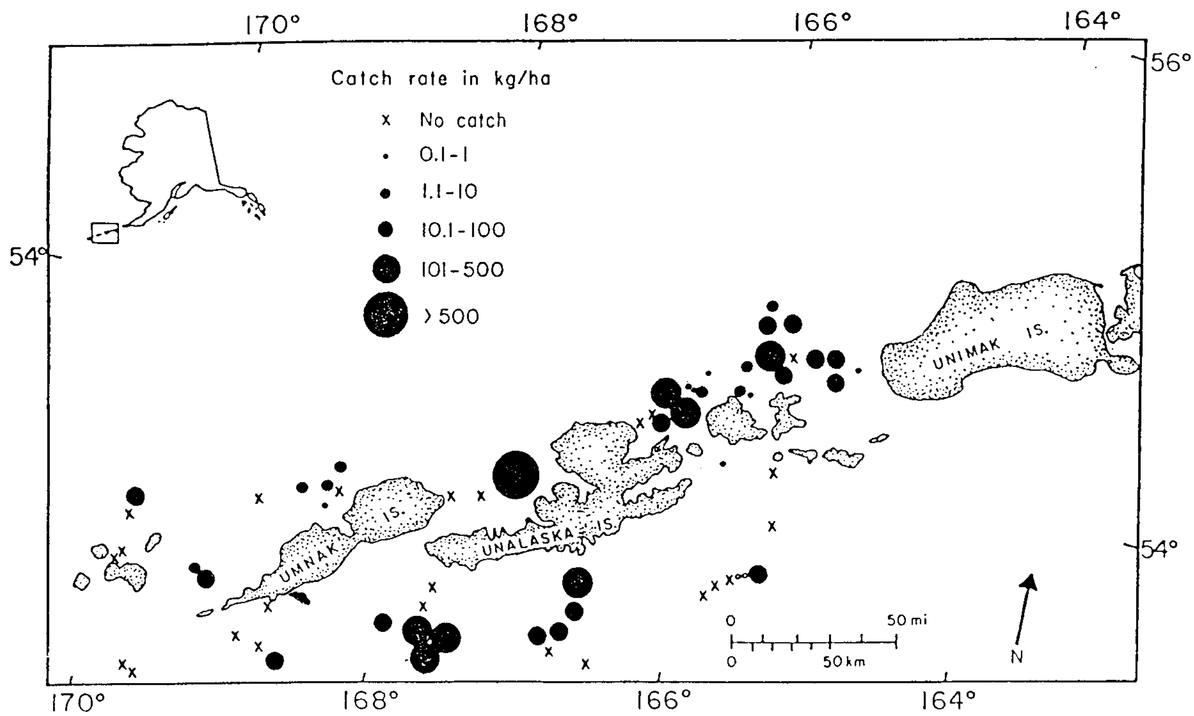


Figure 4C-24. Pollock range and distribution in the eastern Aleutian Islands (top, from Smith 1981, ADFG 1985a; bottom, from Ronholt et al. 1986).

constituting about 80% of the commercial groundfish harvest in this region (Bakkala, pers. comm.). Figure 4C-14, which shows the pattern of total groundfish harvests, is thus largely a reflection of the pollock catches.

Pollock catches on the Bering and Pacific sides of the eastern Aleutians differed somewhat (Table 4C-4). The fish were more abundant on the Pacific side where the population estimate (88,171 tons) and catch per unit effort (56 kg/ha) were higher than for the Bering side (53,725 tons, 42 kg/ha). Note that these values pertain only to the bottom-dwelling segment of the pollock population; the mid-water segment was not sampled during this survey. In the Bering Sea, only about 8% of the pollock biomass occurs on the bottom (Ronholt et al. 1986).

Pollock on the Bering side tended to be smaller and younger fish: mean length = 41.0 cm and mean age = 3.9 years on the Bering side, and length = 45.9 cm and age = 5.9 years on the Pacific side. Pollock on the Bering side also tended to inhabit shallower waters than those on the Pacific side (Fig. 4C-25). These differences were also reflected in catches of fish within the bays of Unalaska Island where pollock were by far the dominant species (Fig. 4C-21). Pollock, mostly juveniles, were 3-20 times more abundant in bays on the northern side of the island than on the southern side (Fig. 4C-26, Table 4C-3). In general, the southern bays have harder bottoms (less sediment) and seem less productive than the northern bays (P. Anderson, NMFS-Kodiak, pers. comm.).

Pollock in Unalaska bays included large fish (approximately 30-55 cm) that were very similar in size to those caught farther offshore on both the Bering and Pacific sides of the Aleutians, but there were also smaller fish (approximately 15 cm) present which were not caught offshore. This may represent either a habitat preference by juvenile pollock or it may simply result from gear selectivity (trawls used in the bays had smaller meshes). In any case, using these same data, Walters et al. (1985) report that one-year-old pollock were fairly abundant and widespread in the bays of Unalaska Island in 1980 and less so in 1981.

Pollock use the study area and adjacent waterbodies for spawning (February-June), feeding, migration and overwintering. In some years spawning occurs in the region north of Unimak Pass and thus the pelagic eggs may be initially concentrated adjacent to the study area (Fig. 4C-27). Feeding occurs in the bays of Unalaska Island and throughout the

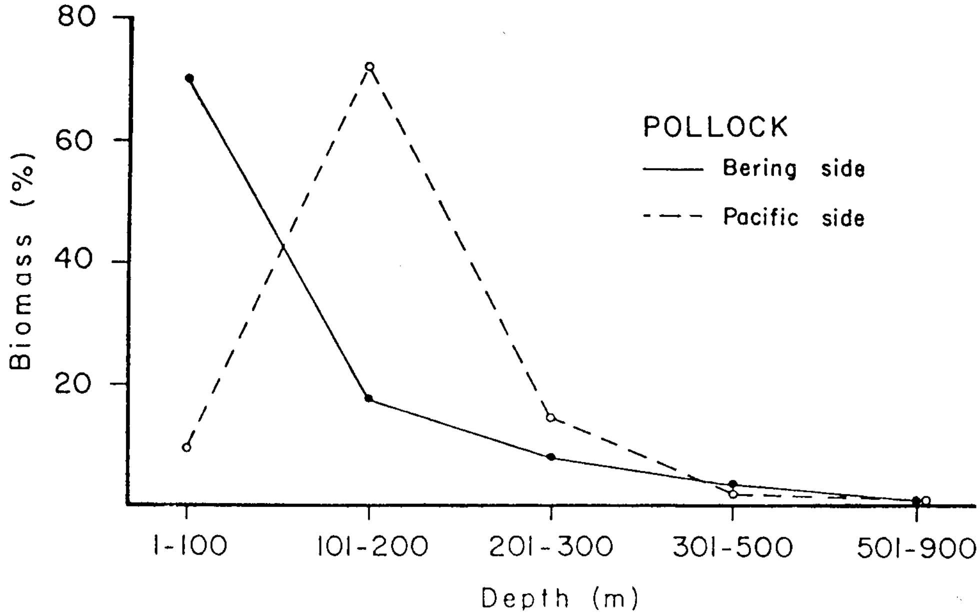


Figure 4C-25. Estimated depth distribution of pollock biomass on the north and south sides of the eastern Aleutian Islands (from Ronholt et al. 1986).

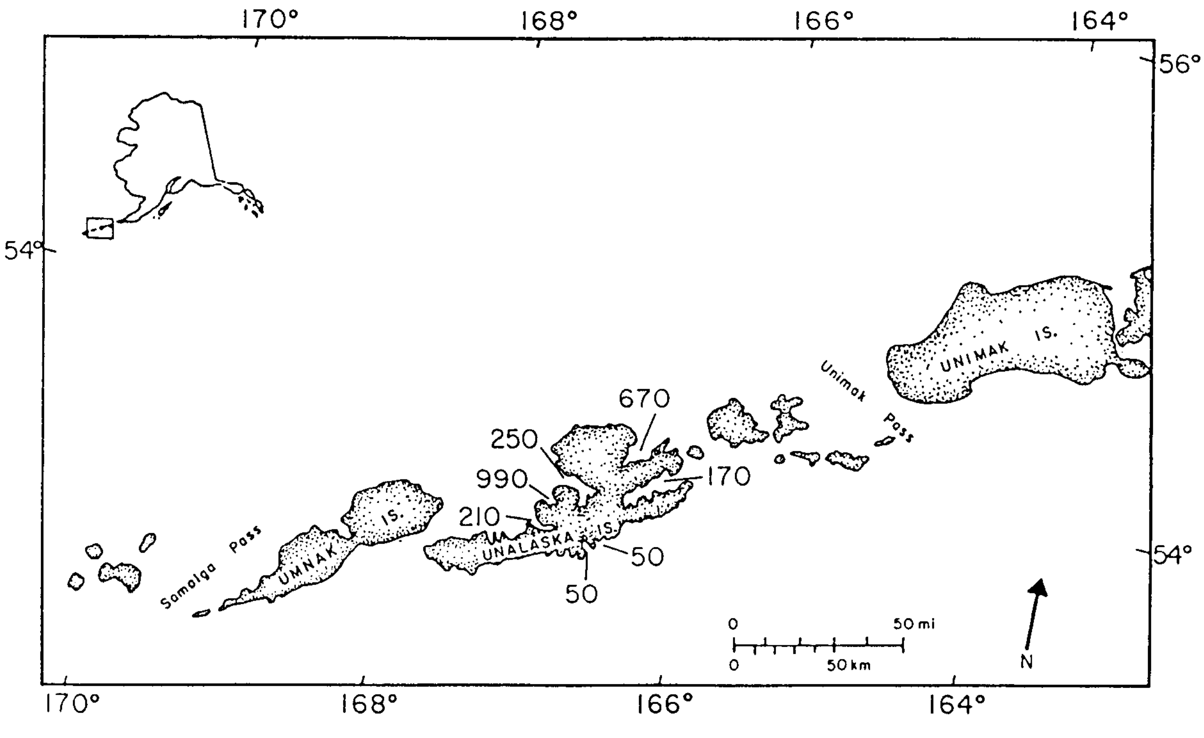


Figure 4C-26. Catch per unit effort (lb/mile trawled) for pollock (mostly juveniles) in bays of Unalaska Island (from NMFS 1975-81).

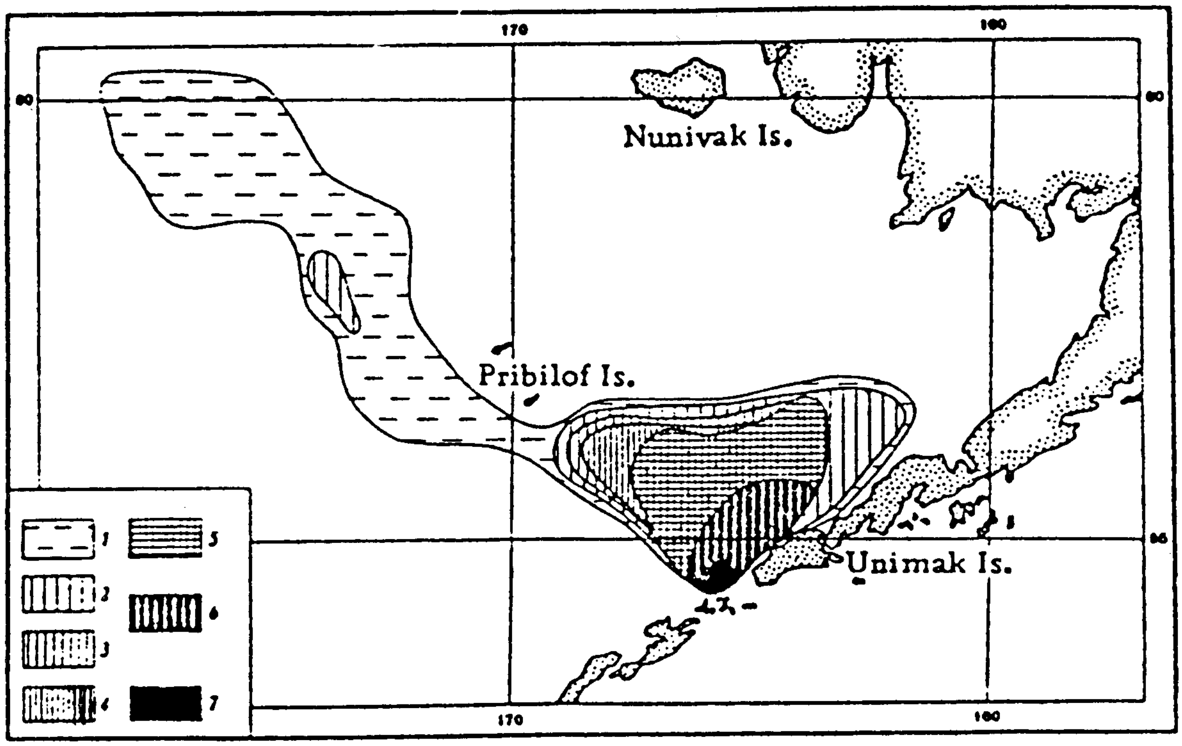


Figure 4C-27. Distribution of pollock eggs in March-May 1965 (from Serobaba 1968.) Number beneath 1 m^2: (1) 1-50, (2) 51-100, (3) 101-200, (4) 201-500, (5) 501-1000, (6) 1001-2000, (7) more than 2000.

study area. Most migration in the region tends to be on/off the continental shelf during spawning and feeding migrations in the Bering Sea (Maeda 1972, Takahashi and Yamaguchi 1972), but migration between the Bering Sea and the Gulf of Alaska is apparently restricted, as indicated by slight genetic differences between Bering Sea and Gulf of Alaska populations of pollock (Grant and Utter 1980). During winter, the pollock tend to concentrate along the deep outer shelf, extending pelagically into the Aleutian Basin.

Pollock food habits have been summarized by ADFG (1985a) as follows. Pollock larvae from the Bering Sea consume mainly copepod nauplii and eggs and adult copepods (especially Oithona similis, Clark 1978). Juveniles (less than 35 cm) consume mainly copepods, euphausiids and amphipods. Adults (greater than 35 cm) consume mainly euphausiids, small pollock, and other fish (gadids, cottids, hexagrammids and zoarcids) (Bailey and Dunn 1979). Fish comprise 70% of the diet (Smith et al. 1978).

Pacific Cod

Pacific cod are widely distributed in the study area (Fig. 4C-28) and their abundance has increased in recent years (Fig. 4C-29). They were often the most abundant fish caught on the Bering side of the Aleutians both in summer and winter during surveys in 1980 and 1982 (Table 4C-4). Population estimates and catches per unit effort on the Bering side (66,106 tons, 52 kg/ha) were larger than those on the Pacific side (52,404 tons, 33 kg/ha) (Ronholt et al. 1986). Fish on the Bering side averaged 55 cm compared with 51 cm on the Pacific side.

Pacific cod were most abundant in the shallower portion (1-200 m) of the study area (Fig. 4C-30). They were also present in the bays around Unalaska Island although they were much less abundant than pollock (Fig. 4C-21). Highest catches of cod were made in Unalaska Bay and Beaver Inlet (Table 4C-3).

The movements and spawning areas of Pacific cod are not well known in the vicinity of the study area. Fredin (1985) remarks that "U.S. fishermen have observed spawning from late December to April in bays and shallow nearshore waters in the eastern Aleutians and along the north side of Unimak Island (K. Uri, pers. comm.)." Bakkala et al. (1983) suggest

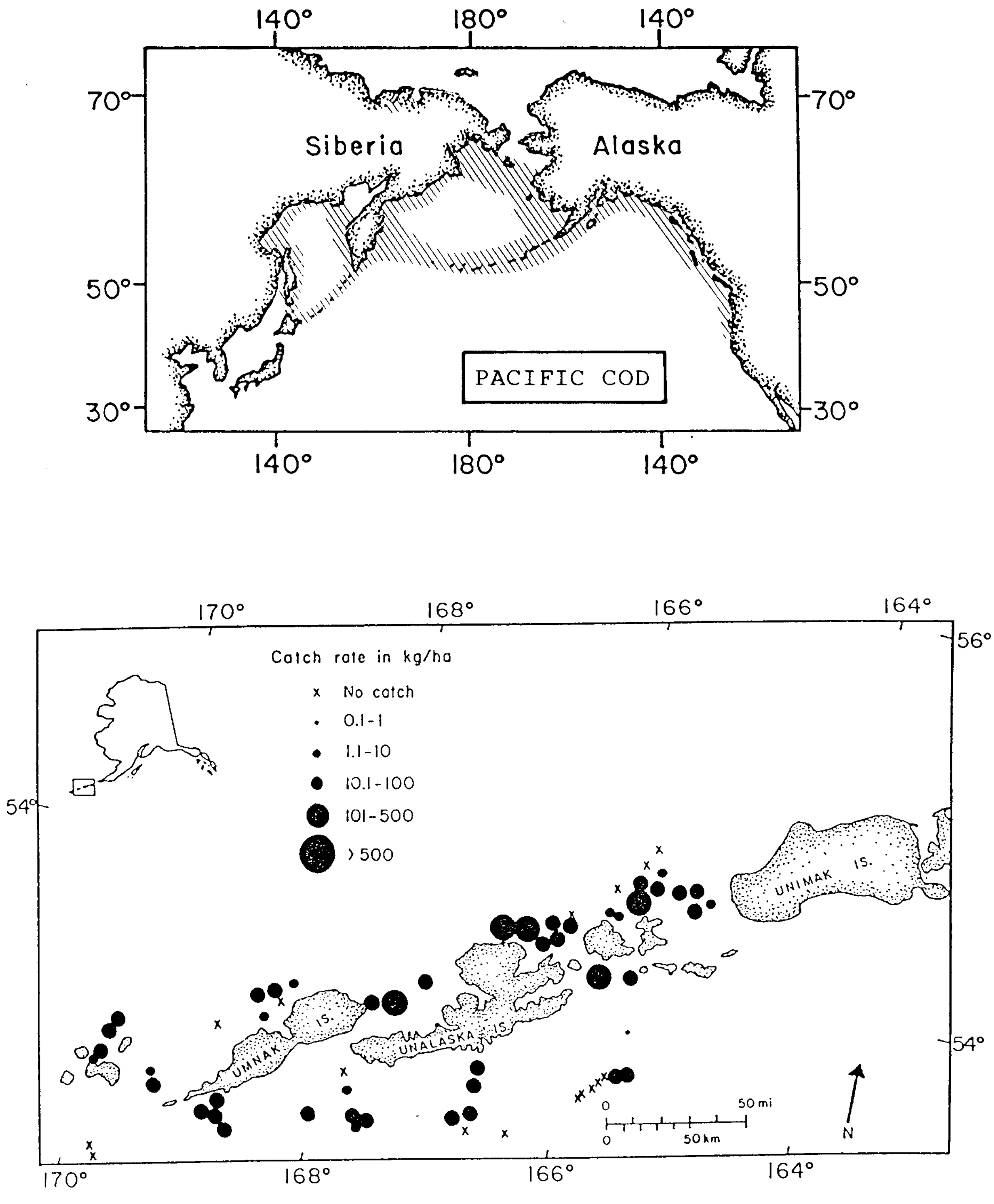


Figure 4C-28. Pacific cod range and distribution in the eastern Aleutian Islands (top, from Salverson and Dunn 1976, ADFG 1985a; bottom, from Ronholt et al. 1986).

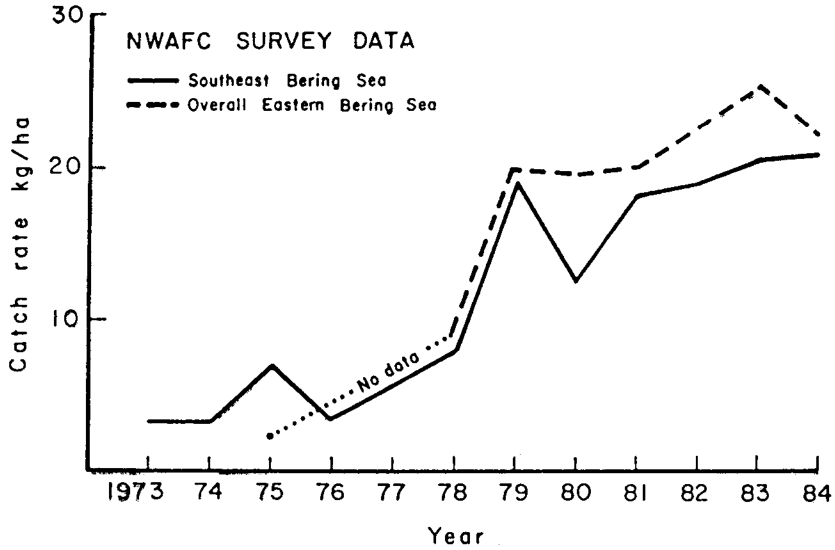


Figure 4C-29. Relative abundance of Pacific cod as shown by Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys (from Bakkala and Low 1985).

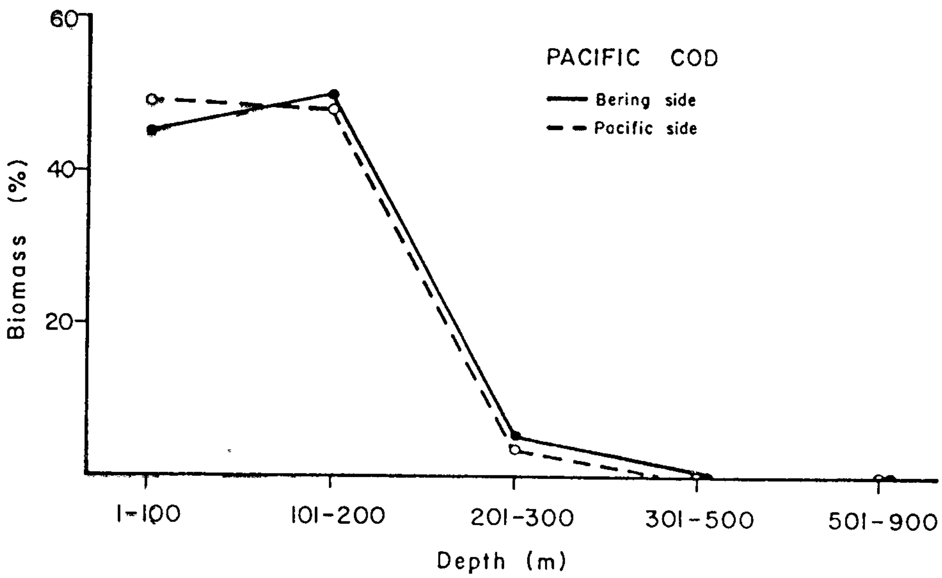


Figure 4C-30. Estimated depth distribution of Pacific cod on the north and south sides of the eastern Aleutian Islands (from Ronholt et al. 1986).

that Pacific cod may migrate in winter into the eastern Aleutian area to spawn.

In the Bering Sea Pacific cod consume pollock, shrimp, other invertebrates, and Tanner crab (Bakkala 1981). Young cod feed on copepods and other invertebrates.

Pacific Halibut

Halibut were distributed throughout the study area but in far lower biomass than pollock or Pacific cod (Fig. 4C-31). Population estimates and catches per unit effort for halibut were similar on both the Bering side (2793 tons, 2.2 kg/ha) and Pacific side (3902 tons, 2.5 kg/ha) of the eastern Aleutians (Ronholt et al. 1986). Almost all were caught in waters less than 200 m deep, and they were present in the bays of Unalaska Island as well (Fig. 4C-21). Halibut on the Bering side of the Aleutians averaged 54 cm in length compared with 50 cm on the Pacific side.

Some halibut spawning occurs in the vicinity of the study area (Fig. 4C-32). Best (1981) suggested that spawning occurs December-January along the shelf break between Unimak Island and the Pribilof Islands, and probably along the Aleutian Islands. One-year-old halibut are regularly caught during IPHC surveys in the bays on the north side of the Aleutian Islands (Best 1981). Around Unalaska Island, halibut were most abundant in Makushin and Usof bays, but this was largely due to catches of a few large specimens (30-130 lbs) rather than numerous small juveniles.

Movements through the Aleutian passes may be very important for halibut. It is generally believed that at least some pelagic larvae from Gulf of Alaska stocks drift into the Bering Sea, and tagging data demonstrate that some juvenile halibut migrate or disperse from the Bering Sea into the Gulf of Alaska and even as far south as California (Fig. 4C-33) (Dunlop et al. 1964, Skud 1977). As many as one third of the juvenile halibut in the Bering Sea are thought to migrate into the North Pacific Ocean (S. Hoag, IPHC, pers. comm.).

Adult halibut are omnivorous, eating anything available (summarized by ADFG 1985a). Halibut less than 10 cm feed primarily on small crustaceans. Larger halibut feed on shrimp, crab, and fish; fish eaten

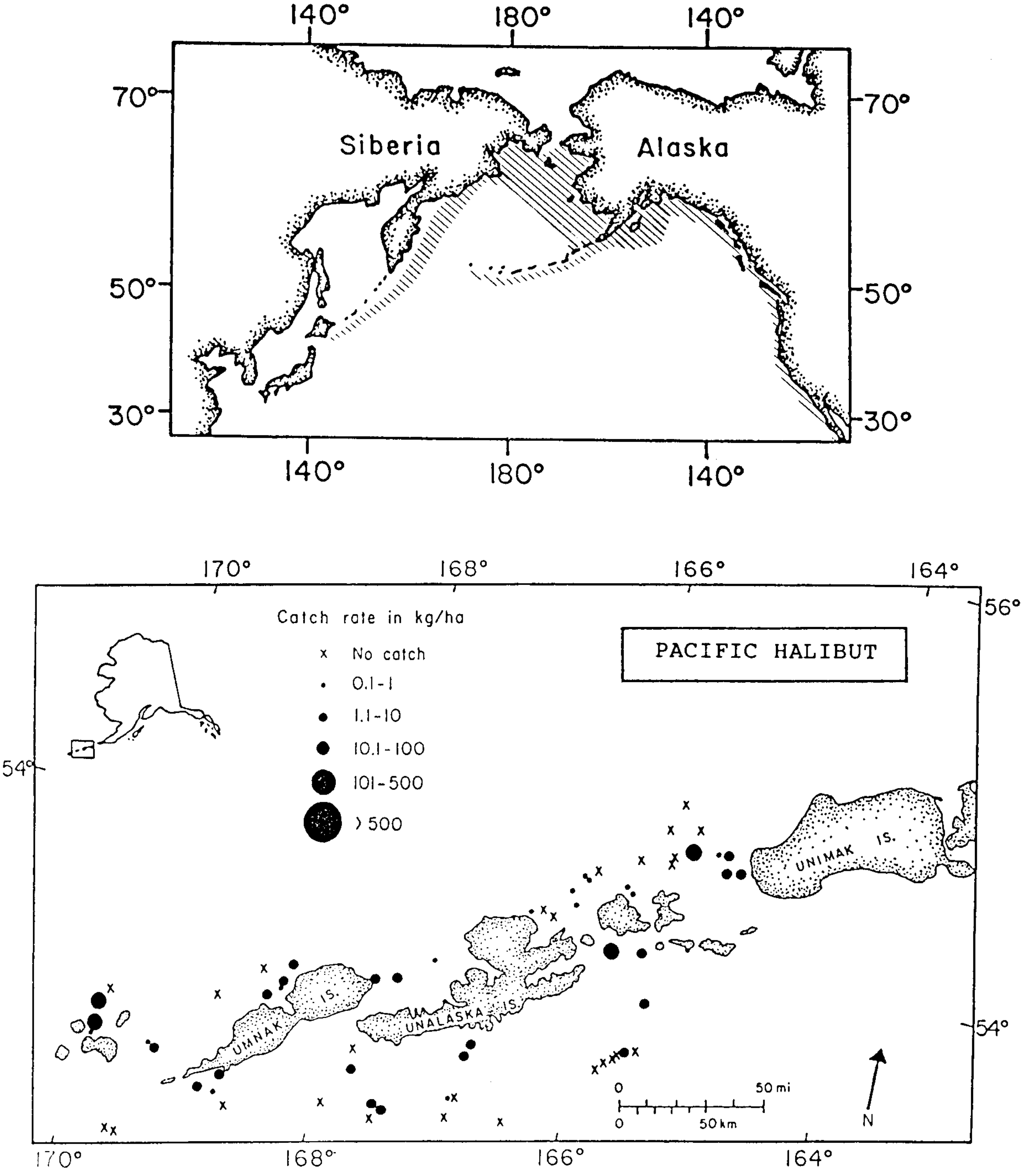


Figure 4C-31. Pacific halibut range and distribution in the eastern Aleutian Islands (top, from Bell and St-Pierre 1970, ADFG 1985a; bottom, from Ronholt et al. 1986).

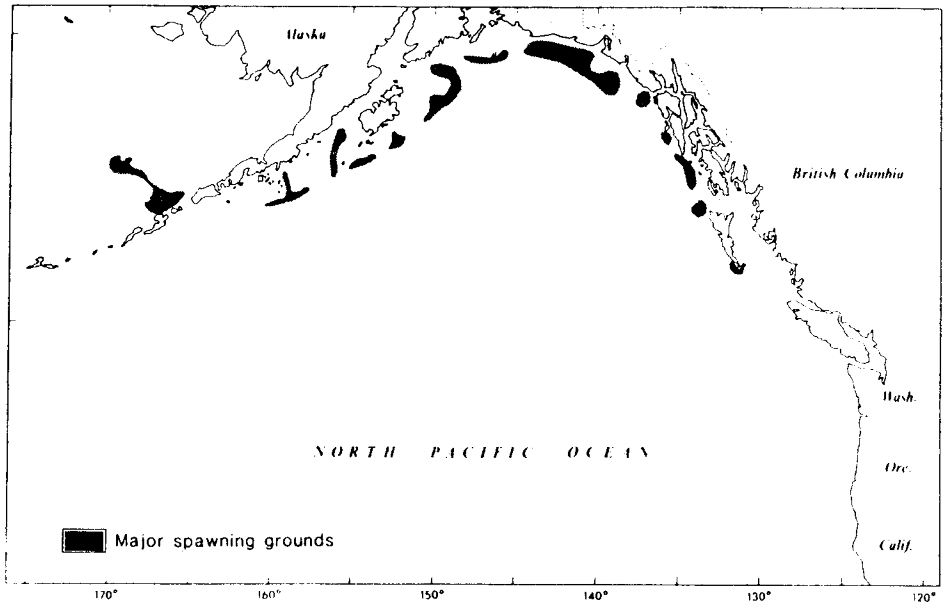


Figure 4C-32. Major halibut spawning locations in the northeast Pacific Ocean (from St-Pierre 1984).

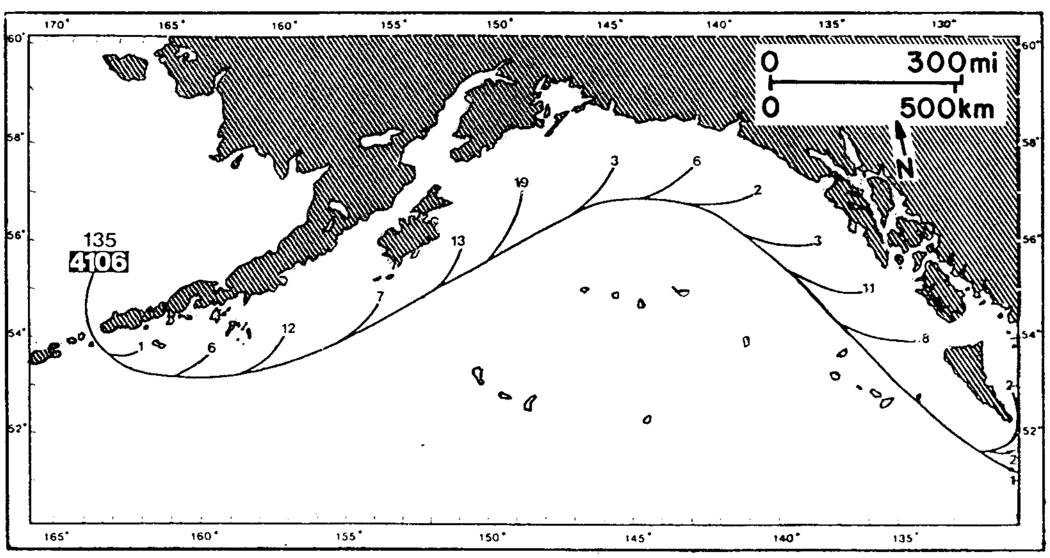


Figure 4C-33. Recoveries of halibut tagged (n = 4,106) in the Bering Sea during 1959 (from Best 1981).

are mostly sand lance but also flatfish, smelt, capelin, and pollock. In the Gulf of Alaska, halibut also eat Tanner and king crabs.

Pacific Ocean Perch

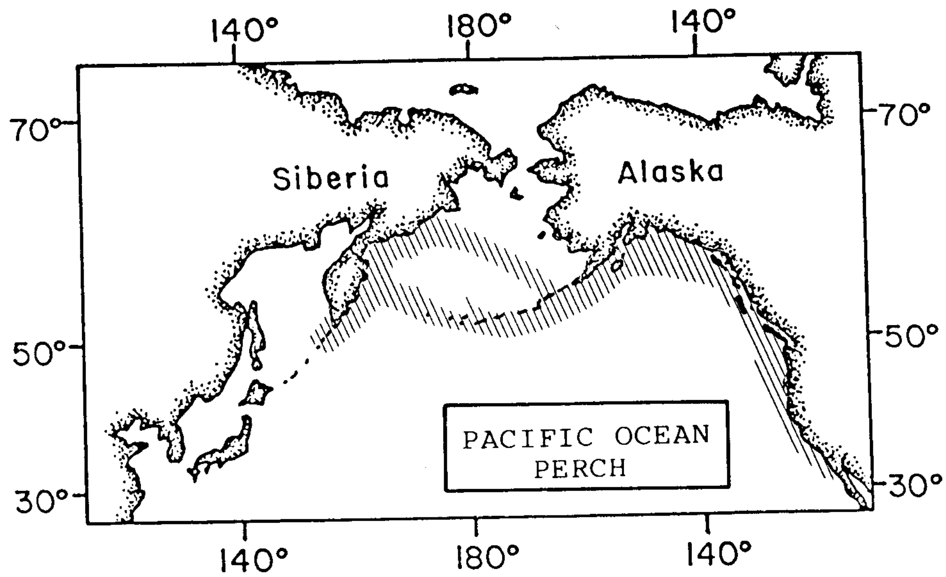
Pacific ocean perch were common in the study area (Fig. 4C-34). Catches were much higher on the Pacific side of the eastern Aleutians (72 kg/h, 113,444 tons) than on the Bering side (6 kg/h, 7035 tons) (Ronholt et al. 1986). Most fish were caught at depths of 100-200m on the Pacific side (99% of catch) and 200-300m on the Bering side (87% of catch). The average size of these fish was similar on both sides (33 cm).

In the study area Pacific ocean perch were most abundant south of Akutan Island (Fig. 4C-34) and a similar distribution was documented during earlier NMFS surveys (Ronholt et al. 1978) and Russian surveys. In the latter, concentrations of larvae occurred along the shelf break south of Unimak Pass in winter (Lisovenko 1963) and older fish fed there from May through September (Lyubimova 1963, 1965). Lyubimova described this area as a primary foraging site, with secondary foraging areas near Kodiak and the Shumagin Islands.

ADFG (1985a) summarized the feeding habits of Pacific ocean perch as follows. Stocks in the Gulf of Alaska fed almost entirely on euphausiids, whereas those in the Bering Sea consumed fish, euphausiids, and other crustaceans (Chikuni 1975). Immature perch fed mainly on copepods (Skalkin 1964).

Sablefish

Sablefish numbers in the Aleutians and Gulf of Alaska have increased sharply in recent years, primarily due to the strong year class of 1977 (Sasaki 1983). They were most abundant in the eastern portion of the study area (Fig. 4C-35), but their total abundance (14,000 tons) was much lower than for most of the previously-mentioned groundfish species (Ronholt et al. 1986). Movements of tagged fish indicate a considerable mixing of sablefish between the north and south sides of the Aleutians (Fig. 4C-36). A current theory is that sablefish spawn only in the



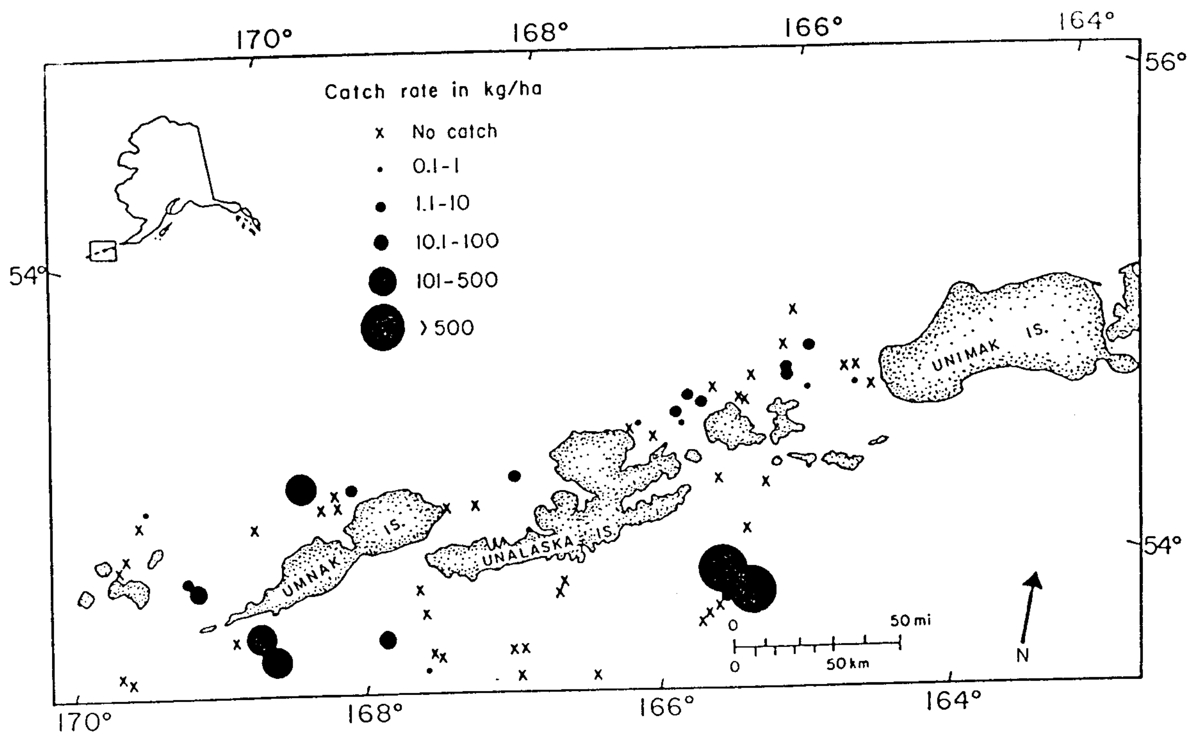


Figure 4C-34. Pacific Ocean perch range and distribution in the eastern Aleutian Islands (top, from Major and Shippen 1970, ADFG 1985a; bottom, from Ronholt et al. 1986).

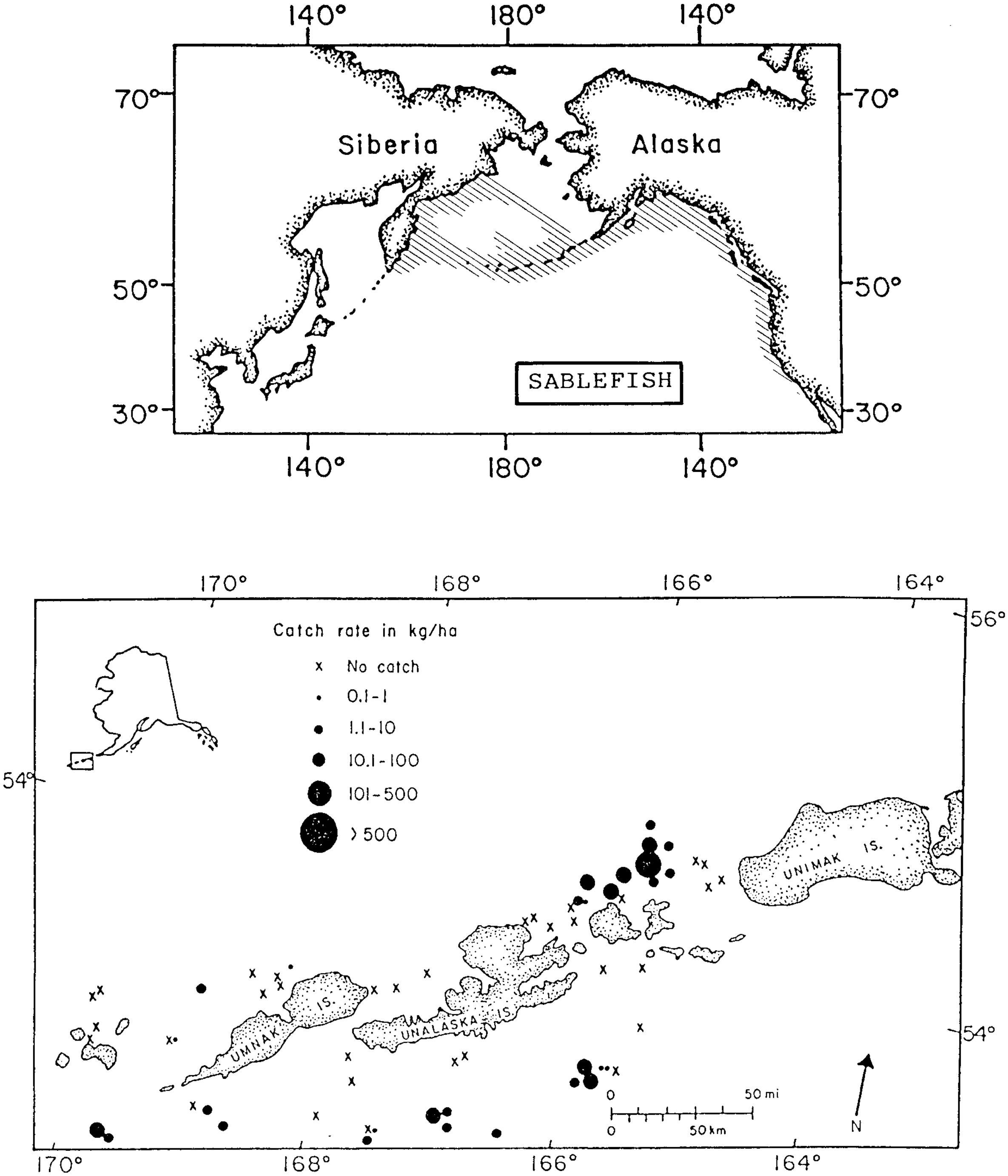


Figure 4C-35. Sablefish range and distribution in the eastern Aleutian Islands (top, from Low et al. 1976, ADFG 1985a; bottom, from Ronholt et al. 1986).

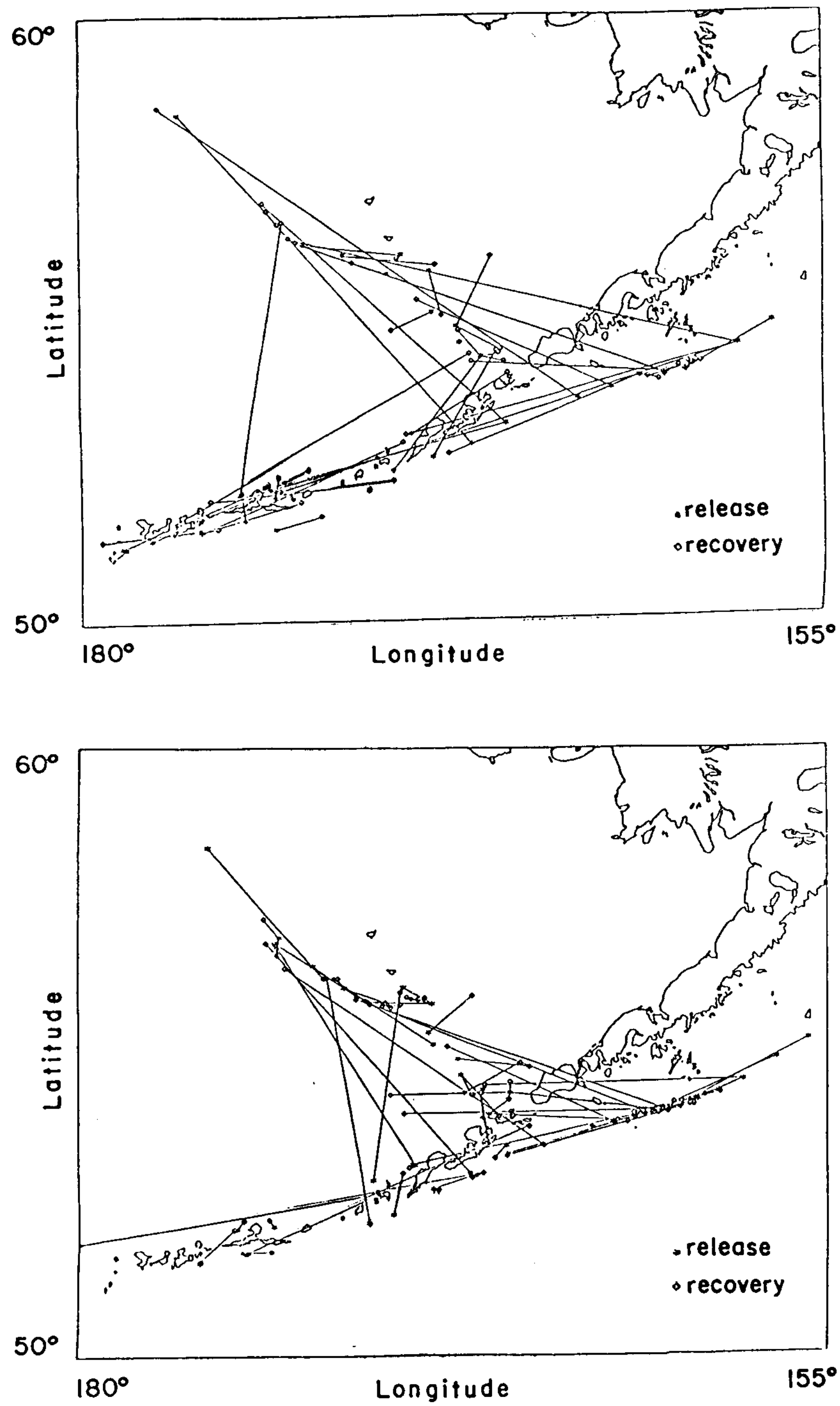


Figure 4C-36. Movements of tagged sablefish: fish 56 cm or less (top) and 57 cm or greater (bottom) (from Fujioka and Sigler 1984).

Pacific, and that a proportion of their juveniles and adults migrate northward into the Bering Sea (Kodolov 1983).

ADFG (1985a) summarized the food habits of sablefish as follows. Sablefish are opportunistic feeders that consume a wide variety of organisms. Adult sablefish in the Gulf of Alaska feed on fish, including pollock, arrowtooth flounder, spiny cheek rockfish, herring, Pacific saury, and sand lance (Kennedy and Pletcher 1968). They also feed on free-swimming and bottom-dwelling invertebrates (Low et al. 1976). In the Bering Sea, Shubinikov (1963) found that sablefish consume pandalid shrimp, sea anemones, brittle stars, amphipods, and euphausiids, in addition to several kinds of fish (saffron cod, Pacific cod, pollock, herring, sculpins, and small flounders). Young sablefish off Oregon feed on fish and euphausiids (Grinols and Gill 1968).

Other Species

Distributions of other groundfish species in the study area are shown in Figure 4C-37. For yellowfin sole, slight genetic differences between populations from the Bering Sea and Gulf of Alaska suggest that movements between these two waterbodies is restricted (Grant et al. 1983).

Factors Affecting Distribution and Abundance

Because of the commercial importance of groundfish, factors affecting their distribution and abundance have received considerable attention (e.g., Alverson et al. 1964; Moiseev 1963; Favorite et al. 1977; Hood and Calder 1981; Laevastu and Marasco 1982; 1984; Wooster 1983; Pola-Swan and Ingraham 1984; Pola 1985; Favorite 1985; and others). A review of these studies and hypotheses regarding population regulation is beyond the scope of this report except to briefly point out some general features.

The first feature is that fluctuations in abundance are a characteristic of marine fish populations. Fluctuations occur in both the short term (several years) and long term (decades) in response to abiotic factors (e.g., water temperature, current patterns) and biotic factors (e.g., food abundance, predation, fishing pressure, changes in migration patterns). These factors, or combinations of factors, occasionally result

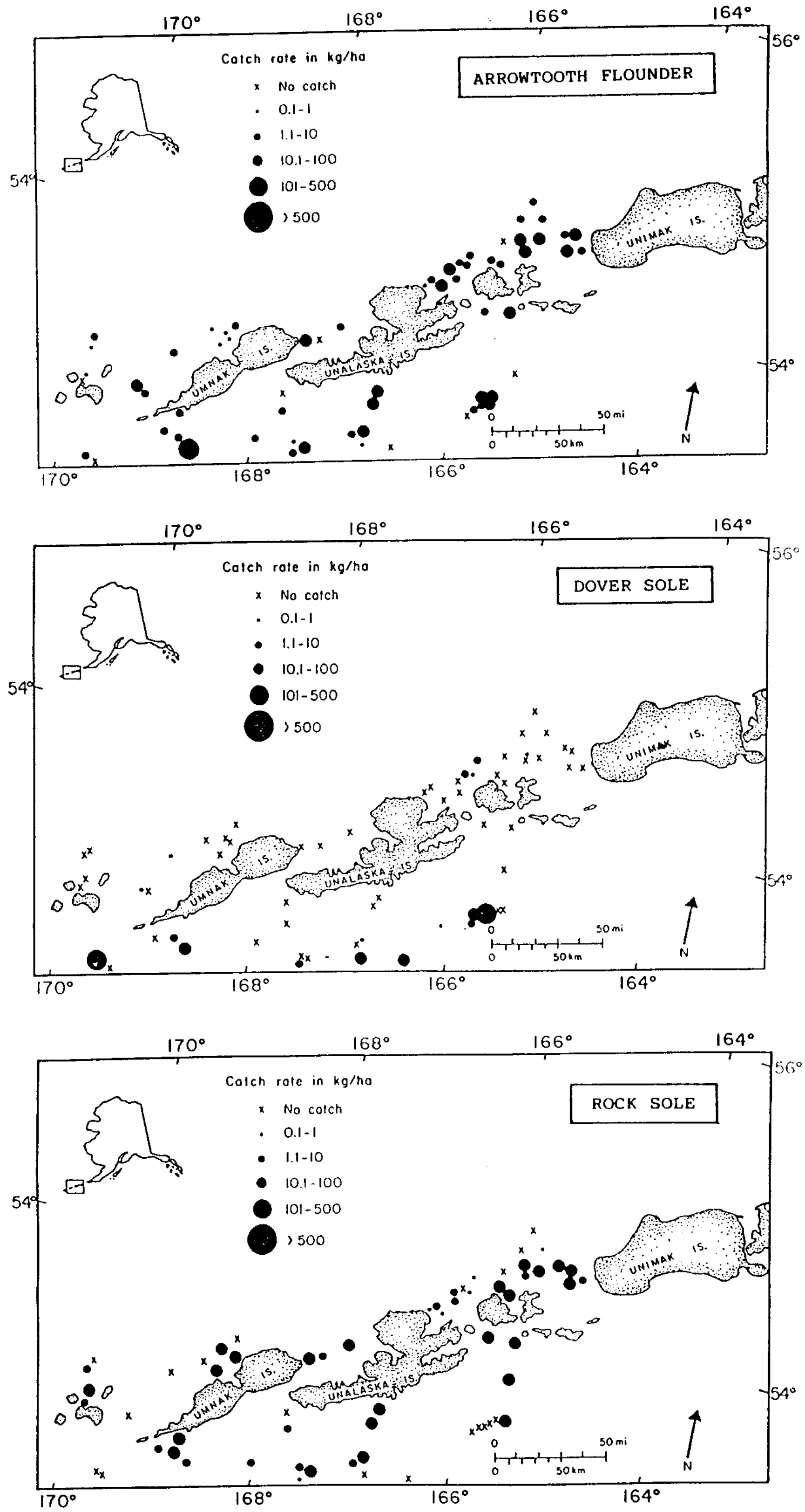


Figure 4C-37. Distribution and relative abundance of demersal fishes, June-November 1980 (from Ronholt et al. 1986).

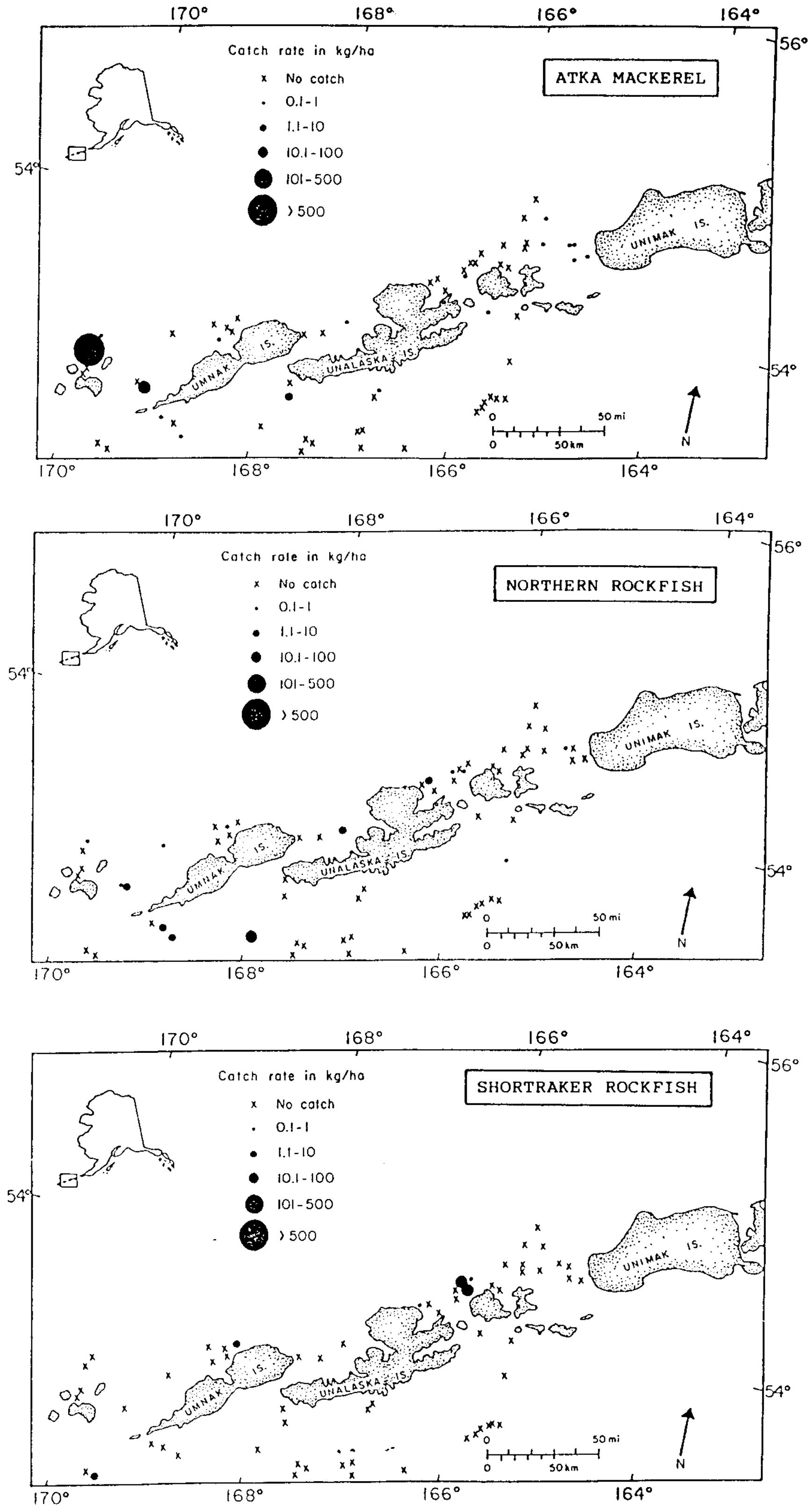
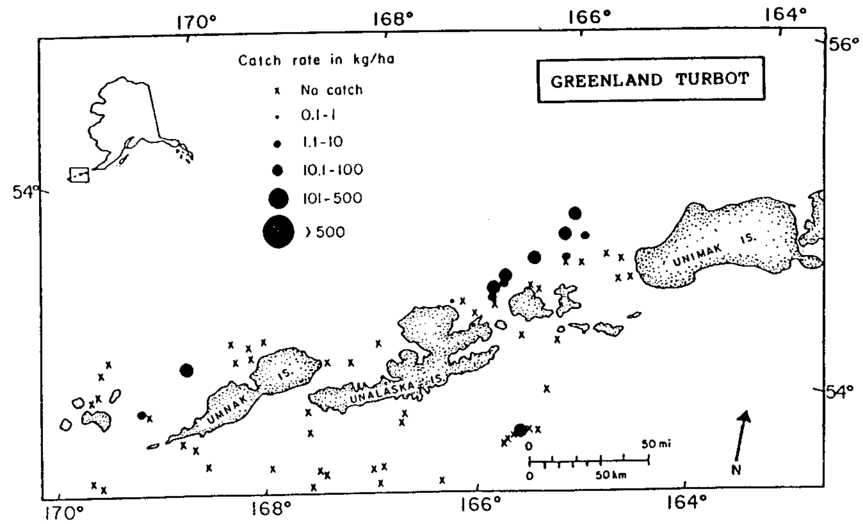
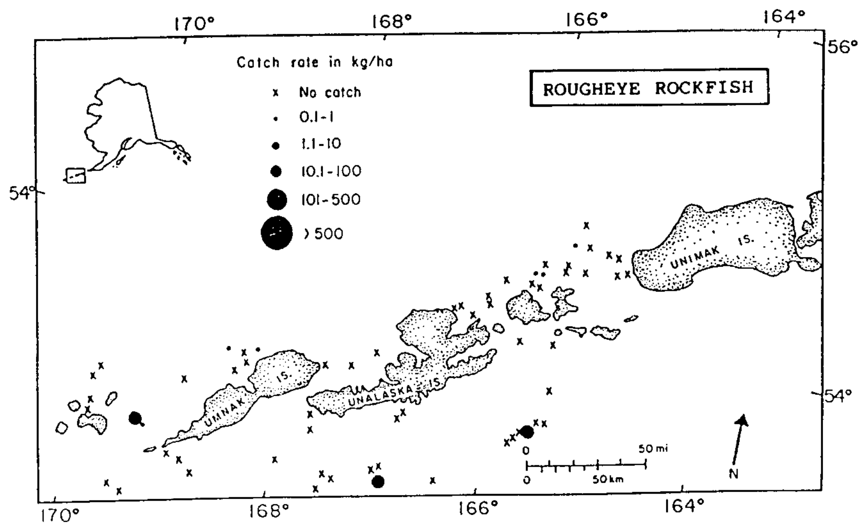


Figure 4C-37. Continued.





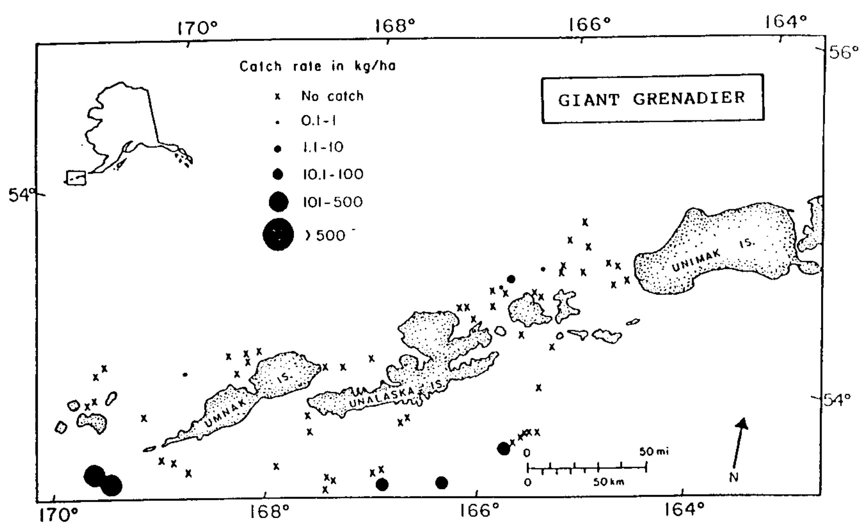


Figure 4C-37. Continued.

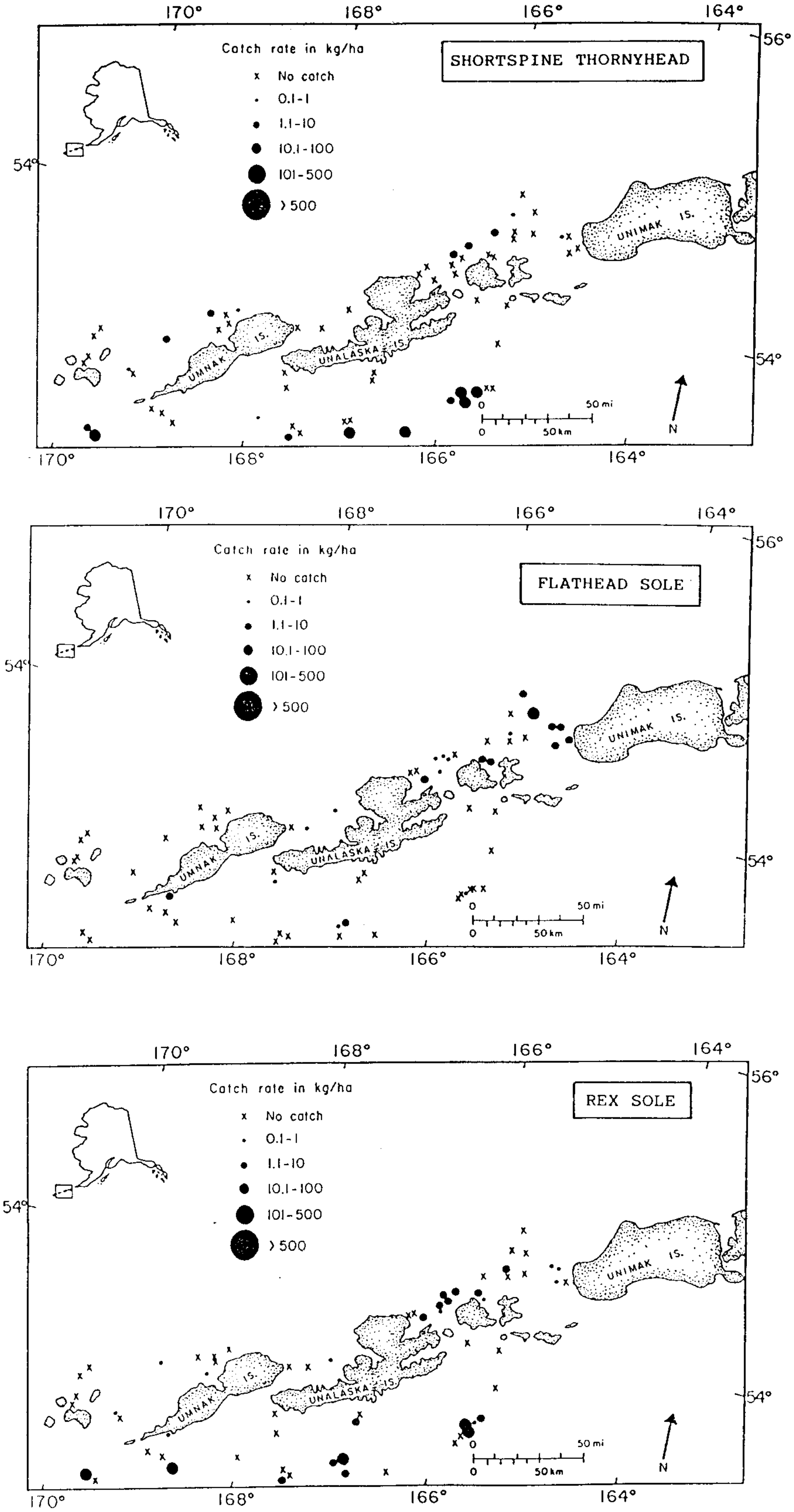


Figure 4C-37. Continued.

in the production of a strong year class of fish for a given species, and this year class then supports much of the commercial catch of that species for several years.

A second feature is that water temperature is a key factor affecting year class strength. The effect may be direct (e.g., warm temperatures may provide better growing conditions and more food for larval stages) or indirect (e.g., cold temperatures may reduce predator populations--Laevastu and Marasco 1984). Indeed, temperature is a key factor affecting most phases of the life cycle of these fishes. Temperature influences where they overwinter, when they migrate to spawning grounds, when they spawn, and all aspects of their energy budgets (the amount of food ingested, the digestion rate, and the general metabolic rate of the fish).

Other factors affecting groundfish distributions in the study area include seabed topography and substrate characteristics. Many species are closely associated with the shelf break which is located immediately north and south of the eastern Aleutians. This association might be due to preferences for a particular water depth, temperature or substrate; it may be due to increased productivity along the shelf break resulting from upwelling of nutrient-rich water; or, it may reflect an "edge effect" where species diversity and abundance is greater at the juncture of different habitats.

Inshore Fishes

The relatively narrow band of water adjacent to the shoreline supports one of the most diverse biological communities in the marine environment. In this zone is a variety of fishes whose utilization of inshore waters is quite dissimilar among species. Included are species which only spawn there, those which only feed there, and those which are entirely limited to inshore waters.

Unlike salmon, herring, and groundfish resources, the inshore fish community receives little use by man. However, when viewed by broader criteria, this group merits consideration because it has direct trophic links to several commercially harvested species, and, as discussed in previous sections, salmon, herring and some groundfishes may spend considerable periods of time in inshore waters.

Knowledge of inshore fishes in the eastern Aleutians is very limited. Some species are mentioned in early records (Turner 1886, Scheffer 1959, FWS 1974); the most complete listing is provided by Wilimovsky (1964) who collected 103 species in the intertidal zone of the eastern Aleutian Islands. Twenty-seven families of fish were represented, including flounders (8 species), salmonids (6), greenlings (5), rockfishes (4), and cods (4), but sculpins (28) were the dominant group present, and Wilimovsky notes, "No other faunae in the world contain such a high proportion of cottoid (sculpin) forms." Hubbard (1964) provides additional information about 33 species from the intertidal waters of Umnak Island.

Simenstad et al. (1977) provide a description of the inshore fishes at Amchitka Island; though farther west, these fish populations probably resemble to some extent those in our present study area. These authors describe two inshore communities (paraphrased):

> Inshore Rock-Algae Community. This community is characterized by a diverse assemblage of fishes intimately associated with the extensive algal growth dominating the rocky nearshore coast. Abundant submarine algal growths cover subtidal rock terraces; most conspicuous are the dense kelp beds of *Alaria fistulosa* which sometimes extend to the 20 m depth contour, thereby increasing the structural complexity of the habitat available to fish. This spatial heterogeneity and diversity of the algal growth and associated food resources are jointly responsible for the abundance and diversity of fishes present.
>
> Representative fishes in this community are the rock greenling, red Irish lord, northern ronquil, silverspotted sculpin, great sculpin, dusky rockfish, and Pacific cod. For the most part, this assemblage consists of sedentary bottom fishes; however, a few occupy the kelp canopy (dusky rockfish, silverspotted sculpin, and some less abundant snailfish species). Although the latter fishes move freely about the kelp blades either singly (silverspotted sculpin, snailfish) or

in schools (dusky rockfish), the bottom-associated fishes appeared restricted to a particular site.

During winter when the kelp forest is greatly thinned, the pelagic fishes descend into the subtidal zone and its lush Laminaria growth. Other species also move into deeper water in winter, perhaps to avoid wave action or to follow their food resources.

Intertidal Community. These fish inhabit the surge channels and tide pools of the rocky intertidal zone. Although this assemblage can be considered an extension of the inshore rock-algae community, it also differs by the presence of distinctive species.

Common fishes in tide pools include the crescent gunnel, high cockscomb, ribbon prickleback, juvenile great sculpin, sharpnose sculpin, and spotted snailfish. Fish densities in the tide pools averaged 98 fish per 3-6 m^3 tide pool (range 20-250 fish).

During high tide when the intertidal zone is flooded, adult rock greenling, anadromous Dolly Varden, and coho salmon are present. This habitat also provides a nursery grounds for juvenile fishes.

Simenstad et al. (1977) found that the prey of these fishes (amphipods, mysids) serve an important role in the transfer of algae-based detritus to the inshore fish community.

Additional information about inshore fishes is available for another region closer to the study area--the northern coastline of the Alaska Peninsula (LGL 1986, Isakson et al. 1986). However, these data have not been included here because the habitats are not similar and thus the fish communities and habitat usage are probably not similar either. The northern coastline of the Alaska Peninsula consists primarily of exposed sand-gravel beaches in contrast to the generally rocky coastline (interspersed by small sections of beach) of the eastern Aleutian Islands.

General Conclusions

1. Local and migratory stocks of salmon, herring, and groundfish are abundant in the eastern Aleutian Island study area where they are harvested in commercial and subsistence fisheries. General abundances of these groups are as follows:

> Salmon. Pink salmon are by far the most abundant salmon species produced in Aleutian streams; however, migratory stocks of other salmon species from Asian and North American origins are seasonally abundant, depending on migratory patterns.
>
> Herring. Spawning populations of herring in the study area are relatively small, but Aleutian waters are an important summer feeding area for major stocks spawned elsewhere in the eastern Bering Sea (principally Togiak).
>
> Groundfish. Many groundfish species are abundant and widely distributed throughout the study area. Catches are dominated by walleye pollock and Pacific cod, followed by rock sole, flathead sole, arrowtooth flounder, Atka mackerel, and Pacific ocean perch.

2. Exchanges between fish populations in the Bering Sea and those in the North Pacific Ocean through Aleutian Island passes vary according to species and life history stages. Major migrations of non-local salmon (e.g., Bristol Bay stocks) may occur in some years. Some groundfish species (e.g., sablefish, juvenile halibut) actively migrate through the island passes, and the larvae of species such as halibut drift with the Kenai Current from the North Pacific into the Bering Sea. In contrast, indirect evidence suggests that several other species (herring, yellowfin sole, pollock) have a restricted exchange between the two waterbodies.

3. Large fluctuations in fish abundance occur in both the short and long term. While many factors are involved in such fluctuations,

variations in water temperature are particularly important, directly or indirectly affecting seasonal movements of fish, reproductive timing, and survival of young.

4. While it is difficult to identify habitats of special importance for fish (because of a limited database), several generalizations can be made. Important areas include:

> Salmon. Nearshore areas on the north side of Unalaska Island where newly smolted salmon, particularly pink salmon, feed before moving offshore.
>
> Herring. Spawning and nursery areas (Unalaska, Makushin and Akutan bays, and possibly Beaver Inlet), and feeding areas (e.g., Unalaska Bay) where stocks from Bristol Bay and other areas migrate in summer to feed.
>
> Groundfish. The "Golden Triangle" area (between Unimak Pass, the Pribilof Islands, and Amutka Pass) is well known as a productive fishing ground, and Unalaska Bay is a major groundfish harvest area (J. Blackburn, ADFG, pers. comm.). The continental shelf breaks on the north and south sides of the Aleutian Islands serve as a feeding, spawning and/or wintering area for many groundfish species. Bays and other nearshore areas serve as rearing areas for juvenile groundfish.

D. INVERTEBRATES

by Joe Truett

Extensive sampling for invertebrates in the eastern Aleutian Islands and Unimak Pass has been largely restricted to commercially important species, mainly crabs. But sampling of other groups has been carried out in nearby regions of the Bering Sea and North Pacific Ocean, and the results suggest much about the invertebrate communities that exist in the study area. The following discussions are based on information collected both within the study area and in nearby areas. The rationale for using outside information to describe the probable fauna of the study area is given where appropriate. Emphasis is on those invertebrate groups important to man and other vertebrate consumers--zooplankton (copepods, euphausiids), nektonic cephalopods (squids, octopuses), epibenthos (crabs, shrimps, echinoderms), and infauna (mainly bivalve mollusks).

Sources of Information

Information on invertebrates in the eastern Aleutians is from two main sources--programs directly supportive of shellfish management and harvest (e.g., Alaska Department of Fish and Game, National Marine Fisheries Service, North Pacific Fishery Management Council) and programs with basic research objectives on OCS impact analysis (e.g., university-sponsored programs, mainly in the United States and Japan, and the Outer Continental Shelf Environmental Assessment Program of the U.S. Department of the Interior). The former programs focus mainly on king and Tanner crabs and other invertebrates harvestable for human use. The latter programs focus on a broader array of invertebrate groups, especially those important in food chains of higher organisms. In the literature as a whole, many more data are available on crabs and other commercially important species than on unharvested components of the fauna.

Zooplankton

Zooplankton are not important commercially. As discussed in sections of this report on mammals, birds, and fishes, the important zooplankton groups in food chains of vertebrates are copepods, euphausiids, and to some extent hyperiid amphipods.

Very little sampling for zooplankton has been conducted in the study area but a look at general circulation patterns suggests that the study area zooplankton communities may resemble those of nearby shelf and oceanic waters. Cooney (1978) notes that the circulation in the northern Gulf of Alaska and Bering Sea provides a near-shelf and coastal "river in the sea" that carries plankton westward along the south side of the Alaska Peninsula and the eastern Aleutians, thence through Unimak and other passes into the Bering Sea, and then eastward along the north side of the Aleutians and the Alaska Peninsula into Bristol Bay.

Copepods

The eastern Bering Sea, including the eastern Aleutian area, has been depicted as containing two major copepod communities, an oceanic-outer shelf (oceanic) community and a middle-shelf and coastal (shelf) community (Fig. 4D-1). These may intermingle to some extent along the outer shelf and along the Aleutians. Very near the coast, a distinct nearshore community may also occur. These communities are found consistently in hydrographically defined domains (Cooney 1981).

The oceanic community is dominated by the large copepods Calanus cristatus, C. plumchrus, Eucalanus bungii, and Metridea pacifica, that overwinter at ocean depths beyond the shelf edge and migrate upward in large numbers in spring to take advantage of phytoplankton blooms at the surface. The shelf community is dominated by the small copepods Acartia longiremis, Pseudocalanus spp., and Oithonia similis that overwinter on the shelf, surviving in low numbers to spring. Shelf waters adjacent to ocean depths, including probably the very narrow shelf along the eastern Aleutian chain, contain a mixture of these dominants in summer. Motoda and Minoda (1974) note that a copepod Centropages abdominales, described by Cooney (1981) as a nearshore species, is also abundant in the shallow waters around Unimak Pass.

Because there has been limited zooplankton sampling in the eastern Aleutians, it is not clear whether the copepod community is typically more of an oceanic type or a shelf type. It seems more likely that the

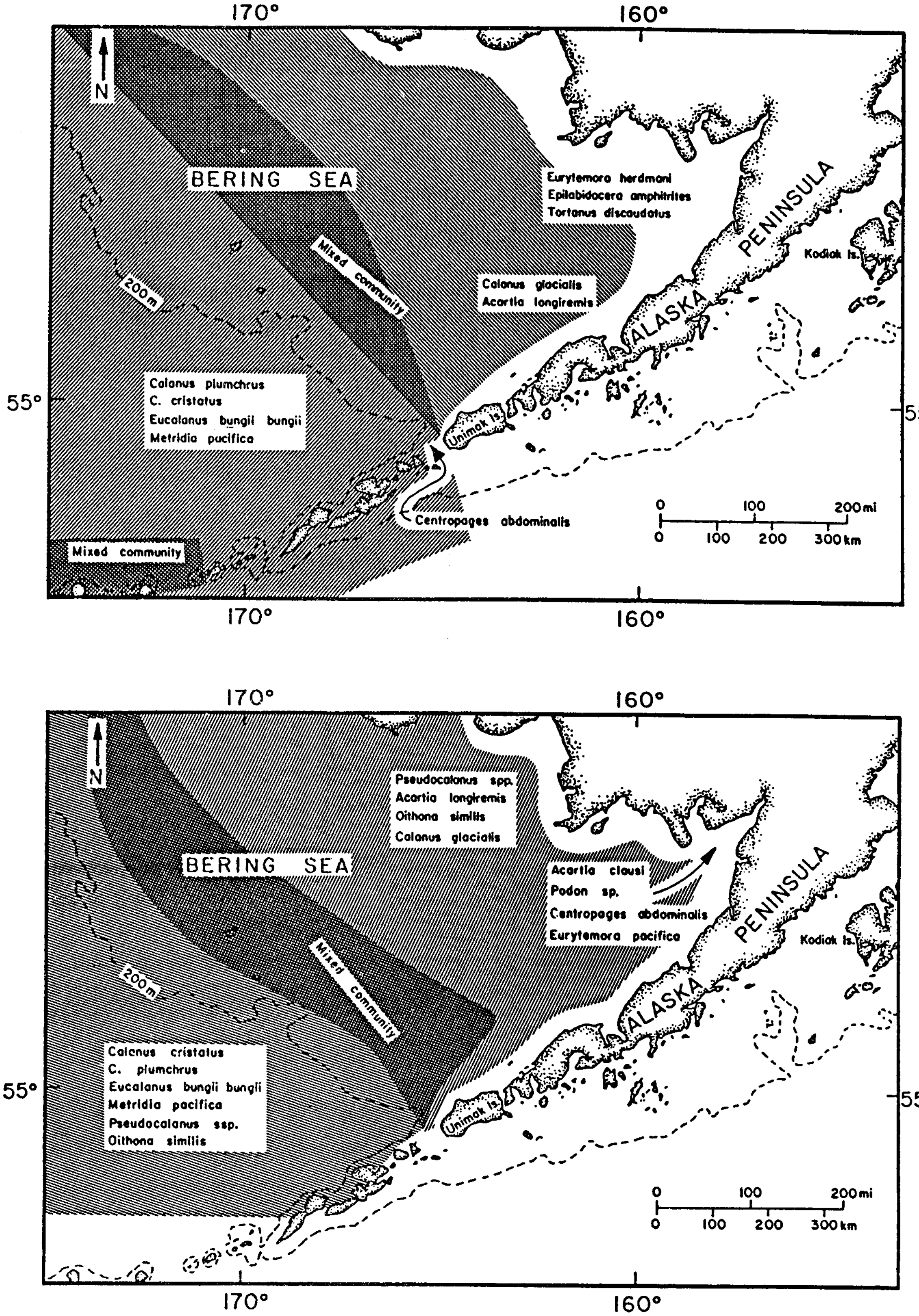


Figure 4D-1. Generalized distribution of copepod communities in the Bering Sea (top, redrawn from Motoda and Minoda 1974; bottom, redrawn from Cooney 1981).

oceanic-type copepods would be dominant because of the proximity of deep waters to the islands and the probable strong effect of upwelling on study area waters. Discussions by Smith and Vidal (1986) on the transport of oceanic forms onto the outer portion of the southeastern Bering Sea shelf lend support to this idea.

The copepods are basically herbivorous; they are the major water-column consumers of the phytoplankton (largely diatom) production of the southeastern Bering Sea and northern Gulf of Alaska. Cooney (1978, 1981) and Smith and Vidal (1986) discuss the tendency for spring-summer standing crops of, and annual secondary production by, copepods to be relatively large (though variable) in outer shelf and shelf break waters (Fig. 4D-2). This high production is caused by two interacting factors. First, spring and summer phytoplankton production is relatively high in the shelf break area, probably enhanced by nutrient upwelling from depth. Second, the shelf break and outer shelf copepod communities are dominated by oceanic species that overwinter (and reproduce) at depth and move to the surface in sufficient numbers in spring to consume most of the primary production. (In contrast, the inner shelf copepods greet the spring plankton bloom in low numbers, consuming only a small proportion of the primary production.)

Because these same phenomena (i.e., high primary production, dominance by oceanic copepods) probably characterize much of the waters in the eastern Aleutians, high copepod productivity is likely to characterize much of that area. Primary and secondary productivity is likely to be especially high in and near passes such as Unimak and Samalga where upwelling has been documented (see Hattori and Goering 1981).

Low water temperatures in winter that restrict the development of an efficient grazing community appear to limit copepod productivity in the middle and inner domains of the southeastern Bering Sea (Dagg 1982). However, outer shelf and slope copepods, and probably those in the eastern Aleutian passes as well, appear to graze most of the phytoplankton productivity. Thus it is likely that copepod annual productivity in the study area is a direct function of food (diatom) abundance.

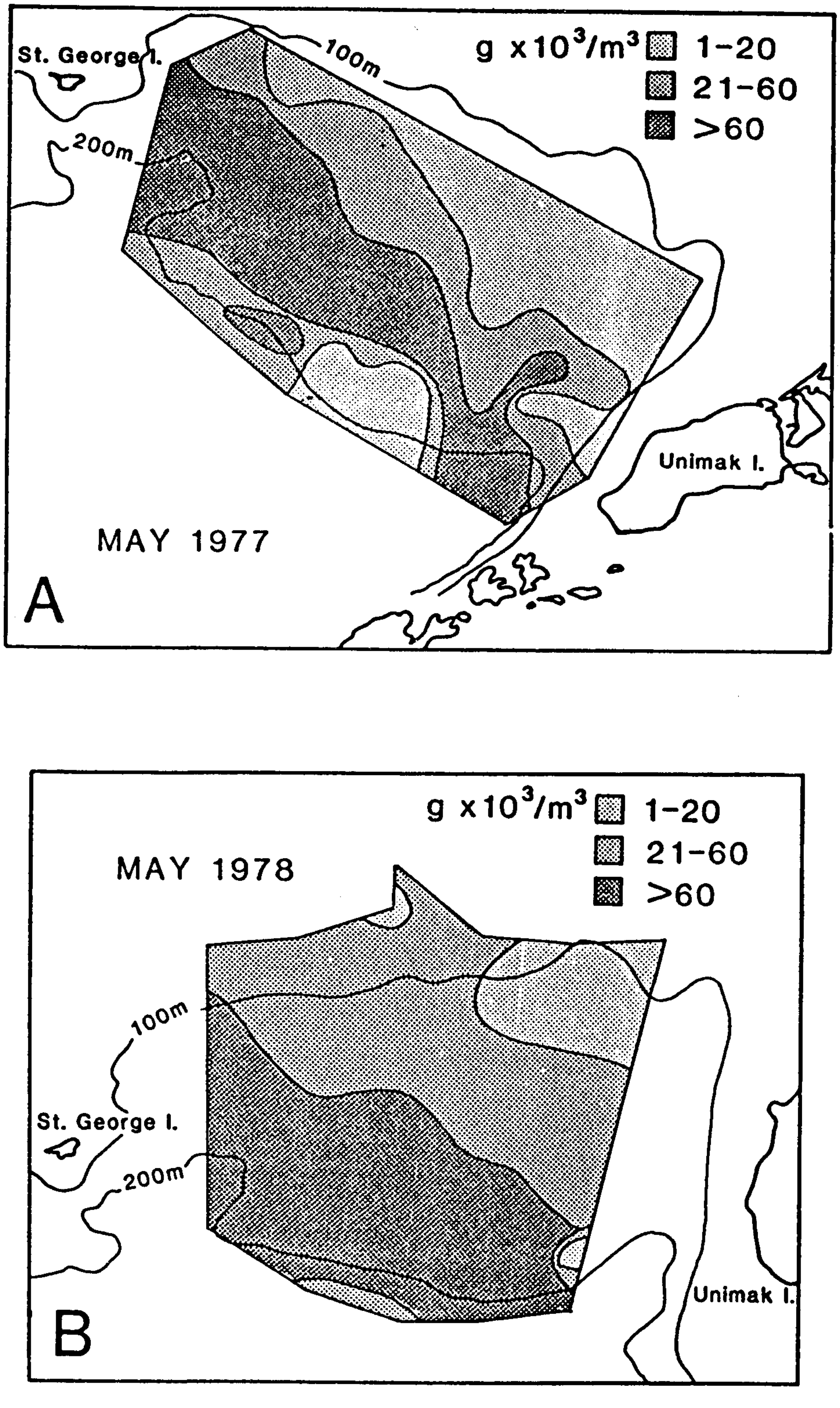


Figure 4D-2. Distribution of zooplankton dry weight along the shelf break of the southeastern Bering Sea, May 1977 and 1978 (from Cooney 1981).

Euphausiids

Similarly to copepods, euphausiids in the southeastern Bering Sea are distributed according to major hydrographic domains. It is generally agreed that two major communities exist--an oceanic community occupying the outer shelf, shelf break, and oceanic waters, and a shelf community found in the middle shelf and coastal waters. A "mixed" community occupies a zone of overlap on the outer shelf (Fig. 4D-3). The geographic distributions of these communities are very similar to those of the two major copepod communities described earlier. [A separate "nearshore" community equivalent to that described for copepods by Cooney (1981) has not been described.]

Reasons for this segregation of euphausiid communities has not been as clearly explained as it has been for copepod communities. Motoda and Minoda (1974) note that Thysanoessa longipes prefers higher-salinity water than T. raschii; however, over large parts of the range of T. raschii in the middle and inner shelf of the southeastern Bering Sea, salinities are not appreciably different from those of the oceanic and outer shelf areas dominated by T. longipes. Perhaps temperatures in winter habitats are a crucial factor, as they are with copepods.

The dominant euphausiids of the oceanic community are Thysanoessa longipes and T. inermis; the dominant species of the shelf community is T. raschii (Motoda and Minoda 1974, Minoda and Marumo 1975, Cooney 1981). Few reports specifically characterize the euphausiid community of the eastern Aleutians, though Motoda and Minoda (1974) state: "... Tessabrachion oculatus is distributed only along the Aleutian Islands, being absent in the central Bering Sea. ... Thysanoessa inspinata appears in the area east of Attu Island. This (latter) species inhabitats the Gulf of Alaska and the Pacific coast of the Alaska Peninsula, so that the species would be transported by the Alaskan Stream to the Bering Sea area." It appears likely that both oceanic and shelf species occur in the study area, with the oceanic species perhaps dominant in more westerly parts of the study area because of the nearness of the deep ocean environment and the apparent prevalence of upwelling. Shelf species may be common in Unimak Pass proper because of the influence there of the Alaska Coastal current, but this is largely speculation.

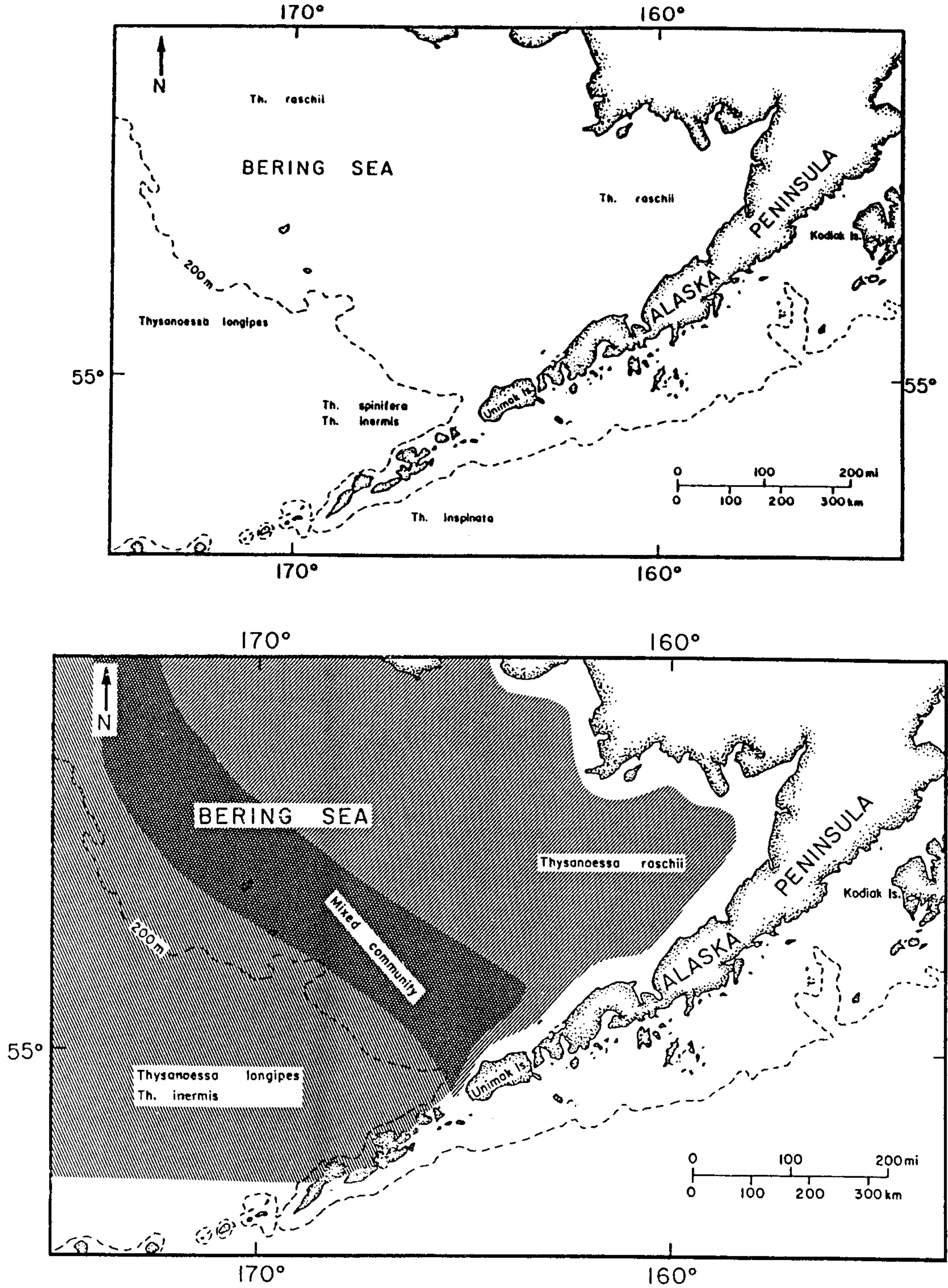


Figure 4D-3. Generalized distribution of major euphausiid communities in the Bering Sea (top, redrawn from Motoda and Minoda 1974; bottom, redrawn from Cooney 1981).

Dagg (1982) showed that, in the southeastern Bering Sea, Thysanoessa individuals eat mostly phytoplankton, but they can derive most of their energy requirements from phytoplankton only if the phytoplankton standing stocks reach bloom levels. At sub-bloom levels, they consume more copepods, crustaceans, and fish and invertebrate eggs. Because they are more readily omnivorous than copepods, their standing stocks exhibit less drastic depressions between phytoplankton bloom periods than do stocks of copepods.

Dagg (1982) maintains that euphausiids are probably not sufficiently abundant to contribute prominantly to Bering Sea carbon budgets. But Motoda and Minoda (1974) and LGL (1986) note that they are important as foods of fishes and birds, and the former authors believe that their low biomass representation in zooplankton samples may be caused by avoidance of sampling nets. Minoda and Marumo (1975) found that euphausiids are an important part of the standing stock of zooplankton in the Bering Sea.

It is not clear what regulates the annual productivity or standing stock of euphausiids. Dagg's (1982) work indicating that low densities of phytoplankton cells causes euphausiids to become more carnivorous suggests that food supply may play a role. It is also not clear why species assemblages are different between inner shelf and outer shelf/oceanic waters. These uncertainties, coupled with the scarcity of past sampling in the study area, make most conclusions about euphausiid species composition and productivity in the eastern Aleutian Islands speculative.

Otner Zooplankton

Other important components of the zooplankton community in the southeastern Bering Sea, and presumably of the eastern Aleutian Islands as well, are chaetognaths and pelagic (mainly hyperiid) amphipods. Hyperiid amphipods are important prey of vertebrates, and chaetognaths are major predators of other zooplankton. Parathemisto is the major amphipod, with P. pacifica occurring largely in the outer shelf and oceanic areas and P. libellula assuming dominance in middle shelf and coastal areas (Motoda and Minoda 1974, Cooney 1981). Among the chaetognaths, Sagitta elegans is abundant in all hydrographic regions--the oceanic and all shelf zones; Eukrohnia hamata is also common in the oceanic realm (Cooney 1981).

Both the amphipod Parathemisto and the chaetognath Sagitta are largely carnivorous; in and near the study area they probably feed mainly on copepods. Parathemisto is an important food source for some vertebrates (e.g., short-tailed shearwaters--Hunt et al. 1981a); Sagitta is seldom listed as an important food item for vertebrates. No site-specific information is available on the diets or predators of these animals in the study area.

We found no information describing specific factors that influence population levels or distributional patterns of hyperiid amphipods or chaetognaths in or near the study area.

General Characterization of Zooplankton

As noted in the sections above, very little sampling for zooplankton has been conducted in the eastern Aleutians, and knowledge of the study area's zooplankton must be largely inferred from what has been found in adjacent areas. Because of the existing circulation patterns and the tendency for zooplankton to be more-or-less passively transported, the study area zooplankton populations are likely to exhibit similarities to those on either side of the study area, in the Bering Sea and the Gulf of Alaska. Most data are available from the nearby southeastern Bering Sea; its zooplankton communities have been aptly described by Cooney (1981) as dominated by (1) an oceanic and outer-shelf community dominated by large, interzonal copepods, the hyperiid amphipod Parathemisto pacifica, the chaetognaths Sagitta elegans and Eukrohnia hamata, and the euphausiids Thysanoessa longipes and T. inermis; (2) a middle-shelf and coastal community dominated by small copepods, the amphipod Parathemisto libellula, the chaetognath Sagitta elegans, and the euphausiid Thysanoessa raschii; and (3) a nearshore copepod community associated with the brackish coastal lagoons and estuaries. Between the relatively stable middle-shelf water and that of oceanic origin, the zooplankton community becomes a mixture of shelf and oceanic species. This spatial partitioning of the zooplankton communities is maintained by the presence of an oceanographic front which parallels isobaths between 100 and 80 m. Because the waters of the study area are very near and exhibit many qualities of the oceanic/outer shelf hydrographic domains, it is likely that the study area zooplankton fauna and its general qualities resemble those of the Bering oceanic and outer-shelf community.

Cephalopods

Squids and octopuses in the southeastern Bering Sea and northern Gulf of Alaska are of considerable importance to vertebrate consumers, particularly mammals (Fiscus 1982, Lowry et al. 1982). Some have potential significance as human food (Wilson and Gorham 1982a,b). Characteristics of their populations and their trophic significance in the eastern Aleutians Islands must be evaluated mostly on the basis of information from adjacent areas, but even these data are scarce. It is surprising that a group so important in food chains and potentially important for human use has been so little studied.

Squid

Wilson and Gorham (1982a), referencing Okutani (1977), indicate that at least 10 species of squid are relatively abundant in the Bering Sea and/or the northern North Pacific. Ronholt et al. (1984) note that the red squid, *Berryteuthis magister*, accounted for nearly 85% of the total squid biomass in demersal trawl catches in the Aleutians from Attu to Unimak Pass.

Most information on squid distribution in and near the study area has been obtained from stomach analyses of whales, seals, and salmon (Wilson and Gorham 1982a). This information suggests that squid (and their predators) concentrate in areas with abrupt changes in depth, areas of upwelling along the continental slope or slopes of underwater ridges near oceanic islands, and areas of convergence and divergence (Wilson and Gorham 1982a, quoting Lipinski 1973 and Okutani and Nemoto 1964). The eastern Aleutian study area would therefore appear to be excellent habitat for squids.

Wilson and Gorham (1982a) examined records of individual catches of squids by National Marine Fisheries Service (NMFS) trawling and by foreign fleet trawling and seining in the southeastern Bering Sea and the northern Gulf of Alaska. High catches of the squids *Berryteuthis magister*, Onychoteuthis banksii, and unidentified squids clustered along the southeastern Bering shelf break and slope and along the Aleutian chain. This reflected to some extent the areas receiving greatest fishing pressure, but probably also showed squid habitat preferences for these areas. Figure 4D-4 shows the highest abundance of squids caught by trawl in 1980 in the vicinity of the study area to be in eastern and western parts near passes.

Fiscus (1982) observed a pattern in the diets of mammals that suggests something about squid distribution among habitats in the Bering Sea and North Pacific Ocean. He noted that over the continental shelf, fish were more common than squids in mammal diets, but that over the continental slope and in the deep seas, squids became much more important.

Squids are near the top of the food chain. When young, they feed upon small planktonic crustaceans and fish larvae. As adults, most are predatory, feeding on other pelagic animals and upon each other (Wilson and Gorham 1982a).

In turn, squids are major foods for many mammal species. Most of the small cetaceans, several of the large cetaceans, and most pinnipeds prey on squids (Fiscus 1982). This author notes that most marine mammals that forage along the continental slope or in the deeper oceanic waters of the North Pacific Ocean and Bering Sea have squids as major parts of their diets. Because mammalian predators and squids both occur in the study area, one might suspect heavy use of squids by mammals in the area, and Figure 4D-5 supports this hypothesis.

Factors regulating squid abundance in the study area are not known. Given that squids seem to frequently concentrate near upwellings or other areas of prey concentrations (Fiscus 1982, Wilson and Gorham 1982a), one might speculate that their abundance is at least partly food-limited.

Octopus

The distribution and abundance of octopuses in and near the study area are difficult to determine from existing data. Analyses of NMFS trawl survey data, observations of divers and biologists, and foreign fleet catch data from the northern Gulf of Alaska and the southeastern Bering Sea (Wilson and Gorham 1982b) show octopuses to have somewhat

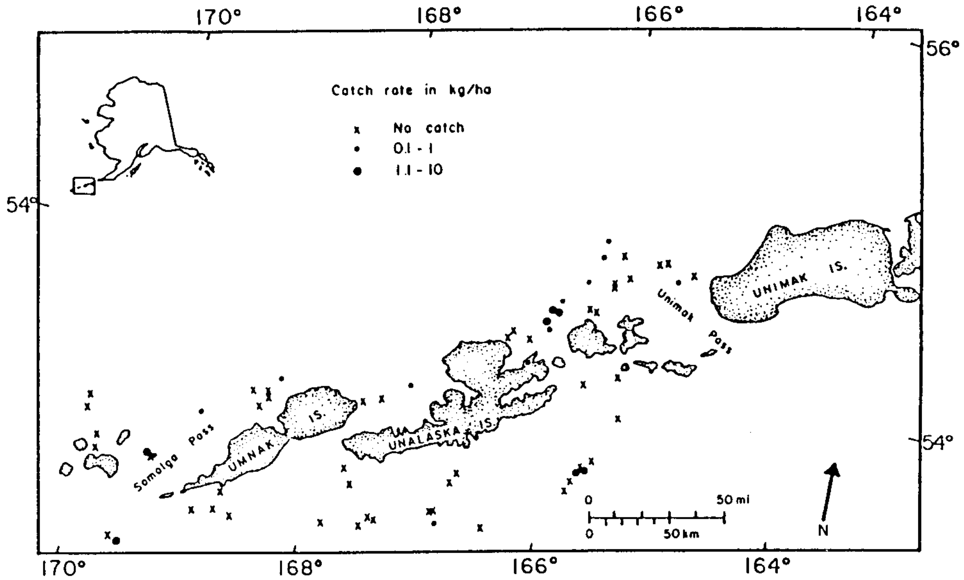


Figure 4D-4. Distribution of catch rate of squids by commercial trawlers in the eastern Aleutians during the cooperative U.S.-Japan groundfish resource assessment survey, June-November 1980 (adapted from Ronholt et al. 1986).

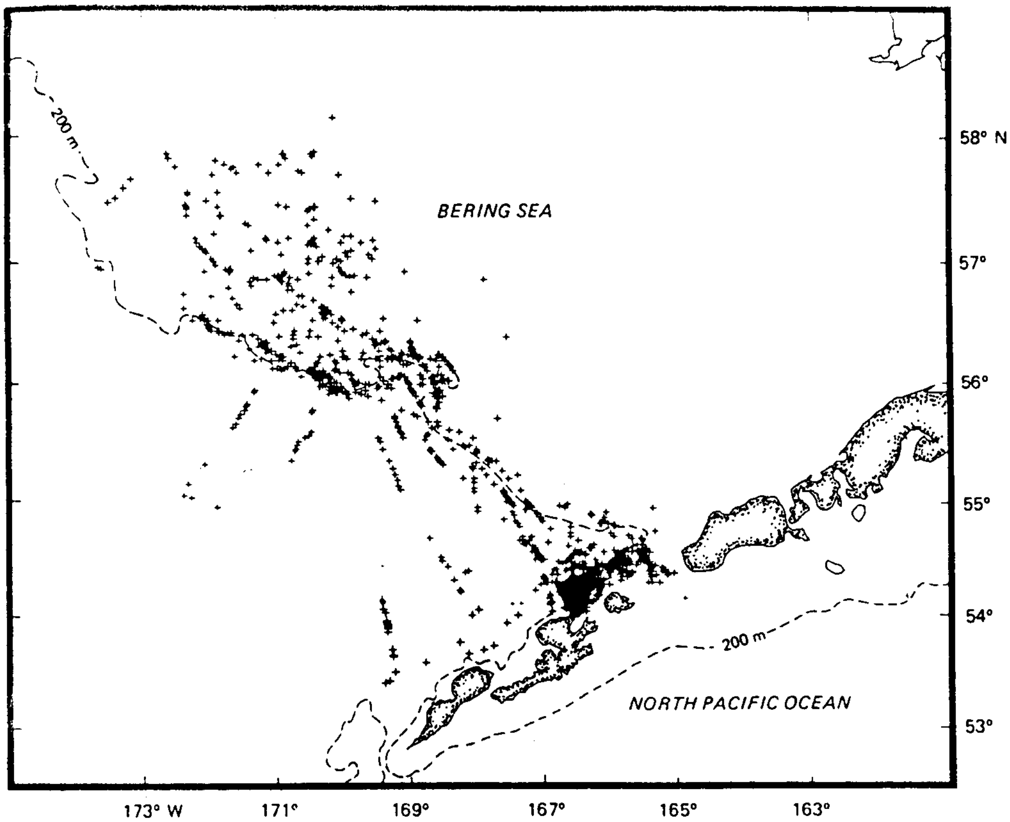


Figure 4D-5. Locations in the Bering Sea where northern fur seals had gonatid squids (Gonatus, Berryteuthis, Gonatopsis) in their stomachs (from Fiscus 1982).

similar distributions to squids in these areas. That is, catches seem to be concentrated along the Bering shelf break, with sporadic catches in the eastern Aleutians (Fig. 4D-6). Ronholt et al. (1986) found octopuses to occur at low densities (relative to squids) throughout the eastern Aleutians; densities were somewhat higher immediately north of the study area in the Bering Sea at 1-200 m depths. The historical octopus catch (trawls and crab pots) in the eastern Aleutians has been generally small and sporadic among years (ADFG 1985a). Identified species in the catch included Octopus dofleini (the giant Pacific octopus) and Opisthoteuthis californiana (the flap-jack devilfish).

Octopuses, like squids, are carnivorous. Generally, they feed on benthic organisms such as crabs and bivalve molluscs, but little has been reported on their diets in the vicinity of the eastern Aleutians. In contrast, their utilization as important prey by marine mammals and other vertebrates in the southeastern Bering Sea has been noted by several authors (Feder and Jewett 1981, Fiscus 1982, Lowry et al. 1982).

What regulates population abundance and distribution of octopuses in the region surrounding the study area is not known. Their tendency to concentrate along the Bering Sea shelf break and slope may offer some initial insight into this question.

Epibenthos

Epibenthic species of concern include the commercially important king crab, Tanner crabs, Dungeness crab, and shrimp. King and Tanner crabs are particularly valuable; for example, catches of these species in 1978 were the primary reason why Dutch Harbor was the most economically productive fishing port in the United States (Otto 1981). Echinoderms, which dominate the epibenthic biomass of the southeastern Bering Sea secondarily to crabs (Feder and Jewett 1981), are also discussed in this section.

Red King Crab

The red king crab (Paralithodes camtschatica) is the most economically important shellfish in the eastern Bering Sea region (Otto 1981). It is distributed from the North Pacific Ocean to the southern

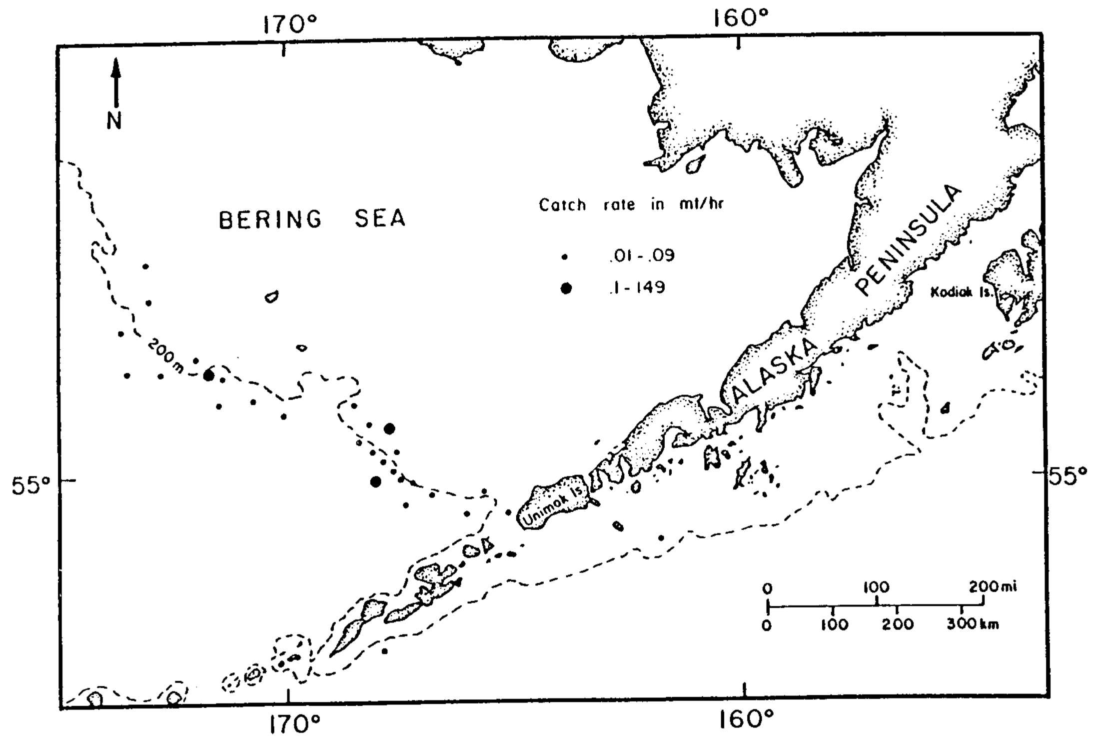


Figure 4D-6. Distribution of catch rates of octopus in 1978 by foreign stern trawl and mothership fleets (from Wilson and Gorham 1982b).

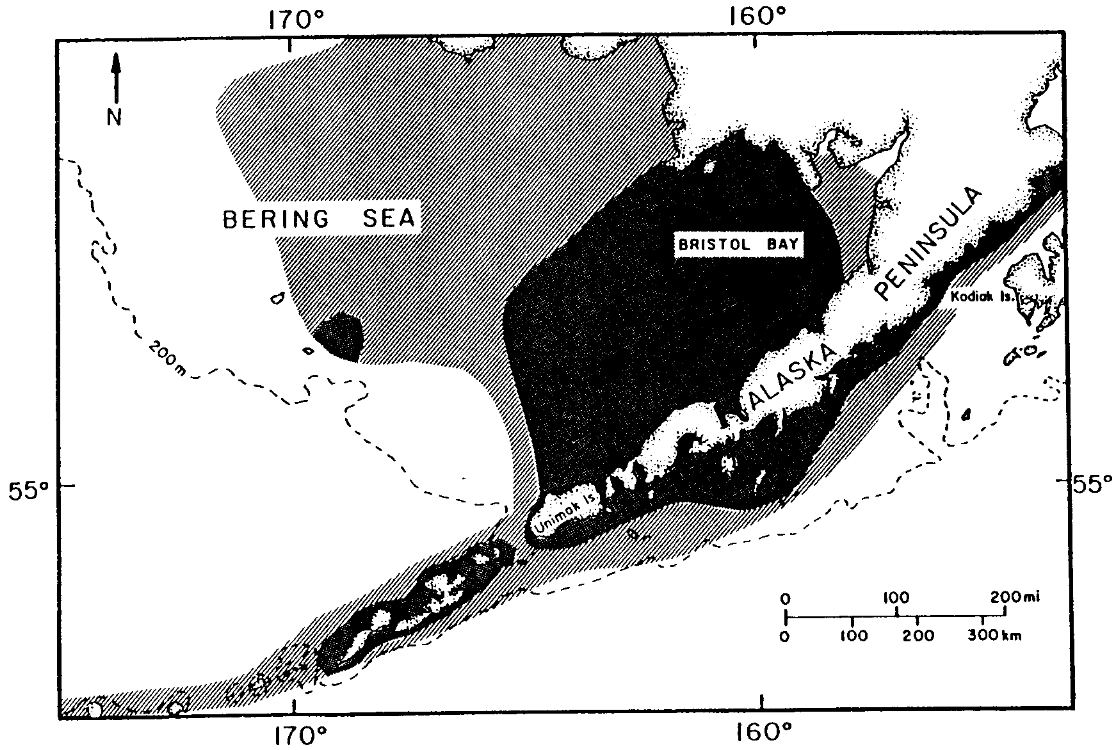


Figure 4D-7. Distribution of red king crab in western Alaska waters. Darkly shaded portions indicate areas of consistently high abundance (redrawn from Otto 1981).

Chukchi Sea (Fig. 4D-7), and is relatively common throughout the eastern Aleutian Islands (Fig. 4D-8). Mating areas and juvenile rearing areas occur near some of the islands.

Foods of the red king crab are varied and change with growth stage. Larvae and post-larvae eat such foods as diatoms, copepods, other crab larvae, ostracods, and other small animals (Fukuhara 1985). Pearson et al. (1984) found juveniles north of the Alaska Peninsula to consume polychaetes, sand dollars, bivalves, oligochaetes, and other small, poorly motile benthic organisms living on or just beneath the seafloor. Adults consume a variety of polychaetes, molluscs, crustaceans, and echinoderms throughout their range (Fukuhara 1985).

Red king crabs are prey for many vertebrates and invertebrates. Larval and juvenile crabs are consumed in abundance by yellowfin sole in the southeastern Bering Sea (Haflinger and McRoy 1983) and probably by other bottom fishes as well (Fukuhara 1985). Pacific cod and halibut are important predators of adult crabs (Fukuhara 1985).

The marked annual fluctuations in king crab stocks have been of great concern to the fishery, but no clear factor that causes the population changes has yet been isolated. Hayes (1983), Armstrong (1983), and McMurray et al. (1984) discuss several potential environmental factors that might limit populations at different levels among years and thus lead to the observed fluctuations. Included are ocean temperature and hydrographic transport patterns that affect transport and growth of larvae or predation pressures on larvae, and the availability of benthic "refuge" habitats for early life stages.

It is possible that the eastern Aleutians area might be especially important in some years as a source of red king crab larvae that are transported eastward to settle on the NAS (McMurray et al. 1984). Further, it could provide benthic "refuge" habitats for young-of-the-year crabs; current theory holds that only certain substrate types (cobbles, boulders) promote young crab survival and that these "refuge" habitats are scarce (McMurray et al. 1984). These issues have yet to be studied thoroughly.

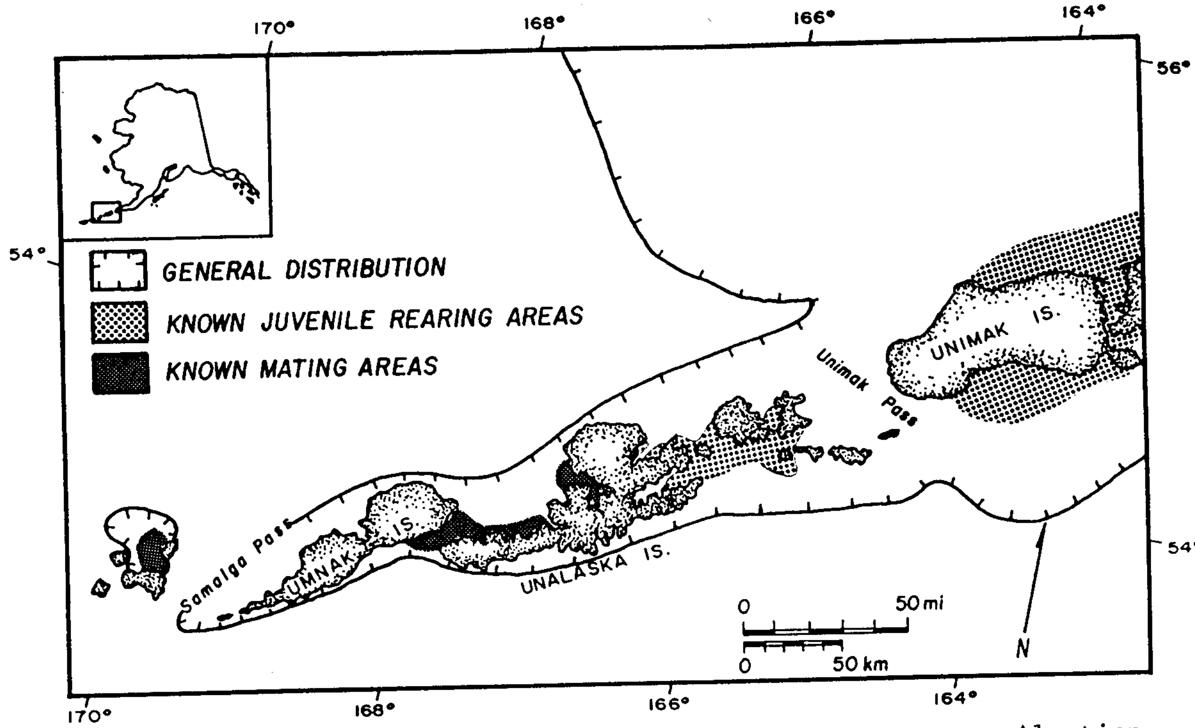


Figure 4D-8. Distribution of red king crab in the eastern Aleutian Islands, Alaska (from ADFG 1985c).

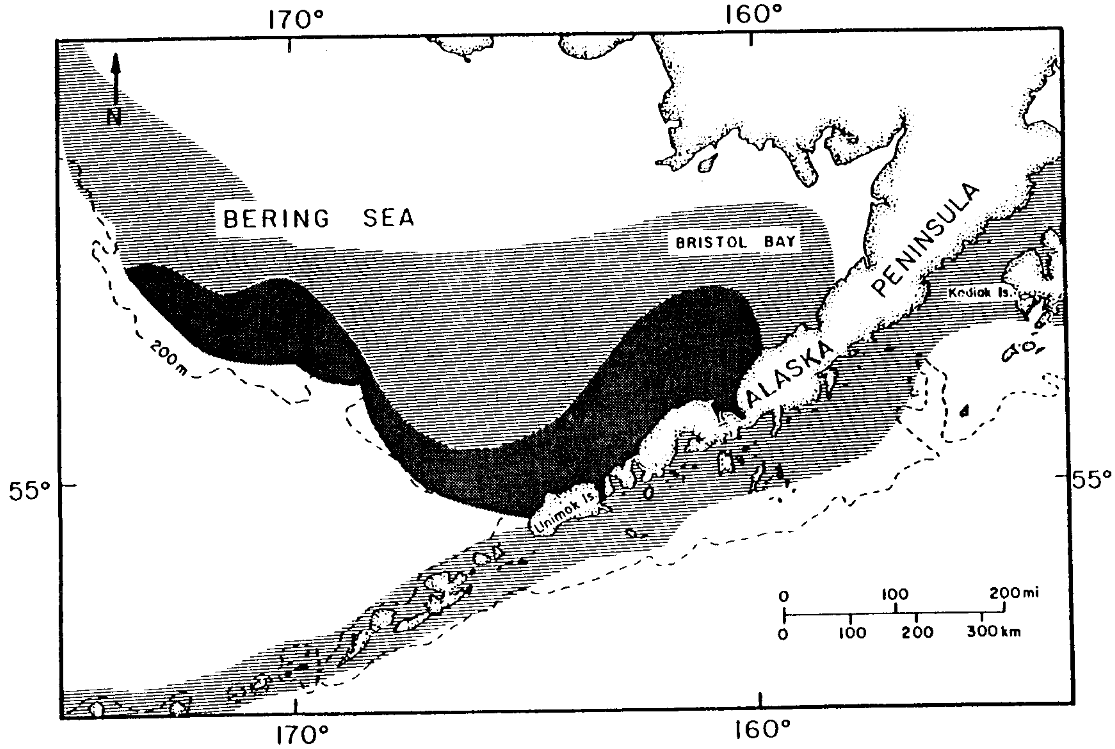


Figure 4D-9. Distribution of Tanner crab (Chionoecetes bairdi) in southwestern Alaska waters. Darkly shaded areas indicate areas of consistently high abundance (redrawn from Otto 1981).

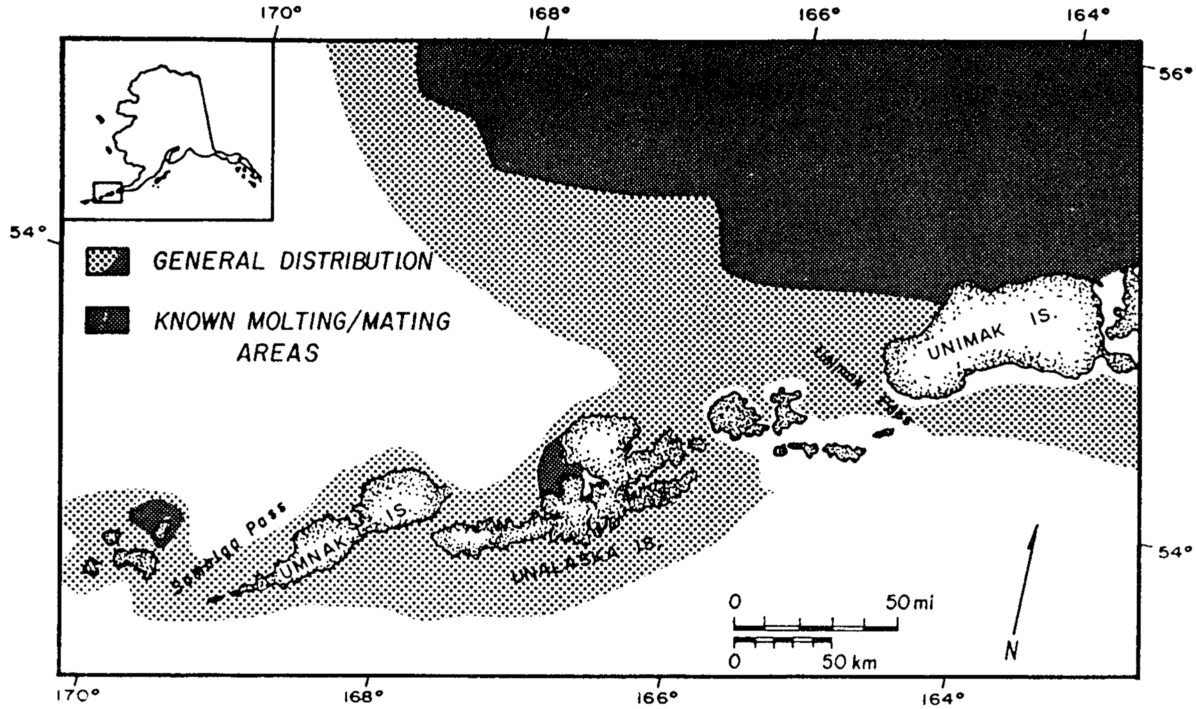


Figure 4D-10. Distribution of Tanner crab (Chionoecetes bairdi) in the eastern Aleutian Islands area, Alaska (from ADFG 1985c).

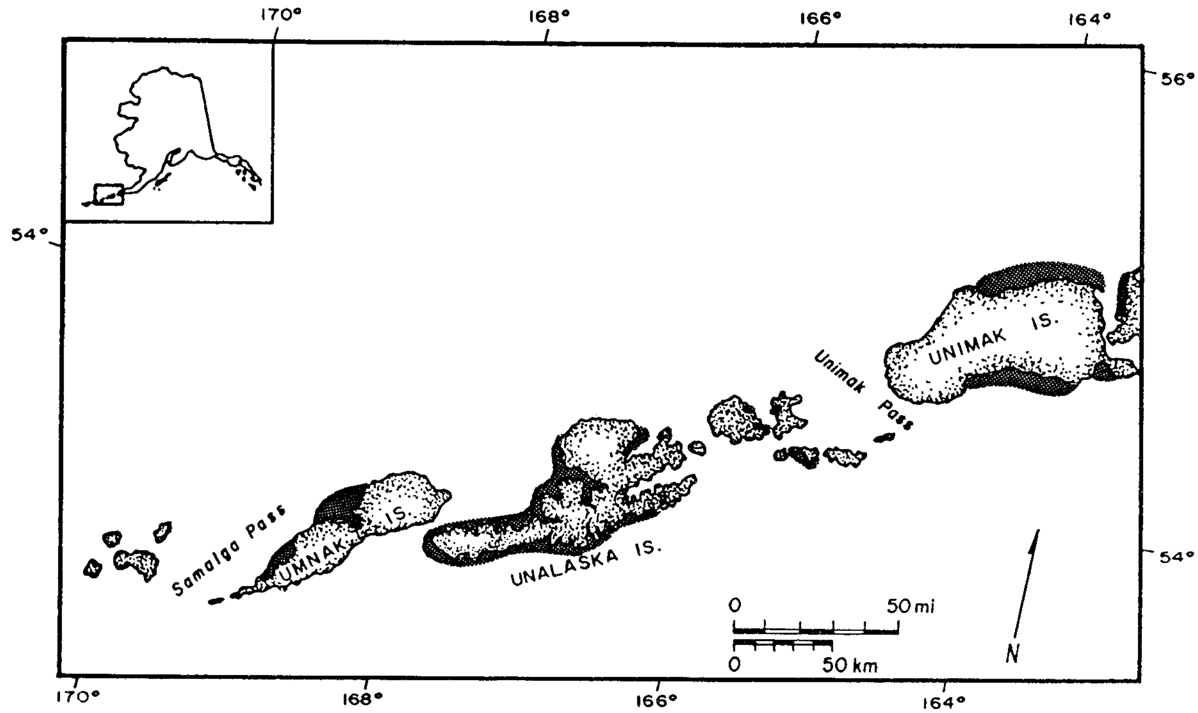


Figure 4D-11. Distribution of Dungeness crab in the eastern Aleutian Islands area, Alaska (from ADFG 1985c).

Tanner Crab

Two species of commercially harvested Tanner crab, Chinoecetes bairdi and C. opilio, are found in the eastern Aleutians study area, but C. opilio occurs only sparingly in the extreme northeastern part (ADFG 1985c) and will not be addressed here. C. bairdi occurs in the southern Bering Sea and the North Pacific Ocean (Fig. 4D-9), and throughout the eastern Aleutians (Fig. 4D-10). Molting and mating areas of this species occur locally in Makushin Bay of Unalaska Island and in the vicinities of Kagamil Island just west of Samalga Pass, but the major molting/mating region is outside the study area to the north. Low numbers of mostly adult males have been caught by an experimental fishery in the study area (Donaldson and Hicks 1980).

Food groups used by Tanner crabs are similar throughout their range (Feder and Jewett 1981). Juvenile C. bairdi from the southeastern Bering Sea feed mainly on crustaceans, polychaetes, and molluscs, in that order of importance. Adult Tanner crabs feed largely on polychaetes and brittle stars. Clams, shrimps, pelecypods, barnacles, and conspecifics have been important dietary items of adults in the Gulf of Alaska.

Tanner crabs are in turn eaten by many predators in the southeastern Bering Sea (Feder and Jewett 1980). They are consumed by king crabs, walleye pollock, Pacific cod, halibut, great sculpin, and several species of sole. As noted above, they are also cannibalistic.

The Tanner crab C. bairdi apparently fluctuates less in juvenile survival and in recruitment to the adult population than does the red king crab (Hayes 1983), suggesting that population limiting factors are more uniform from year to year. What these factors are is unclear. Both abiotic factors (water temperature and circulation patterns) and biotic factors (predation) could be implicated. The conventional wisdom is that limiting factors operate most strongly in the larval stages (Hayes 1983).

Dungeness Crab

The Dungeness crab (Cancer magister) is found locally throughout the eastern Aleutians study area (Fig. 4D-11). Because of its preference for shallow bays, which are few and far between in the study area (ADFG

1985b), it is not as widely distributed in the eastern Aleutians as are the deeper-water king and Tanner crabs. Armstrong et al. (1983) reported larvae of *Cancer* spp. (some of which were presumably other than *Cancer magister*) to be more plentiful in and near the Unimak Pass area than in other parts of the southeastern Bering Sea (Fig. 4D-12) (in contrast to larvae of king and Tanner crabs, which are more abundant north and east of the study area).

Stevens et al. (1982) found that Dungeness crabs in a Washington State estuary changed food habits as they grew. First-year crabs preyed mainly on very small bivalves. Second-year crabs fed on shrimp (*Crangon* spp.) and to a lesser extent on small fish. Third-year crabs ate more fish and fewer *Crangon*.

Armstrong (1983) notes the apparent cyclic trends in Dungeness crab abundance and discusses the hypothesized population regulating factors. As with other crabs, it is believed that limiting factors causing variations in populations of adults operate mostly in the larval and juvenile stages. Such factors as hydrographic patterns (levels of upwelling, variation in transport patterns), predation (mostly on eggs and young), and food supply have been postulated by various workers to strongly affect the recruitment levels of young into the populations.

Other Crabs

Crabs of lesser interest to the fishery include the Korean hair crab (*Erimacrus isenbeckii*) and the golden king crab (*Lithodes aequispina*) (McBride et al. 1982; Stevens and MacIntosh 1985). Though sizable numbers of these and other species with little commercial value are often caught by groundfish surveys and other fishing efforts (Armstrong et al. 1983), little information has been published on these species in the vicinity of the study area.

A 1985 eastern Bering Sea trawl survey by the NMFS Northwest and Alaska Fisheries Center (Stevens and MacIntosh 1985) found large male Korean hair crabs in major concentrations to the east and northeast of the Pribilof Islands and in low numbers in a band along the southern edge of Bristol Bay. (Few females or young crabs are ever caught; little is known of their distribution.) The catches nearest the study area were north of

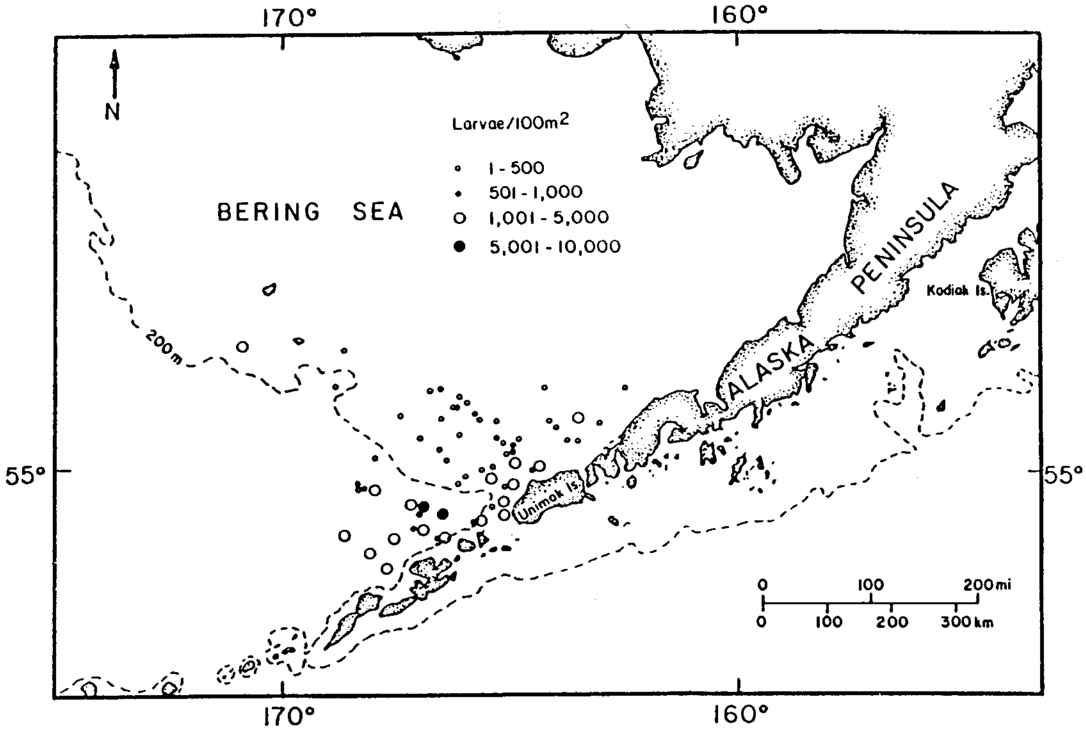


Figure 4D-12. Distribution of Cancer spp. larvae collected in the southeastern Bering Sea, 1977-81 (from Armstrong et al. 1983).

Unimak Island. ADFG (1985b) notes that hair crabs have been commercially fished in the eastern Aleutians since 1978-79. But fishermen there found them unevenly distributed, without concentrations that could support a full-scale fishery. The bulk of the present catch comes from Akutan and Unalaska bays. Armstrong et al. (1983) found that Korean hair crab larvae are relatively abundant in the northeastern corner of the study area, north of Unimak Pass and Unalaska Island.

The golden king crab is generally found at depths of from 200 to 800 m in the North Pacific from British Columbia to Japan (Otto and Cummiskey 1985); in the Bering Sea it is typically an inhabitant of the continental slope (Tarverdieva and Zgurovsky 1985). Catch rates of golden king crabs by the Alaska fishery are usually relatively low (especially in the Bering Sea) in comparison with catches of other species such as Tanner and red king crabs (McBride et al. 1982). But since about 1982, catches have increased as a proportion of the total Alaska crab catch (Otto and Cummiskey 1985). Relative to other parts of the Bering Sea, sites near the east and west ends of the Unimak Pass study area produce good catches (Fig. 4D-13). Diet of golden king crabs is not known in the study area, but in the Navarin Basin they ate mainly ophiuroids, sponges, and fish (Tarverdieva and Zgurovsky 1985).

Shrimps

The dominant shrimp in the general vicinity of the study area and the only one of consequence to the shellfishery is Pandalis borealis, the pink shrimp (Ronholt 1963, Hayes 1983, Armstrong et al. 1983). Shrimp have been fished in the eastern Aleutians since 1972, when two vessels first shrimped there. Catch and effort increased in subsequent years, peaking at 6.8 million pounds in 1977-78, but declining since then (ADFG 1985b). Four main shrimping areas exist: Unalaska Bay, Makushin Bay, Usot Bay, and Beaver Inlet (Fig. 4D-14).

The only available feeding data for Alaska pink shrimp are from east of the study area--Kodiak Island waters and Cook Inlet (Feder and Jewett 1981). Typically, stomachs contained diatoms, crustacean remains, small bivalves, polychaetes, and small fishes. Pink shrimp are used as food by many demersal fishes, including walleye pollock, Pacific cod, rex sole,

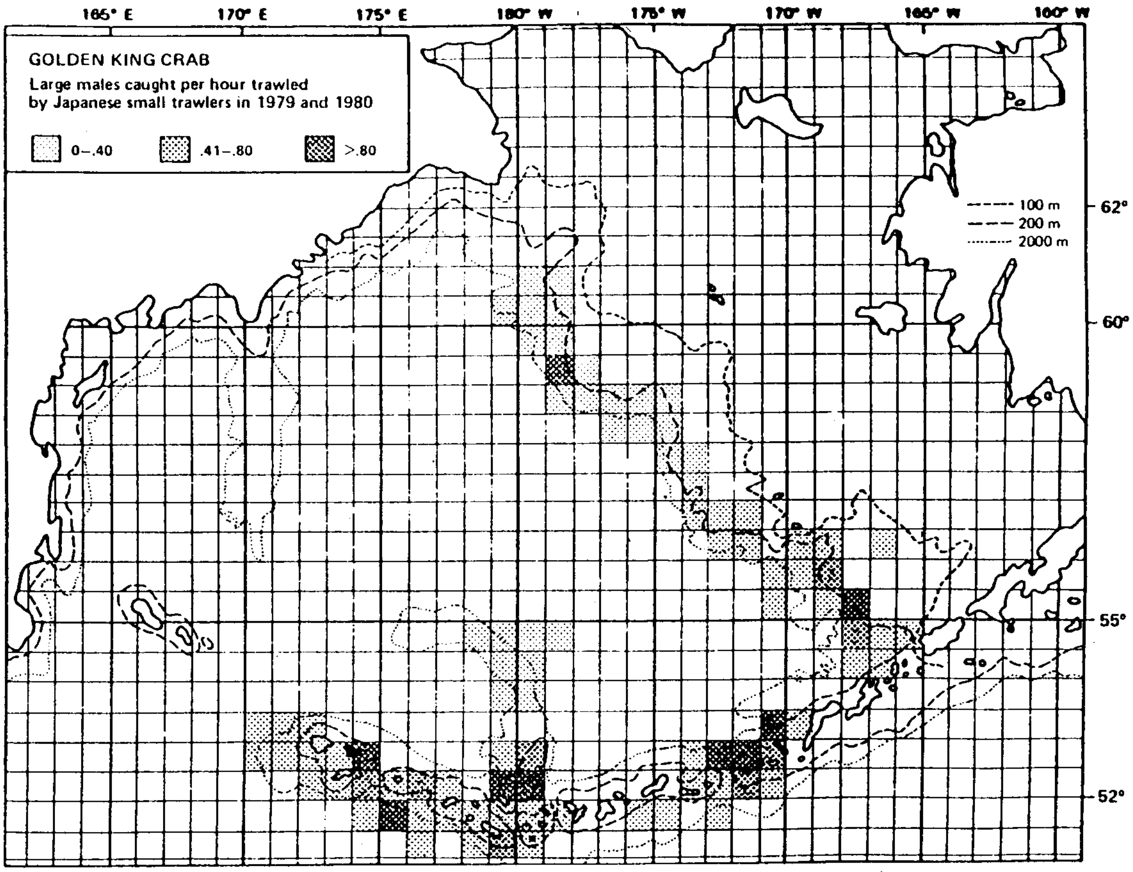


Figure 4D-13. Distribution of large male golden king crab in the eastern Bering Sea and Aleutian Islands, based on foreign trawler observer data for 1979 and 1980 combined (from McBride et al. 1981).

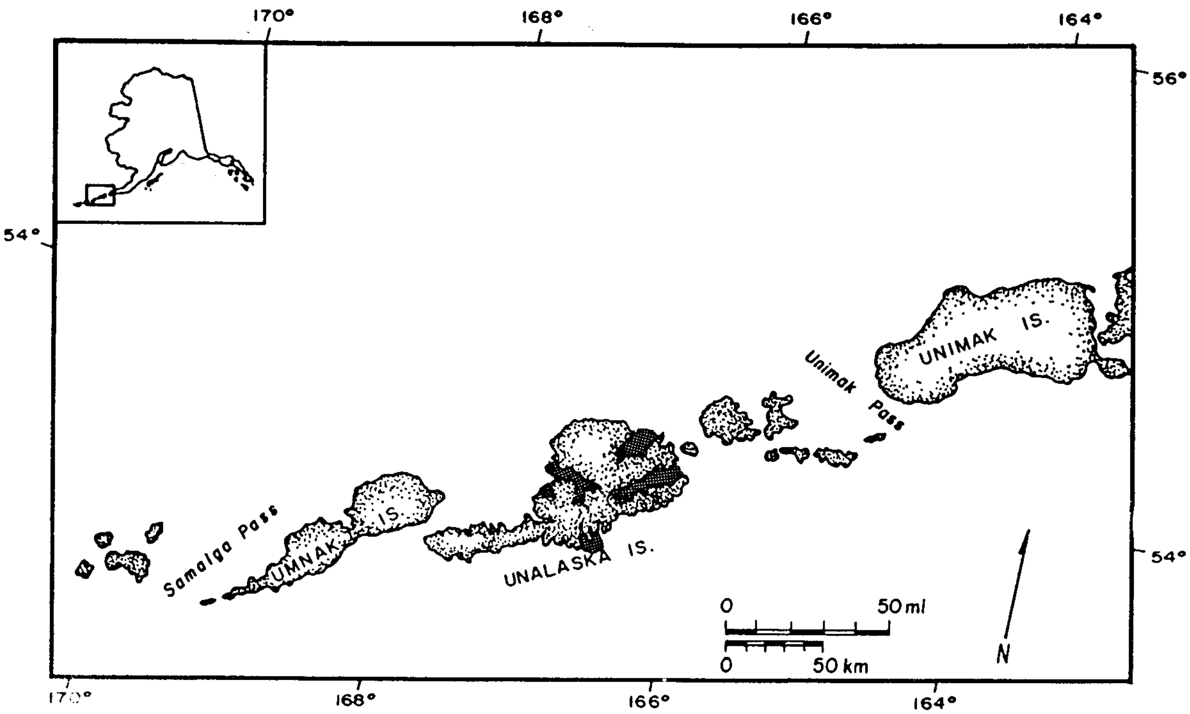


Figure 4D-14. Commercial harvest areas for shrimp in the eastern Aleutian Islands, Alaska (from ADFG 1985c).

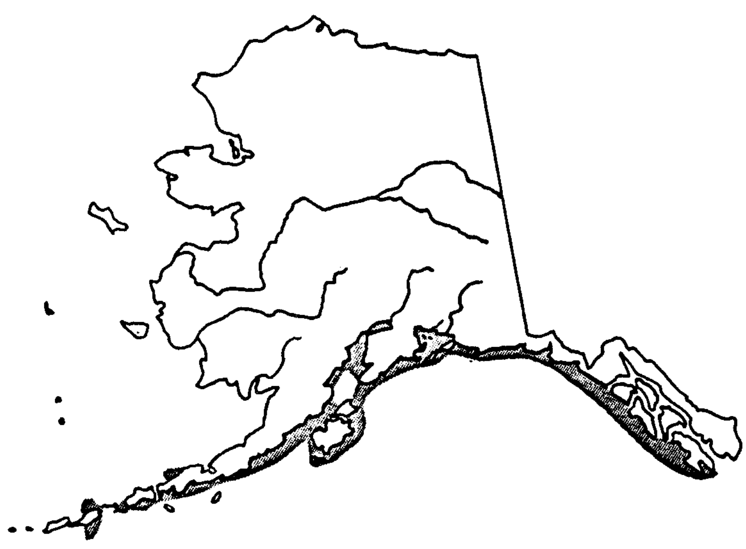


Figure 4D-15. Range of razor clam in Alaska (after Nickerson 1975).

yellowfin sole, flathead sole, and arrowtooth flounder (Feder and Jewett 1981).

Shrimps, like some of the crabs discussed earlier, have interannual variations in abundance that range over an order of magnitude in adult numbers (Hayes 1983). This implies limiting factors that vary greatly from year to year in the magnitude of their effects. Many of the population variations can be detected early in the life history stages, suggesting (as in crabs) that the limiting factors act most intensely on very early stages (eggs, larvae). As is the case with crabs, causes of these variations are largely speculative, ranging from abiotic factors such as hydrographic characteristics to predation to overharvest by man (Hayes 1983, ADFG 1985b).

Echinoderms

Echinoderms, especially sea stars (Asteroidea), are biomass co-dominants with crabs in the epifauna of the southeastern Bering Sea. Though little is known of their species composition or abundance in the eastern Aleutians, information from the nearby southeastern Bering shelf may suggest much about their populations in the study area. Common sea stars on the Bering Shelf are *Asterias amurensis*, *Evasterias echinosoma*, and *Leptasterias polaris*. In general, the sea star biomass is greatest on middle and inner shelf waters, declining with distance southwestward toward the Unimak Pass area (Jewett and Feder 1981).

Though neither commercially valuable nor preyed upon (as adults) to any extent by more "useful" species, echinoderms may be important nonetheless in food chains of commercially valuable species. For example, they may be in competition with crabs and bottom-fishes for food, and their annual volume of gamete production (which is presumably used by other organisms) is tremendous (Feder and Jewett 1981).

Infauna

Infaunal studies are of two main types in the study area--surveys of intertidal biota and analyses of grab samples from subtidal locations.

Both intertidal and subtidal communities contain infaunal populations directly important to humans or to other species valued by humans.

The abundance of information from subtidal areas is especially sparse in the eastern Aleutians. A number of programs have sampled the nearby Bering shelf and slope but have analyzed few or no samples from stations in our area of interest. Because of the very small amount of site-specific information available, guesses at the general infaunal characteristics of the study area must be based largely on data from nearby locations. Information from both within and near the area demonstrates that the infaunal composition responds to two major factors--water depth and substrate composition (Cimberg et al. 1984; Haflinger 1981; McDonald et al. 1981). The following discussions of intertidal and subtidal infauna depend heavily on what is known about these biophysical relationships.

Intertidal Species

The razor clam (*Siliqua patula*) is one of the few intertidal species in the study area that is of commercial interest, though so far the nearest commercial harvests are on beaches on the south side of the Alaska Peninsula (Swikshak area) (ADFG 1985b). It is found intertidally on exposed sandy-silty beaches of the open coast as far west as Unalaska Island (Fig. 4D-15), where a small concentration exists on the east side of Unalaska Bay (ADFG 1985c).

Razor clams are filter feeders, consuming detritus and drifting plankton. Adult clams are consumed by starfish, crabs, flatfishes, octopuses, diving ducks, and gulls. Their populations are limited by the occurrence of suitable substrates in the intertidal zone and apparently by physical and biological factors (current patterns, water temperature, predation) that affect recruitment of larval and juvenile stages to the adult population (ADFG 1985a).

O'Clair et al. (1981) surveyed the intertidal infauna at four stations in the study area (Fig. 4D-16). Substrate types and dominant infaunal species at each of these sites were as follows:

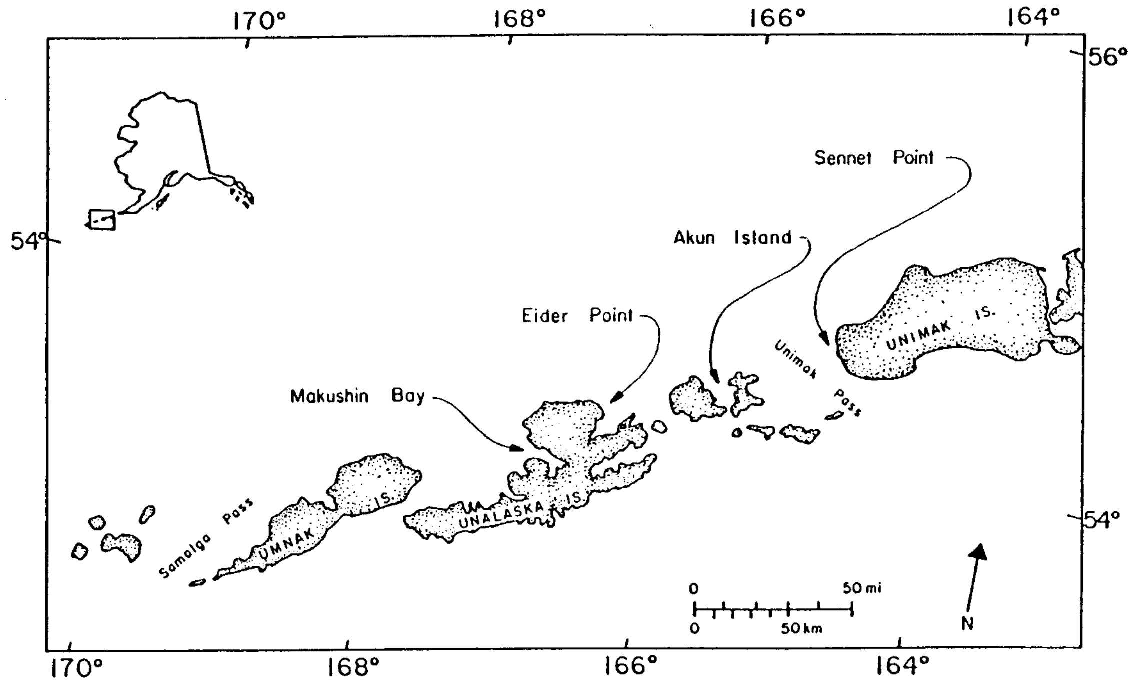


Figure 4D-16. Locations in the Unimak Pass study area at which O'Clair (1981) sampled intertidal communities.

Sennet Point, Unimak Island--Bedrock beach with boulders and rubble, exposed to storm waves. Dominated by herbivorous invertebrates such as the snail *Littorina sitkana* and the chiton *Katharina tunicata*. Mussels (*Mytilus edulis*), barnacles (*Balanus* spp.), and the predatory snail *Nucella lima* were uncommon.

Akun Island--Protected reef with dense cover of algae. Barnacles (*Balanus* spp., *Chthamalus dalli*), polychaetes, gastropods (*Littorina sitkana*, *Margarites helicinus*, and *Barleeia*), and nesting bivalves (*Turtonia occidentalis*, *Musculus discors*) were common. Predators such as *Nucella lima* were uncommon.

Eider Point, Unalaska Island--Low-gradient, east-facing beach of cobble, rocks, and boulders. Four transects sampled a variety of communities. Littorina sitkana, Nucella lima, barnacles, the sea urchin Strongylocentratus droebachiensis, sea stars, the mussel worm Nereis, bivalves, oligochaetes, polychaetes, and the alga Fucus were typical abundant constituents.

Portage Bay, Makushin Bay, Unalaska Island--Rocky point with bedrock and large rocks. Barnacles were extremely dense; the snail Littorina sitkana was common. Predators such as Nucella spp. and sea stars were scarce.

Subtidal Species

It is apparent that substrate type and water depth influence infaunal distribution (see Cimberg et al. 1984, Haflinger 1981). Sand appears to predominate in subtidal sediments in the north parts of the study area (Fig. 4D-17), and probably in southern parts as well. Immediately north of Unimak Pass proper, gravel is common. Rapid changes in depth over short distances are the norm.

Though very little sampling of subtidal infauna has been done in the study area, it is likely that communities resemble to some extent communities in similar substrates and depths in nearby areas. Haflinger (1981), based on one sampling station in over 150 m depth just north of Unimak Pass, notes that the dominant infaunal species found there are also present sporadically at shallower (inshore) Bering Sea stations. Cimberg et al. (1984) report infaunal communities inhabiting sand and gravel substrates (Fig. 4D-18) off the north side of Unimak Island as follows:

Shallow Sand Community--The nearshore region between about 10 and 30 m depths contained an infaunal community predominated by species ubiquitous to all depths and sediment types. The characteristic species are the bivalve Siliqua patula, along

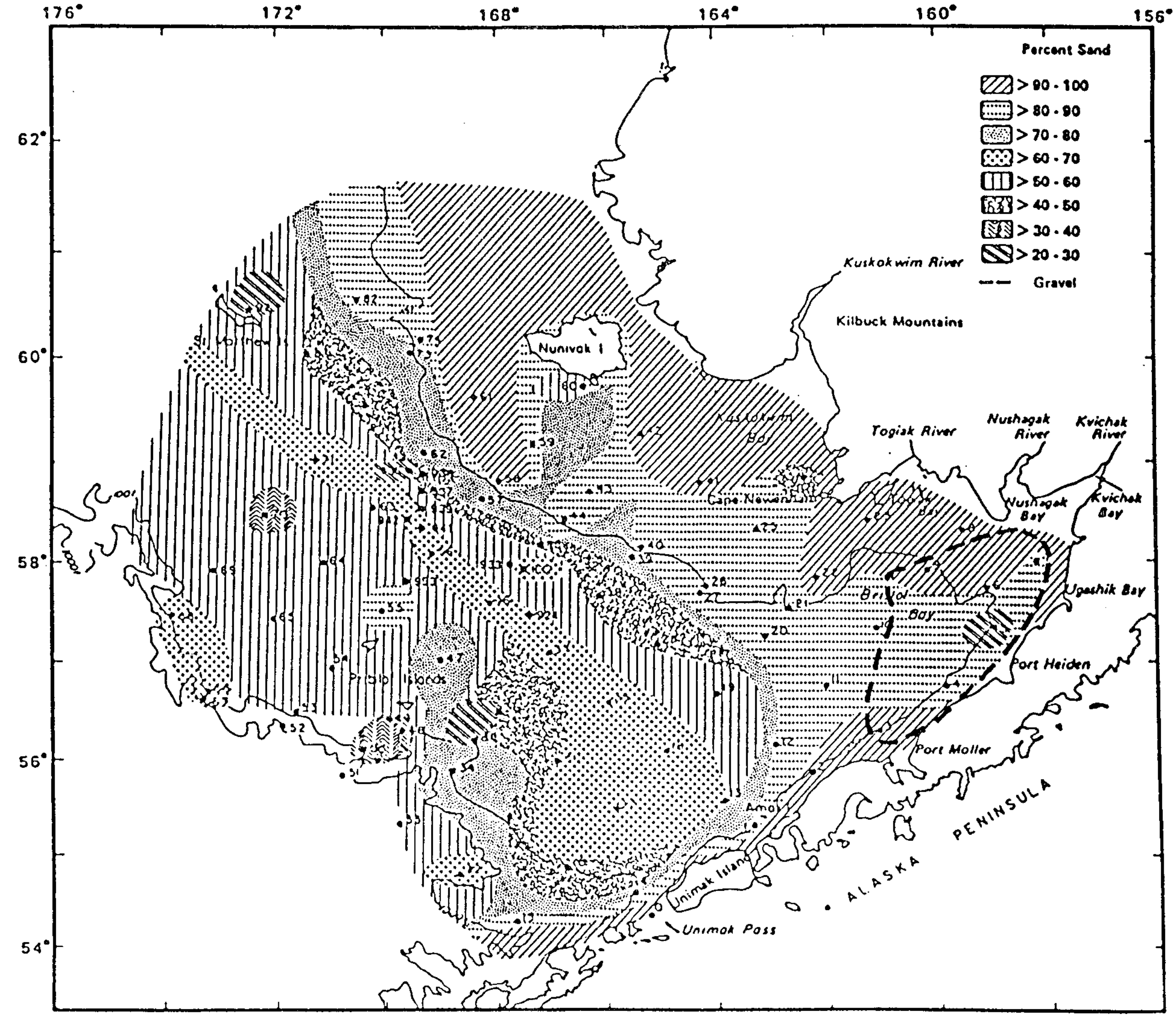


Figure 4D-17. Distribution of sand and gravel fractions in sediments of the southeastern Bering Sea (adapted from McDonald et al. 1981).

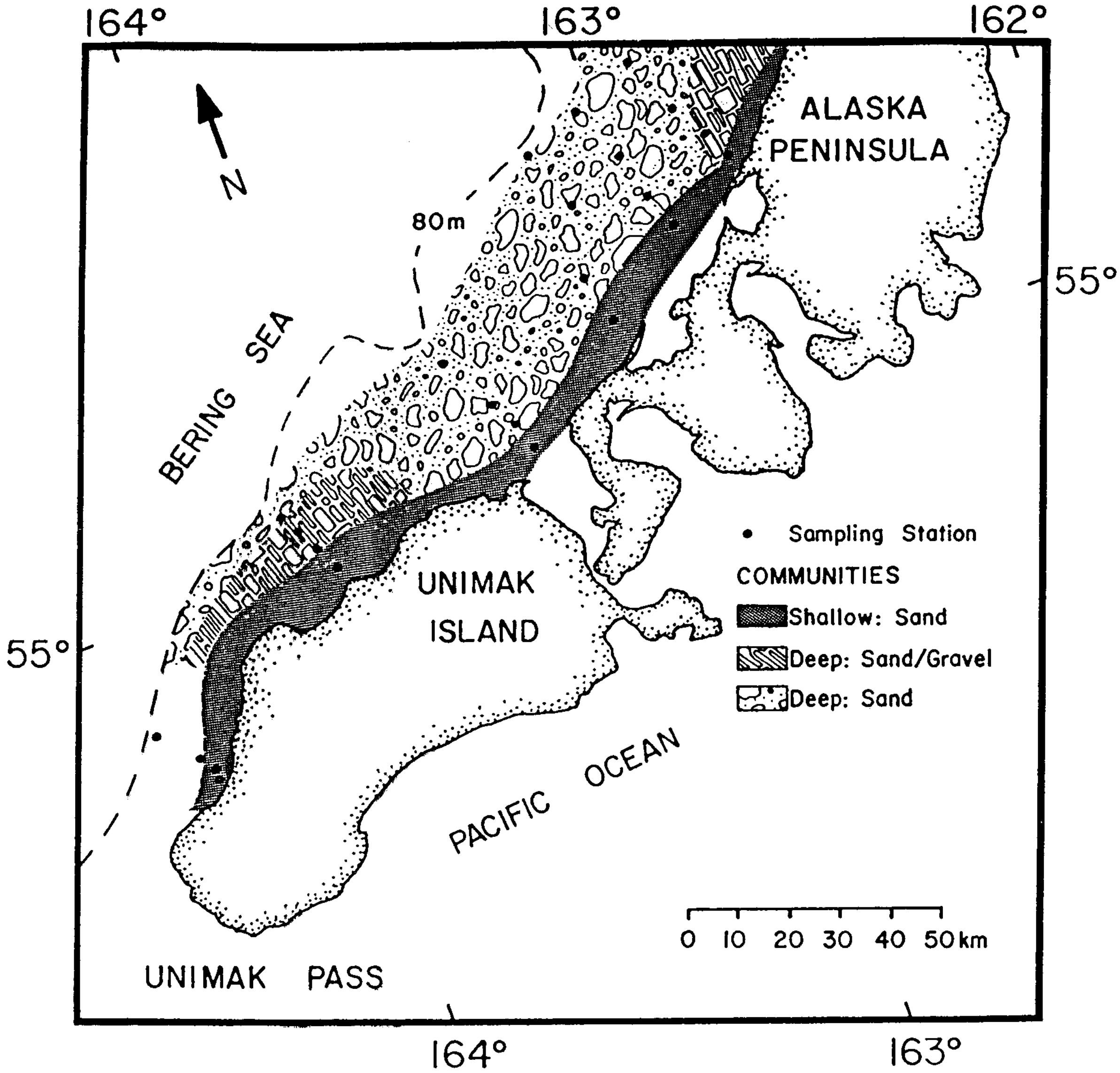


Figure 4D-18. Spatial distribution of infaunal communities as a function of sediment composition and depth on the North Aleutian Shelf, Alaska (from Cimberg et al. 1984).

with the polychaetes Capitella capitata, Magelona sacculata, Nephtys longisetosa, Scolopus armiger and Travisia pupa.

Deep Sand Community--This community, between about 30 and 60 m depths, had many of the ubiquitous species of the shallow sand community plus deeper-water species such as the sand dollar Echinarachnius parma.

Deep Sand/Gravel Community--This community, also between 30-60 m depths, had many of the ubiquitous species of the shallow sand community, plus gravel-preferring species such as the polychaetes Owenia fusiformes, Eteone longa, Glycera capitata, Megacrenella columbiana and Polygordius sp.

It is likely that infaunal standing stocks are relatively low in the Unimak Pass area. Alton (1974) shows that benthic standing stocks (including epibenthos) are considerably lower in the southeastern Bering Sea in general than they are in the more northerly parts such as the Chirikov Basin. McDonald et al. (1981) show that clam biomass at stations along the northeastern border of the Unimak Pass area are very low (<40 g/m^2 wet weight) compared with that at many southeastern Bering shelf and North Aleutian Shelf stations (some >120 g/m^2). Total infaunal wet-weight distributions show peaks (300-1000 g/m^2) on the middle southeastern Bering shelf, inner Bristol Bay, and North Aleutian shelf; biomass declines drastically as Unimak Pass is approached from the northeast, though no samples from well within the study area have been analyzed (Haflinger 1981).

E. PRIMARY PRODUCTION

by Joe Truett

By far the major proportion of carbon fixation important to animals in the eastern Aleutian Islands area is by phytoplankton (see Goering and Iverson 1981, Schell and Saupe 1986), though eelgrass (McRoy 1968) and benthic algae (O'Clair 1981, Sears and Zimmerman 1977) are locally important in the littoral zone. Because this report focuses on major energy pathways to the fauna, our emphasis is on phytoplankton.

Two aspects of the phytoplankton community--its composition and its rate of carbon fixation (or productivity)--strongly influence the fauna that it supports. Composition is important because grazers of phytoplankton (which are mainly copepods) preferentially consume certain species or species groups, the individuals of which are of an appropriate size (Goering and Iverson 1981, Cooney 1981). Productivity is important because it s annual level is the major determinant of the total biomass of the faunal community and because its seasonality influences the temporal availability of food for higher trophic levels.

The phytoplankton in and near Unimak and adjacent passes includes both oceanic and littoral species. Based on collections made in Unimak Pass (Cupp 1937) and in nearby areas of the southeastern Bering Sea (Oshite and Sharma 1974, Goering and Iverson 1981, Schell and Saupe 1986), it appears that oceanic diatoms probably dominate in the eastern Aleutians in all but extreme nearshore situations. Because large oceanic copepods, which are efficient consumers of these diatoms (Cooney 1981, Goering and Iverson 1981), probably dominate in most deeper waters of the eastern Aleutian Islands study area (see previous section on Invertebrates), the trophic transfer from phytoplankton production to pelagic secondary production is probably fairly efficient (see Cooney 1981).

The annual phytoplankton productivity in Unimak Pass and nearby areas is probably quite large, driven by nutrients upwelled from deep Pacific and Bering Sea waters (see also the following section, "Physical and Chemical Processes"). Though extensive data from within the study area are lacking, the proximity of Unimak Pass to the southeastern Bering Sea shelf break, where nutrients are upwelled and productivity is known to be high (Schell and Saupe 1986, Kinder and Schumacher 1981a), supports this supposition. But because of the spatial heterogeneity in the topography and (by inference) in the circulation and upwelling patterns in the Unimak Pass area, it is likely that phytoplankton production is quite patchy in distribution.

It is also likely that phytoplankton production in the Unimak Pass area has seasonal peaks in late spring and early summer, conforming somewhat to seasonal peaks observed on the adjacent Bering Sea shelf. On the Bering shelf, the annual pattern of light availability and of nutrient supply to the surface controls phytoplankton production levels, generating a major peak in spring and minor ones later in summer. Primary production is low in winter on the shelf because ambient light is limited and the water column is well mixed, thereby reducing the time that phytoplankton are exposed to sufficient light for growth and reproduction (Sambrotto and Goering 1983). It is possible that vertical mixing of water in the Unimak Pass area is even more vigorous and persistent than on the shelf, thus constricting even more the times in spring and summer when physical conditions for primary production are optimum. Conversely, the resupply of nutrients to the photic zone might be greater in the Unimak Pass area, lengthening the period in summer when nutrient conditions are optimum.

Discussion from Schell and Saupe (1986) about the spatial and seasonal nature of primary production levels in Unimak Pass and on the North Aleutian Shelf immediately northeast of the Pass suggest what may happen within the study area:

> "Nutrient supply processes and consequent primary production on the North Aleutian Shelf (NAS) are complex and subject to wide variations in magnitude. The advection of nutrient-rich Pacific deep water onto the shelf in the vicinity of Unimak Pass is followed by intense primary production as the water moves northeastward. Since nitrate supply to the euphotic zone represents the basis for the "new" productivity of each summer season (Dugdale and Goering 1966), we have focused on its supply and consumption in the analysis of our data. ...
>
> "Nitrate concentrations are often as high as 10 mmoles/m^3 in surface water near Unimak Island but biological consumption reduces the concentrations to levels limiting to phytoplankton

growth by midsummer. ...Northeast toward Bristol Bay the water column is much more depleted in nutrients during the spring and fall. Apparently the replenishment of the nitrate may not be as effective toward the northeast over the winter due to the greater cross-shelf distances (from the shelf edge). ...By early April the maximum amount of deep mixing has occurred (on the NAS) and the concentrations of nitrate present in the surface waters are the highest in the annual cycle. ...Assimilation reduces the surface nitrate available to less than 1.0 micromolar by midsummer over the NAS study area. In contrast, a July station in Unimak Pass had surface nitrate concentrations greater than 8 micromolar, indicating effective mixing by through-pass turbulence."

Much of the direct information about primary production levels and seasonal variability in the Unimak Pass study area has to be based on evidence from nearby areas, where sampling related to primary production has been more intensive. But evidence of upwelling of nutrient-rich waters from deep Pacific and Bering Sea basins and associated changes in water chemistry in the study area offer other kinds of evidence about primary productivity in the Unimak Pass area. These phenomena are addressed in the following section "Physical and Chemical Processes".

F. PHYSICAL AND CHEMICAL PROCESSES

by Donald W. Hood

In this section we discuss information on circulation, upwelling, and water chemistry for the Unimak Pass area and vicinity. Characteristics of a large region surrounding the eastern Aleutians are discussed, because what happens in the study area is dependent on these regional characteristics. Place names used in the discussions are illustrated in Figure 4F-1.

Circulation

An analysis of circulation in the eastern Aleutians requires a close look at larger-scale water movement patterns to the south (Gulf of Alaska) and north (Bering Sea), for two reasons. First, oceanographic measurements in the eastern Aleutian Passes are scarce. Second, circulation in the eastern Aleutians is driven largely by water movement in adjacent areas.

Gulf of Alaska. As early as 1890 (Tanner et al. 1890), it was observed that in the northern Gulf of Alaska, the predominantly westward-flowing currents transferred waters into the Bering Sea through the Aleutian Passes (Fig. 4F-2). The Alaska Coastal Current (sometimes called the Kenai Current in its northern parts) has become identified as a coastal flow that originates in the eastern Gulf of Alaska along the shores of British Columbia and extends first northwest to the northern Gulf and then southwest to Unimak Pass (Royer 1979) where, apparently, much of its flow passes into the Bering Sea (Schumacher and Reed 1980, Schumacher et al. 1982). The flow of this current is between 10 and 20 cm/s throughout its length, except near the Kenai Peninsula where it intensifies to as much as 100 cm/s.

The Alaska Stream parallels the Coastal Current in waters off the shelf (Fig. 4F-2). It moves in the same direction at generally higher speeds.

The general distribution of surface salinity in the Alaska Coastal Current and the Alaska Stream is shown in Figure 4F-3. The salinity of

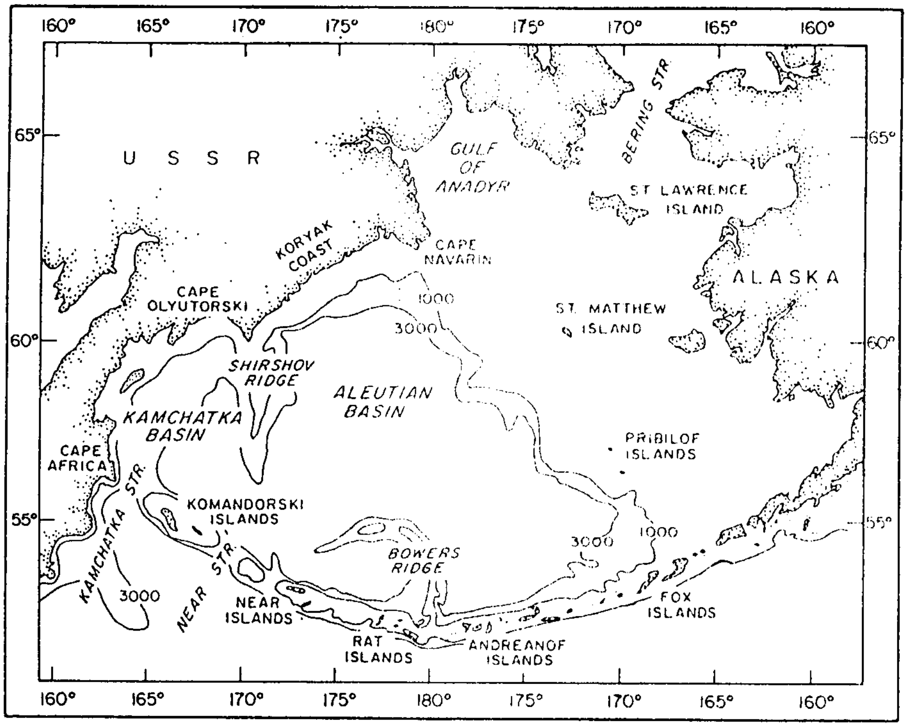


Figure 4F-1. The Bering Sea (depth contours in meters).

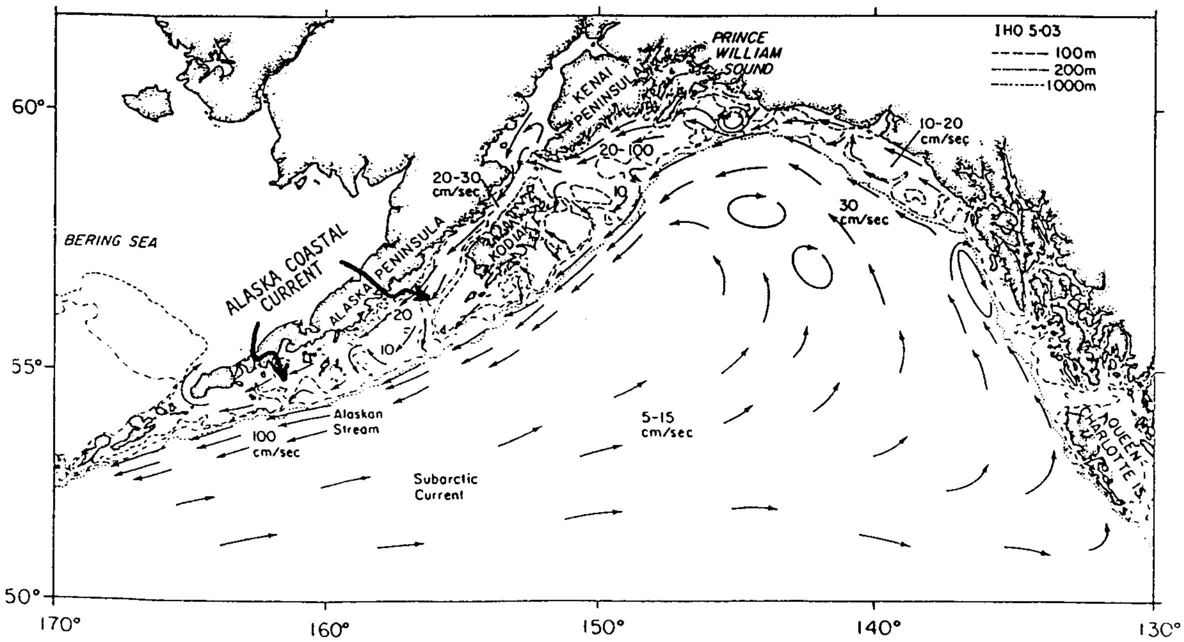


Figure 4F-2. Major currents (speed in cm/sec) in the Gulf of Alaska. The depth contours are in meters from International Hydrographic Chart 5.03. The westward flow on the continental shelf is called the Alaska Coastal Current (from Reed and Schumacher 1986).

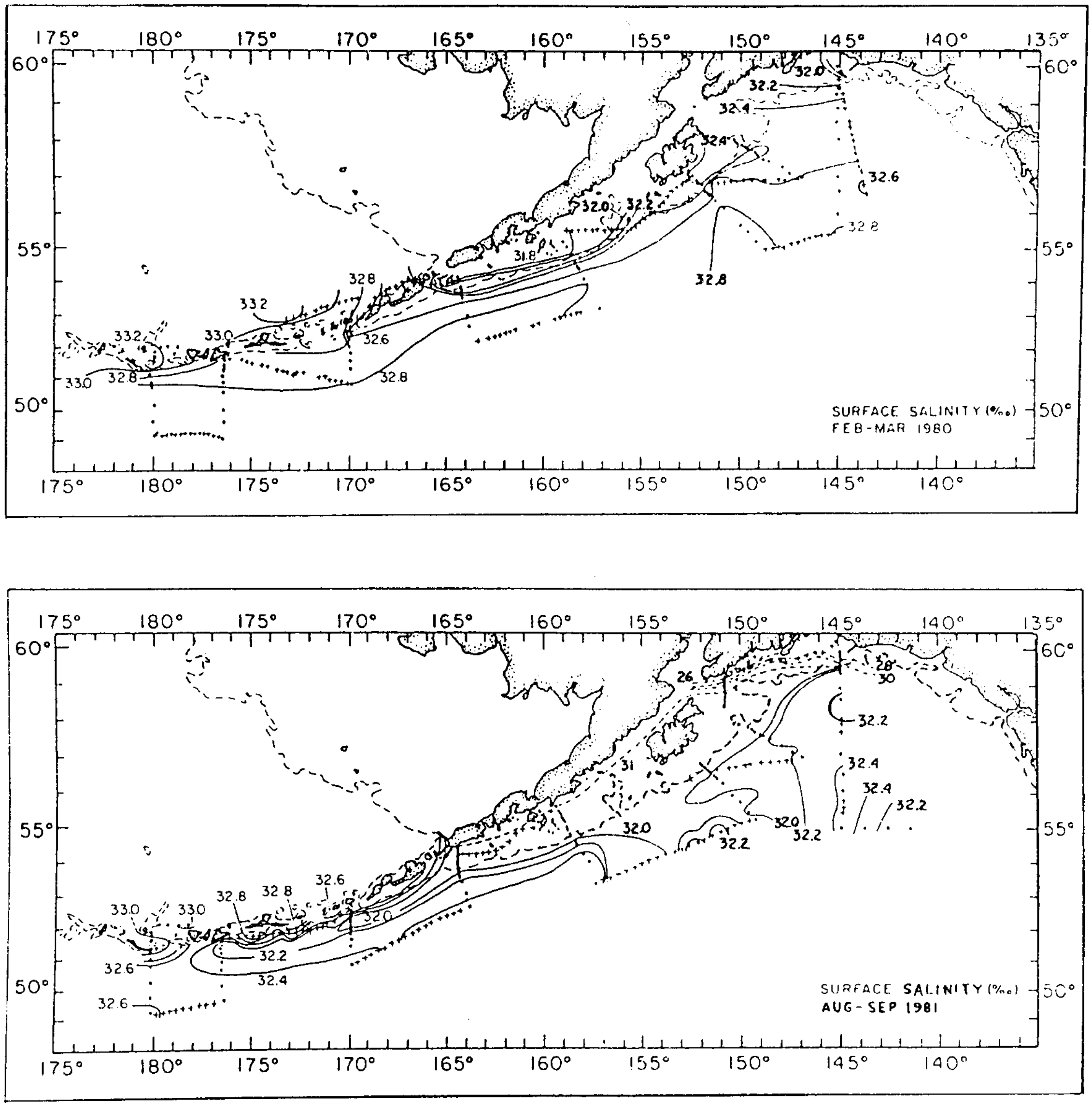


Figure 4F-3. Distribution of surface salinity (°/∘∘) during 9 February to 9 March 1980 and during 25 August to 16 September 1981 (from Reed and Schumacher 1986).

the coastal waters in the eastern portion of the Coastal Current may change as much as 7 parts per thousand (ppt) from winter to summer, but the diluted water of summer (26 ppt) in the eastern portion moderates as it moves westward to near 31 ppt as it reaches Unimak Pass. From the distribution of salinity, Royer (1979, 1981, 1982) concluded that the variations in salinities of the nearshore current around the Gulf of Alaska are largely controlled by freshwater discharge from land.

Flow in the Coastal Current west of Shelikof Strait (between Kodiak Island and the mainland) and through Unimak Pass has been examined by Schumacher et al. (1982). They concluded that fluctuation in flow through Unimak Pass is largely barotropic because of wind-induced sea level changes, but that a net flow into the Bering Sea was present. Further studies of the continuity of the coastal current between 155° and 159°W longitude conducted by Schumacher and Reed (1986) gives evidence for continuity of flow that is highly correlated with upstream stations, and property distributions suggest westward baroclinic flow.

The Alaska Stream is formed in the eastern Gulf of Alaska (where it is called the Alaska Current) as a result of bifurcation of the Subarctic Current (Fig. 4F-2). This feature is the eastern and poleward boundary of the large-scale, counterclockwise rotating subarctic gyre.

Typical distributions of physical properties in the Alaska Stream just south of Unimak Pass are shown in Figure 4F-4. This section shows cold (<4°C), low-salinity (<33 ppt) water near the surface, formed as a result of winter cooling and convection (Dodimead et al. 1963). A zone of relatively warm (>5°C) water underlies the cold, near-surface water. In general, winter surface temperatures decrease from 5-6°C in the head of the Gulf to <3°C near the Aleutian Islands. Surface salinity decreases toward shore to <32 ppt on the shelf in winter.

Isolines of all properties slope down sharply near the continental slope; this is reflected by the maximum computed geostrophic flow of >80 cm/s. Values in excess of 100 cm/s are often found near the Aleutian Islands (Reed 1984). Reed et al. (1980) examined the transport of the Alaska Stream near Kodiak Island and obtained a transport of 12×10^6 m^3/s after adjusting for near bottom depths of less than the reference level of 1500 m. Some temporal variations in transport were observed that were not correlated with seasonal variations in wind-stress and it was concluded

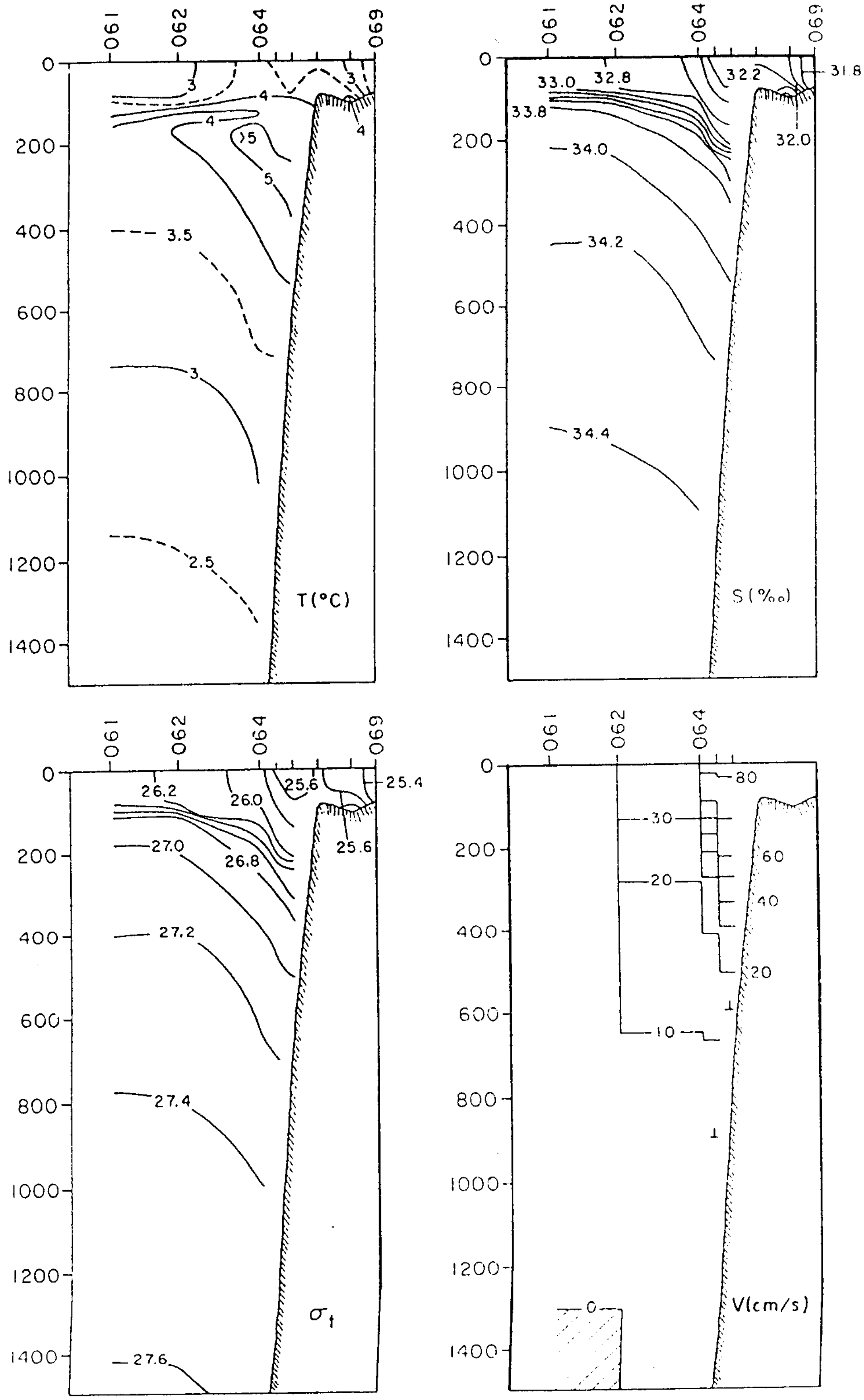


Figure 4F-4. Vertical sections of temperature (C), salinity (ppt), Sigma t density, and geostrophic flow (cm/sec, referred to 1500 db) across the Alaska Stream at approximately 164° W, 24-25 February 1980 (from Reed and Schumacher 1986).

that seasonal variation of the Alaska Stream does not exist. In Figure 4F-5 the geopotential topography for both February-March 1980, and August-September 1981 show westward flow from the eastern Gulf to the Western Aleutian Islands but the relief across the flow, and thus the transport, is much less for the 1981 conditions. The flow in 1981 in the eastern Gulf was about 6×10^6 m^3/s, but west of 165°W was up to 12×10^6 m^3/s. This disrupted inflow is not a normal seasonal occurrence as discussed by Dodimead et al. (1963) and Favorite et al. (1976).

Bering Sea and Aleutian Passes. The development of a circulation scheme for the Bering Sea has evolved over many years and has resulted in many changes from the circulation patterns originally envisioned. An early chart by Ratmanov (1937), based on dynamic height calculations showed some transport of the Alaska Stream through Unimak Pass into the Bering Sea, but showed the major flow to be through Near Strait in the western Aleutians (see Fig. 4F-1). In 1938 the U.S. Hydrographic Office prepared a chart, presumably based on direct and indirect techniques, that indicated current speeds of 0.1 to 0.5 knots through Unimak Pass. Flow was indicated through all the Aleutian passes, but with the major transfer in the passes farther west.

Natarov (1963) considered it erroneous that Near Strait or other western passes admitted the bulk of Pacific Ocean water. He claimed that the main inflow took place through numerous eastern passes, though a constant flow through the eastern portion of Near Strait was recognized. Arsen'ev (1967) supported the idea of the main inflow through eastern Near Strait, but envisioned little inflow through Unimak Pass, a major inflow at Samalga Pass in the Fox Islands, and a number of permanent gyres throughout the Bering Sea.

The discussion by Dobrovol'skii and Arsen'ev (1959) of the main currents within the sea was a departure from earlier ideas. Rather than showing the main currents crossing over the deep Bering Sea basin from Near Strait to St. Matthew Island as in other schemes, these workers thought currents moved easterly along the north side of the Aleutian arc. North of the Adreanof Islands the flow supposedly turned north and then northwest, paralleling the continental slope. Natarov, because of his conclusions about flow through Near Strait, did not show the eastern flow,

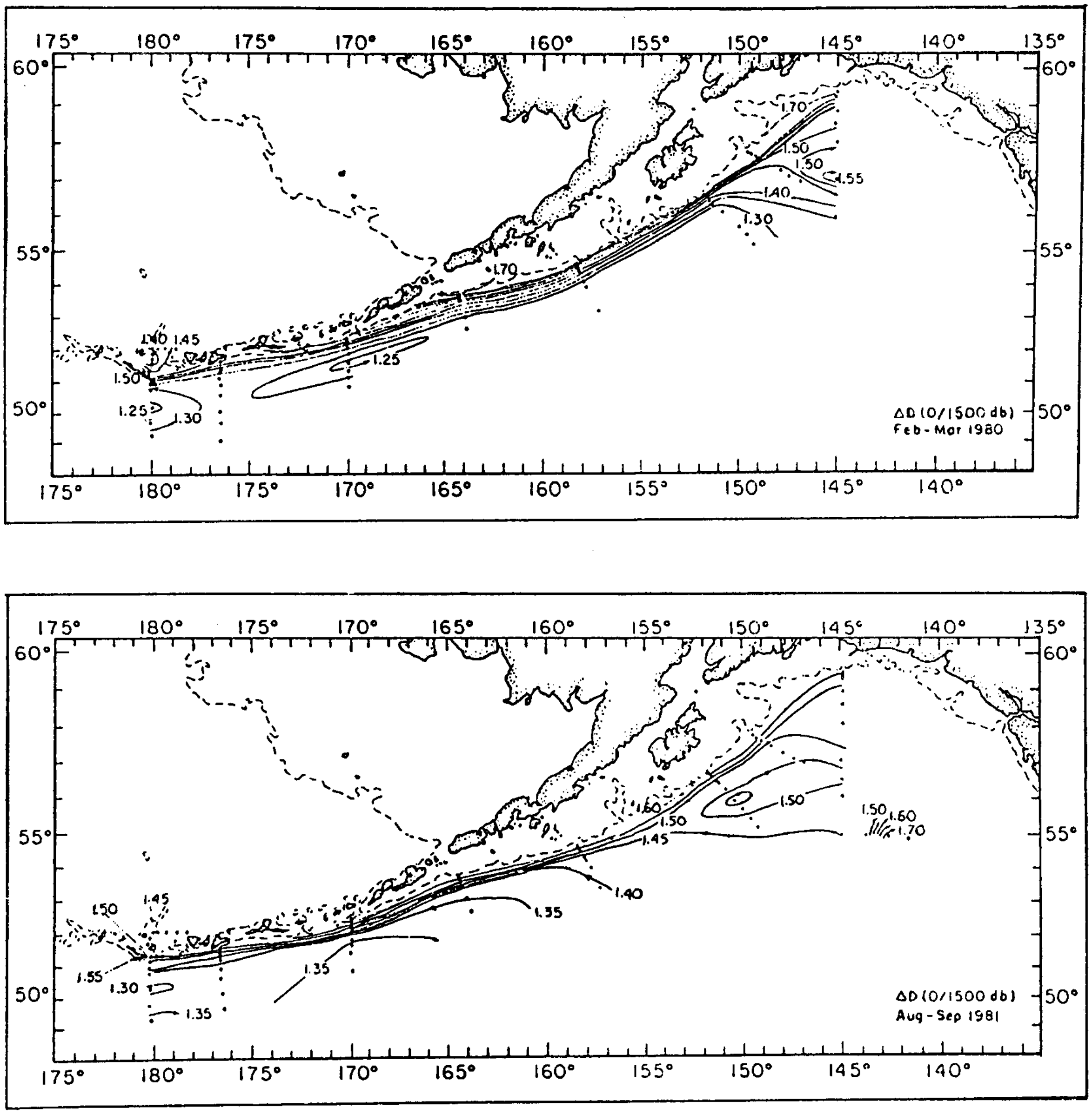


Figure 4F-5. Geopotential topography of the sea surface, referred to 1500 db, 11 February to 3 March 1980 and 25 August to 16 September 1981 (from Reed and Schumacher 1986).

but did show the northern flow along the continental slope originating from transport through the eastern Aleutian passes.

Favorite (1974) summarized the hypothesized flow through the Aleutian passes based on data available to that time. Of 39 openings through the arc only 14 have an area greater than 1 km^2 or sill depth of at least 200 m (Table 4F-1). The passes have been classified into three groups in addition to the Near and and Kamchatka straits. These five classifications constitute 99.9% of the area penetrating the island arc; not included are Unimak and Unalga passes (the most eastern) with sill depths of less than 100 m.

Reed (1971) analyzed 25 surface tidal flow records from buoys anchored in various passes for intervals of over four days during the period 1949 to 1956 and observed both northerly and southerly net flows through all passes. These studies dispelled the idea that all flow through the passes was northerly, but gave little information on the character or origin of the water constituting the flow.

In the mid-1970's two schemes for circulation through the passes and in the Bering Sea appeared in the literature (Takenouti and Ohtani 1974, Favorite et al. 1976). Shortly thereafter, results from the intensive oceanographic studies undertaken on the eastern Bering Sea shelf by OCSEAP and by the PROBES program of the National Science Foundation corrected some of the erroneous concepts of these mid-70's publications, which had been put together with many fewer data available.

The most recent, and undoubtedly the most realistic, scheme for circulation for the eastern Bering Sea relies heavily on OCSEAP and PROBES studies (Fig. 4F-6; see also Coachman 1986). The results of these studies show a rather sluggish net circulation over the central shelf between the 50- and 100-m contours (<1 cm/s); a flow of 2 to 5 cm/s for the coastal domain, shoreward of 50 m; a flow of 1 to 5 cm/s in the outer domain; and a persistent current of 5 to 10 cm/s along the shelf break. Direct current measurements made in the southeastern Bering Sea (Fig. 4F-7), show a mean flow through Unimak Pass 10 m above bottom of about 6 cm/s northwestward. Most of the kinetic energy appears to be dominated by tides (Pearson et al. 1980). Weak subtidal flows, large tidal flows, and surface wind mixing cause highly vigorous vertical mixing.

Table 4F-1. Depth and area of the major openings in the Aleutian-Commander Island arc (Favorite 1974).

General opening	Pass/Strait	Depth (m)	Area (km^2)	
East Aleutian Group	Samalga	200	3.9	
	Chuginadak	210	1.0	
	Herbert	275	4.8	
	Yunaska	457	6.6	
	Amukta	430	19.3	
	Seguam	165	2.1	37.7
Central Aleutian Group	Tanaga	235	3.6	
	Amchitka	1155	45.7	49.3
West Aleutian Group	Kiska	110	6.8	
	Buldir	640	28.0	
	Semichi	105	1.7	36.5
Commander-Near Strait	Near	2000	239.0	
	Commander	105	3.5	242.5
Kamchatka Strait		4420		335.3
			Total area	701.3

Table 4F-2. Flow (Sv) through Aleutian-Commander Island arc according to Arsen'ev (1967).

Pass	Transport Out	Transport In
Kamchatka	21.0[a]	2.6[b]
Commander-Near	--	14.4
Western Aleutian Group	--	0.7
Central Aleutian Group	--	4.4
Total	21.0	22.1[c]

[a] Above 3000 m.

[b] Below 3000 m.

[c] Loss through Bering Strait = 1.1; total transport east of Commander Islands = 19.5.

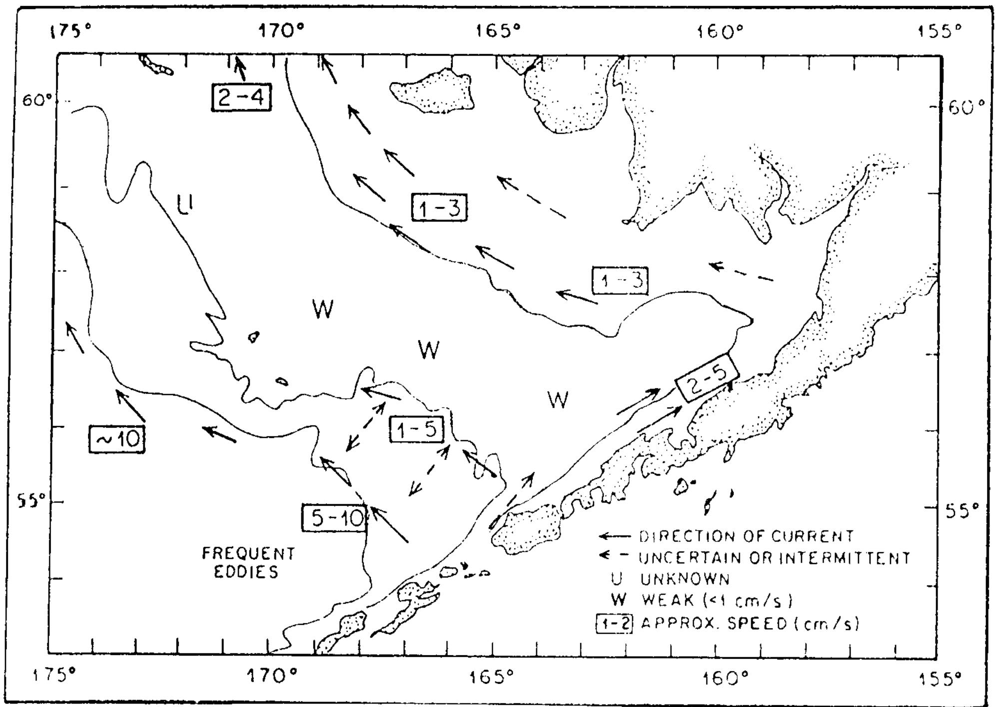


Figure 4F-6. Estimated longer-term circulation of the eastern Bering Sea. Flow over the shelf is mostly tidal, so that instantaneous flow is quite different from that depicted. However, it is this flow which affects the net advective transport of properties (adapted from Kinder and Schumacher 1981b).

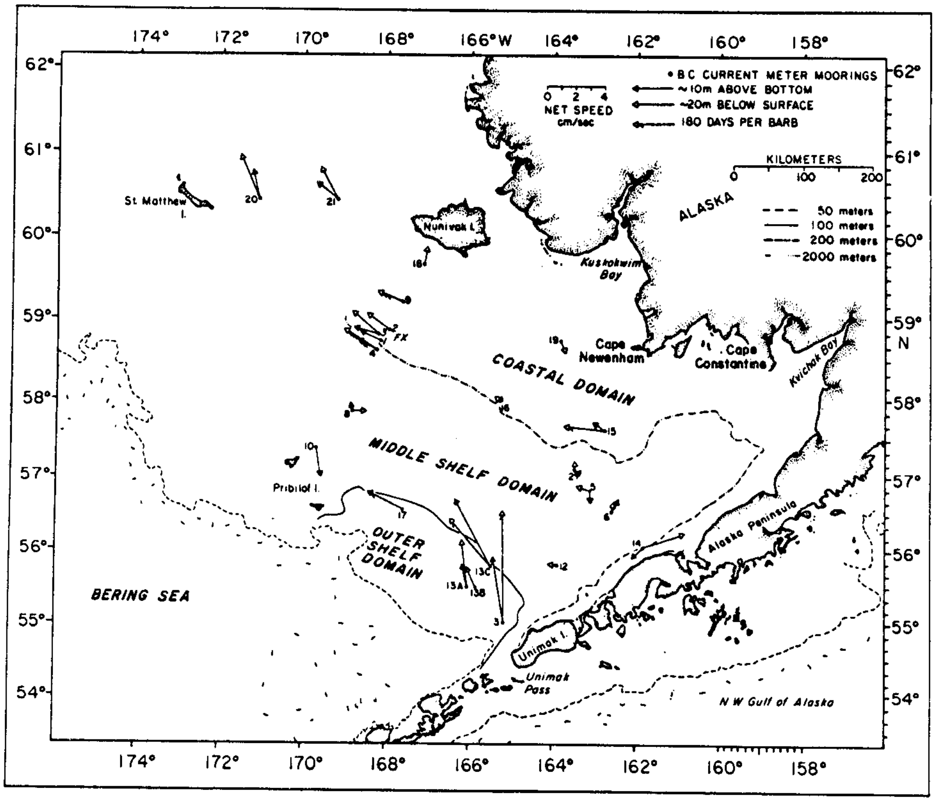


Figure 4F-7. Mean flow based on all records at each mooring site in the southeastern Bering Sea (from Kinder and Schumacher 1981b).

Schumacher et al. (1982) summarized the available data on exchange of water through Unimak Pass and concluded that most of the Alaska Coastal Current moved through the pass. A summary of the data obtained (Fig. 4F-8 indicates that water of salinity less than 31.75 ppt dominates the surface regime on the eastern side of Unimak Pass. This low salinity water has the same characteristics as the Alaska Coastal Current and appears to represent most of the flow of this current since water with these characteristics is not found west of Unimak Pass on the Gulf of Alaska side of the Aleutians.

Results of the only filtered current data available for the pass are shown in Figure 4F-9; station locations are shown in Fig. 4F-10. In the Bering Sea (Station UP1) about 50% of the vectors were in the northwest quadrat with a mean speed of about 15 cm/s. There were, however, pulses toward the south with magnitudes of 15-20 cm/s. Currents at UP2 tended to parallel the isobaths in the pass, and about 75% of the observations indicated flow from the Gulf of Alaska into the Bering Sea. On the Gulf shelf at UP3, flow was highly variable in direction with a slight westward tendency. The progressive vector diagrams show much greater flow during the first half of the observation period than during the second half.

Analysis of the atmospheric pressure gradient during the period showed that, although the direction of the principal axis remained constant, the magnitude increased by a factor of 2 during the second half of the observation period. A dramatic change also occurred in winds--the alongshore magnitude increased from -1.7 m/s in the first period to -3.5 m/s in the later period. This change caused a four-fold increase in wind stress and enhanced coastal divergence along the southern side of the Alaska Peninsula. The high pressure system over the Gulf of Alaska is a summertime feature (Bowers et al. 1977) and influences that component of the currents that is meteorologically forced.

The most recent circulation study of Unimak Pass was that of Nof and Im (1985) who used Unimak Pass in theoretical considerations of suction through broad ocean passes. The problem involved a model of two unbounded basins separated by an infinitely long wall which contains a gap, i.e., Unimak Pass. The wall on the left (west) side of Unimak Pass is represented by the Aleutian Islands and that on the right (east) is the Alaska Peninsula. The inner basin (Gulf of Alaska) contains two layers of

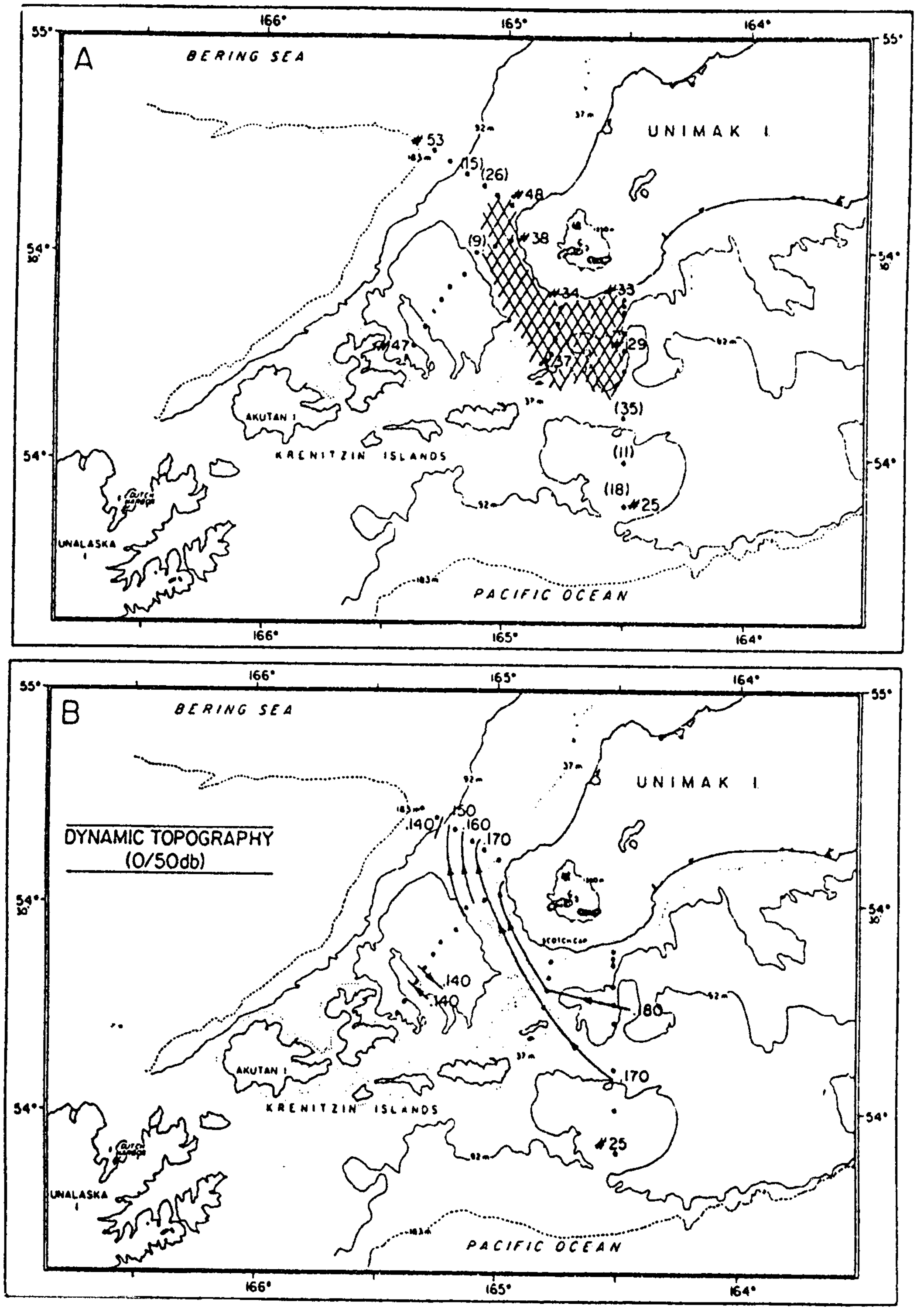


Figure 4F-8. Hydrographic data for Unimak Pass, September 1981, presented as (a) areal extent of waters with salinity ≦ 31.75 m/kg in the upper 50 m (or bottom) where the numbers in parentheses are depths of the low salinity bank for $\underline{z}$ < 50 m, and (b) dynamic topography (0/50 db) with a 0.01 dyn m contour interval. CTD station numbers are indicated by the number sign (#) (from Pearson et al. 1980).

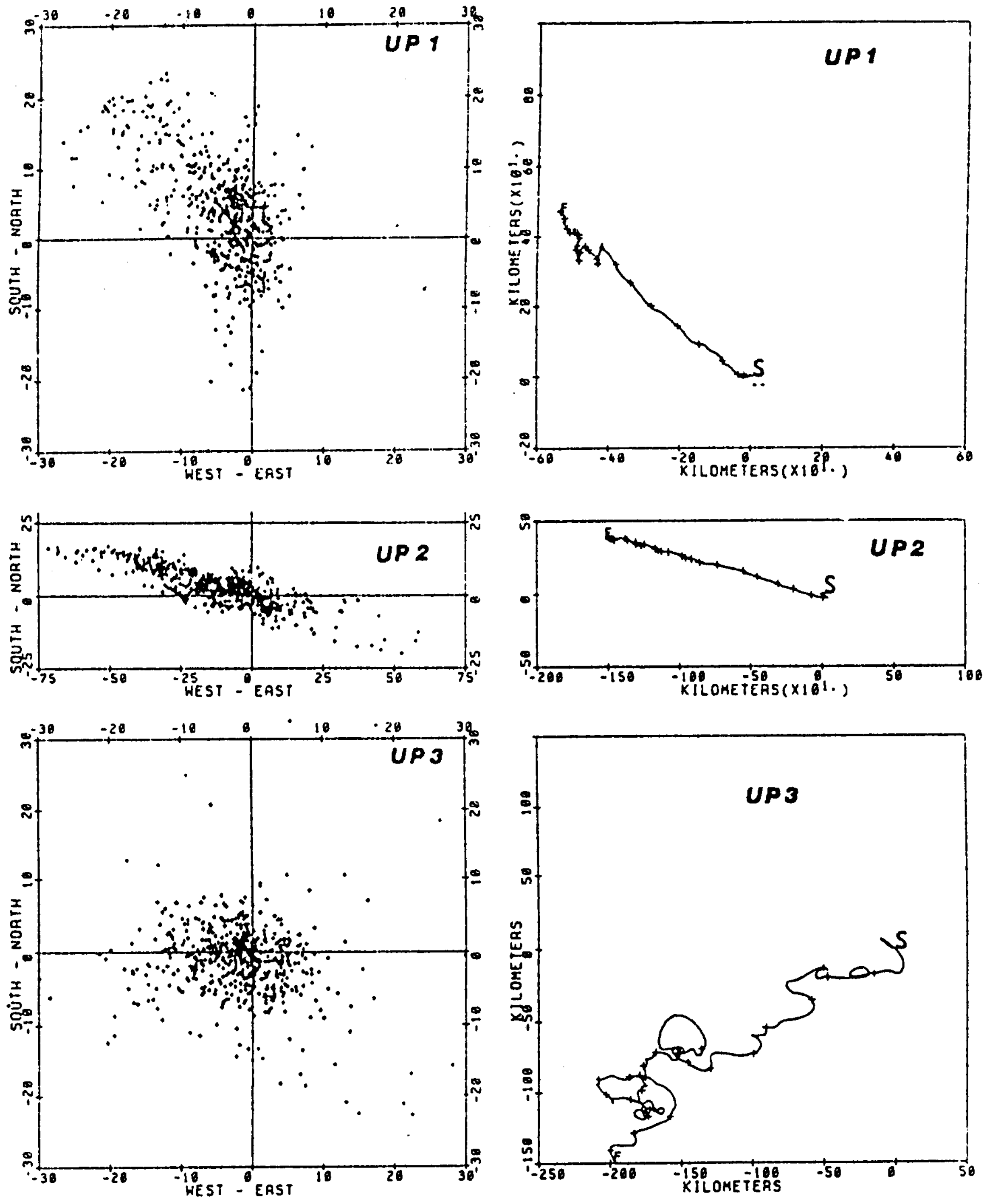


Figure 4F-9. Results from 35-hour filtered current data from Unimak Pass presented as scatter plots and progressive vector diagrams (S represents start of the record, and crosses are at 5-day intervals). Note the different speed and length scales (from Schumacher et al. 1982).

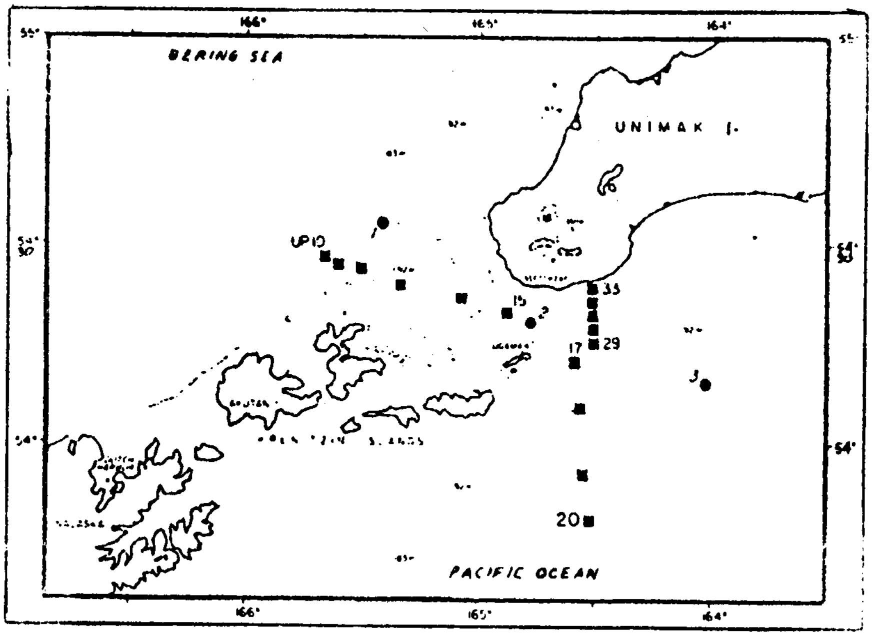


Figure 4F-10. Location of stations in Unimak Pass for data collection in Figure 4F-8 and current meter stations in Figure 4F-9 (from Schumacher et al. 1982).

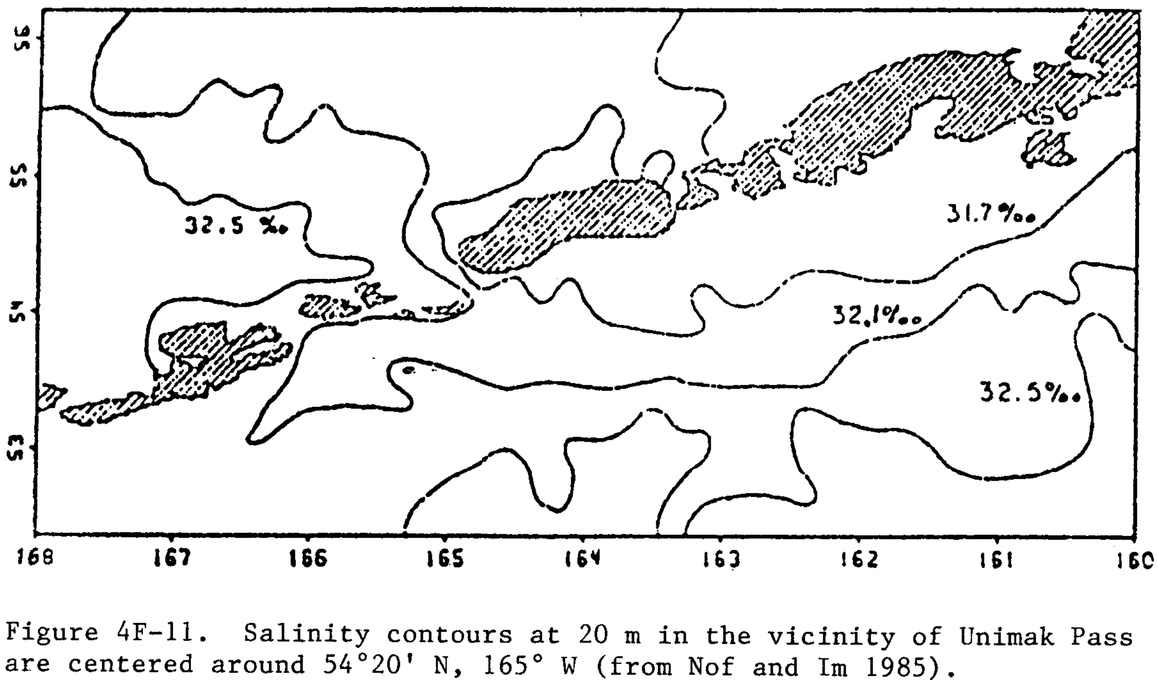


Figure 4F-11. Salinity contours at 20 m in the vicinity of Unimak Pass are centered around 54°20' N, 165° W (from Nof and Im 1985).

which only the surface layer is active; the outer basin (Bering Sea) contains, initially, a single motionless layer.

In the initial state of the problem, the two basins were separated by a gate extending from the free surface to the interface. The current in the inner basin was flowing so that the gate is on the right-hand side of the current. The purpose of this exercise was to determine the steady flow that would exist after the gate was removed and the initial period of adjustment had been reached.

The conditions of the model are met in the Unimak Pass area, which was used for testing the model. The pass has an average depth of about 55 m and at its narrowest point it is about 20 km wide. The Alaska Coastal Current approaches the pass from the east as a separated current, i.e., the isohalines intersect the surface. Schumacher et al. (1982) estimate that, at this location (Fig. 4F-8) the average transport can be up to about 0.25×10^6 m^3/s. The density difference between the upper portion of the water-column and the deep water is roughly 2% and the upper layer depth is approximately 60 m. Using a Coriolis parameter of 1.2×10^{-4} m^3/s, a deformation radius of about 10 km is calculated. With these conditions supplied to the model, the solution gives a geostrophic transport of about 30×10^4 m^3/s (1/3 Sverdrup) or about the same value as estimated by Schumacher et al. (1982).

According to the model all the water of the Alaska Coastal Current should flow through Unimak Pass and make a sharp U-turn to form a similar current flowing northeast along the Alaska Peninsula. In order to answer the question of which water approaches the pass, which water leaks to the Bering Sea, and whether any Alaska Coastal Current water continues to flow along the south side of the Aleutians, Nof and Im analyzed all the salinity data available for the period 1929-1974 (total of 1347 stations) (Fig. 4F-11). It is of interest that water of like salinity appears on both sides of the Alaska Peninsula east of Unimak Pass. The model predicts that a separated boundary current encountering a broad gap on it's right-hand side is sucked in its entirety into the adjacent basin no matter how wide the gap; such a current flowing along a wall with a series of broad gaps will enter only the first gap. No current will be present downstream, resulting in no exchange through the remaining gaps. When the model is applied to Unimak Pass it shows the Alaska Coastal Current flowing through the Pass and then moving northeast along the Bering Sea side of the Alaska Peninsula.

There is some support in the literature for a northeastward flow on the Bering side of the peninsula (Takenouti and Ohtani 1974, Schumacher et al. 1982, Schumacher and Kinder 1983), but not for a continuous flow of the magnitude of the Alaska Coastal Current (Schumacher and Kinder 1983). Kinder and Schumacher (1981) estimated the long-term circulation for the Bering Sea shelf, including that of the Coastal Domain (inside about the 50-m depth contour), and found a net flow of 2-5 cm/s along the 50-m isobath north of the peninsula. Depending on weather and tides, this flow, however, occasionally reversed itself to flow in the southwest direction.

The waters of the farther offshore Alaska Stream do not appear to penetrate the most eastern Aleutian Passes, but instead flow mainly through Near Strait and return to the North Pacific Ocean through Kamchatka Strait (see Fig. 4F-1) (Hughes et al. 1974; Favorite 1974). Arsen'ev's (1967) excellent treatment of oceanographic conditions in the Bering Sea summarized the available data to that time (Table 4F-2). Except for a deep flow, almost the entire flow into the Bering Sea through Kamchatka Pass is from the Alaska Stream.

From the Central Aleutian group of islands east to Unimak Pass, the presently accepted schemes of surface circulation show a current flowing eastward on the north side of the Aleutian Islands in the Bering Sea. The major component of this current turns northward near the eastern Bering Sea shelf break to form the Shelf Break Current (Kinder and Schumacher 1981). It is this current system that has considerable influence on the characteristics of water immediately north and west of Unimak Pass. Takenouti and Ohtani (1974), in their now classic treatment of the water masses of the Bering Sea, indicate the presence of Alaska Stream type water along the north side of the Aleutian Islands including the area north of Unimak Pass. This water is characterized by having homogeneous temperatures between 4 and 5°C down to 100-m depths and homogeneous salinities of about 32.9 ppt to the same depths.

Variability in Flow

Seasonal variability in flow through Unimak Pass is highly influenced by the passage of storm systems along the Aleutian storm track. A detailed treatment of the meteorology of the Gulf of Alaska, which also applies to the southeast Bering Sea, appears in "The Gulf of Alaska" book soon to be published (Wilson and Overland 1986). Because of space limitations only a brief summary of those features of the meteorological system that influences flow through Unimak Pass are presented here.

Through the year, offshore winds are predominately from the south in the eastern Gulf, from the east in the north-central region, and from the west, but highly variable, near the Aleutian Islands, with the intensity being greatest in the winter-season months of October through April. The meteorology and, thus, the wind system is dominated by the passage of storms characterized by low-sea-level pressure and associated cold fronts. During winter there is an average of one storm every four or five days that crosses the Bering Sea and the Gulf generally from west to east. These storms are associated with winds of up to 40 m/sec, nearly continuous cloud cover, and warm moist air ahead of cold fronts. These fronts are intercepted by high mountain ranges in the coastal areas of the Gulf where as much as 8 m of precipitation may occur annually. The runoff from the high rainfall areas in the eastern and central Gulf feeds the Alaskan Coastal Current that eventually constitutes the main flow of Gulf of Alaska water through Unimak Pass into the Bering Sea.

Unimak Pass weather is dominated by the Aleutian low pressure region, which is caused by the passage of intense storms through this area more frequently than almost any place else on earth. This low is a statistically low pressure area in the sense that monthly averaged sea-level pressures along the Aleutian chain are lower than in the surrounding areas. The Aleutian low is the dominant influence on the Gulf of Alaska weather throughout the year, occurring 25% of the time. A monthly-mean 80 year average gives the position of the Aleutian low at 56°N and 168°W with an average central pressure of 1002 mb (Angell and Korshover 1982). This center is approximately 140 nm northwest of Unimak Pass.

The effect of these weather systems on flow through Unimak Pass is largely dependent on differences in water level across the Pass. This in turn is heavily influenced by the direction of the wind field. In an idealized situation the geostrophic winds are caused by a balance between the force of a sea level pressure gradient and the Coriolis force. Surface winds over the ocean are typically 80% of the magnitude of the geostrophic wind and are oriented approximately 20 degrees to the left of the geostrophic wind direction owing to the influence of surface friction. The winds ahead of the cold front are from the south. The winds behind the cold front are northeasterly, and the winds north of the low and ahead of the warm front are northeasterly and easterly. Thus the passage of a low across the Aleutians in the vicinity of Unimak Pass would tend to increase flow into the Bering Sea as the front moves through (due to the easterly and southerly winds), and tend to reverse, or relax, the flow as the storm passes. Since the dominant winds along the Alaska Peninsula associated with the movement of a storm from west to east is easterly, the surface waters south of the Peninsula tend to converge on the coast, causing downwelling of the surface water. But on the Bering Sea side, the coastal waters tend to diverge, causing upwelling. This is the dominant winter regime (October through April).

During summer the low-pressure systems are weaker and tend to migrate farther north owing to decreased differences in temperature between the equator and the pole. The oceanic region is cooler than the adjacent land masses and a large high pressure system is established over the Gulf of Alaska. This east Pacific high-pressure system is present throughout the year off the California and Baja California coasts. It reaches maximum intensity and northward position in June through August when it dominates almost the entire North Pacific. Its 80-year average position is 35°N, 143°W with an average central pressure of 1024 mb (Angell and Korshover 1982). This high pressure system causes a periodic shift in wind patterns from easterly to westerly during summer months, causing divergence of coastal water along the southern Alaska Peninsula, resulting in limited coastal upwelling in this region.

Variability in flow through Unimak Pass is partially controlled by a very complicated weather system dominated by the position and intensity of the Aleutian low. The relative positions of the Siberian high and the Aleutian low have been correlated with variability in air temperature and precipitation over North America, with sea-surface temperature in the Gulf of Alaska, and with Bering Sea ice cover. An intense Aleutian low is associated with relatively high sea-surface temperatures and high sea level in coastal areas in the eastern Gulf of Alaska.

In an interpretation of the atmospheric pressure gradient, geostrophic wind, and CTD (salinity, temperature and depth data in the water column) Schumacher et al. (1982) have reached the conclusion that mean flow was from the Gulf of Alaska shelf westward through Unimak Pass, and reversals occurred in 18% of the spring and 31% of the summer observations, with mean flow in the spring three times greater than in the summer. Currents at periods between 3 and 10 days in Unimak Pass were highly coherent with bottom pressure difference, which provided the dominant forcing for fluctuations. Most of the water level differences were due to alongshore winds along the Gulf of Alaska coast. Longer period flow and variability were accounted for by fluctuations in the Alaska Coastal Current.

Upwelling

In 1966 Dugdale and Goering (1967) observed a high nutrient content in waters near Unimak Pass and suggested that this was caused by deeper Pacific Ocean water passing over the shallow sill of Unimak Pass and effecting vertical transport, a form of upwelling. This phenomenon was subsequently investigated by Kelley et al. (1971) who measured the partial pressure of CO_2 in the surface waters to detect and map areas of upwelling.

This CO_2 technique is based on dynamics of change in the carbon dioxide system in surface ocean waters brought on by utilization and recycling of carbon dioxide in the biological community. Utilization by phytoplankton during periods of primary productivity and deposition of calcareous shells by animals lowers the partial pressure of CO_2 below that of the overlying air mass, thus causing a depression in pCO_2 values in waters not subjected to vertical mixing. Recycling of organic carbon (or dissolution of calcium carbonate) occurs at all depths in the water-column and increases the partial pressure of CO_2. Decomposition of organic matter produces not only CO_2, but also nutrient salts, including ammonium and phosphate ions. In the euphotic zone these are quickly utilized again by photosynthesizing plants, thus recapturing an equivalent amount of CO_2.

However, in deeper water where photosynthesis does not occur, the inorganic materials produced by recycling accumulate. The amounts produced depend on the characteristics of the biological community and the oceanographic characteristics of the water-column.

If these deeper waters are brought to the surface, they are supersaturated in CO_2 with respect to air, rich in inorganic nitrogen and phosphorus, and usually colder and more saline than the surrounding surface water. Any of these parameters are useful signatures of deep water and can be used to detect vertical advection or upwelling. Because of the very large signal in the CO_2 system between surface waters (values as low as 125 microatmospheres) and deeper waters (values up to 600 microatmospheres), measurement of the surface value of pCO_2 is probably the most sensitive and satisfactory method available to oceanographers for mapping upwelling in high latitudes where the conventional sea-surface-temperature method is less sensitive.

Some of the first data utilizing the pCO_2 technique for mapping upwelling were obtained by Kelley et al. (1971) along the eastern Aleutian Islands (Fig. 4F-12). Unimak, Samalga, and Amukta passes were studied in detail. Unimak Pass (maximum sill depth of 55 m) is shallow and is also unique among all the Aleutian Island passes in that it opens on the north directly onto the shallow shelf of the eastern Bering Sea. Samalga and Amukta passes are of intermediate depth (maximum sill depth of 185 and 455 m, respectfully) and open into the deeper water of the southeast Bering Sea. These passes showed major differences in pCO_2 values. During June and September, Unimak Pass waters were undersaturated in CO_2 with respect to air, in contrast to high supersaturated values at Samalga and Amukta passes to the west. The low values at Unimak Pass are interpreted to be caused by primary productivity in the surface waters. The high values near Samalga and Amukta passes are interpreted as resulting from upwelling of Gulf of Alaska water as it flows through the relatively shallow passes.

Further detailed studies of Samalga Pass were carried out by Kelley and Hood (1974), Hood and Kelley (1976), and Swift and Aagaard (1976). An interesting set of data obtained in 1972 (Fig. 4F-13) shows the surface pCO_2 values with respect to air for the region southwest of the Alaska Peninsula and near the eastern Aleutian Islands. Evidence for upwelling based on these data occurs only near the Krenitzen Islands and Samalga

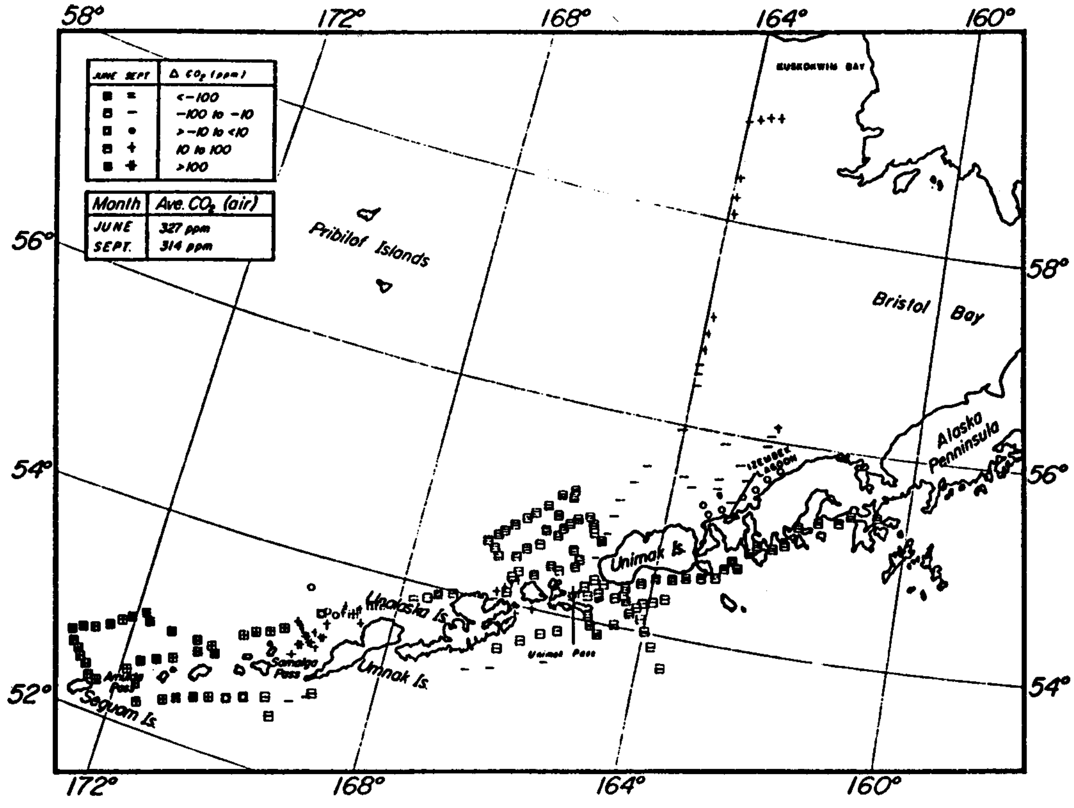


Figure 4F-12. Relative carbon dioxide partial pressures between air and water in the vicinity of the Aleutian Island passes (from Kelley et al. 1971).

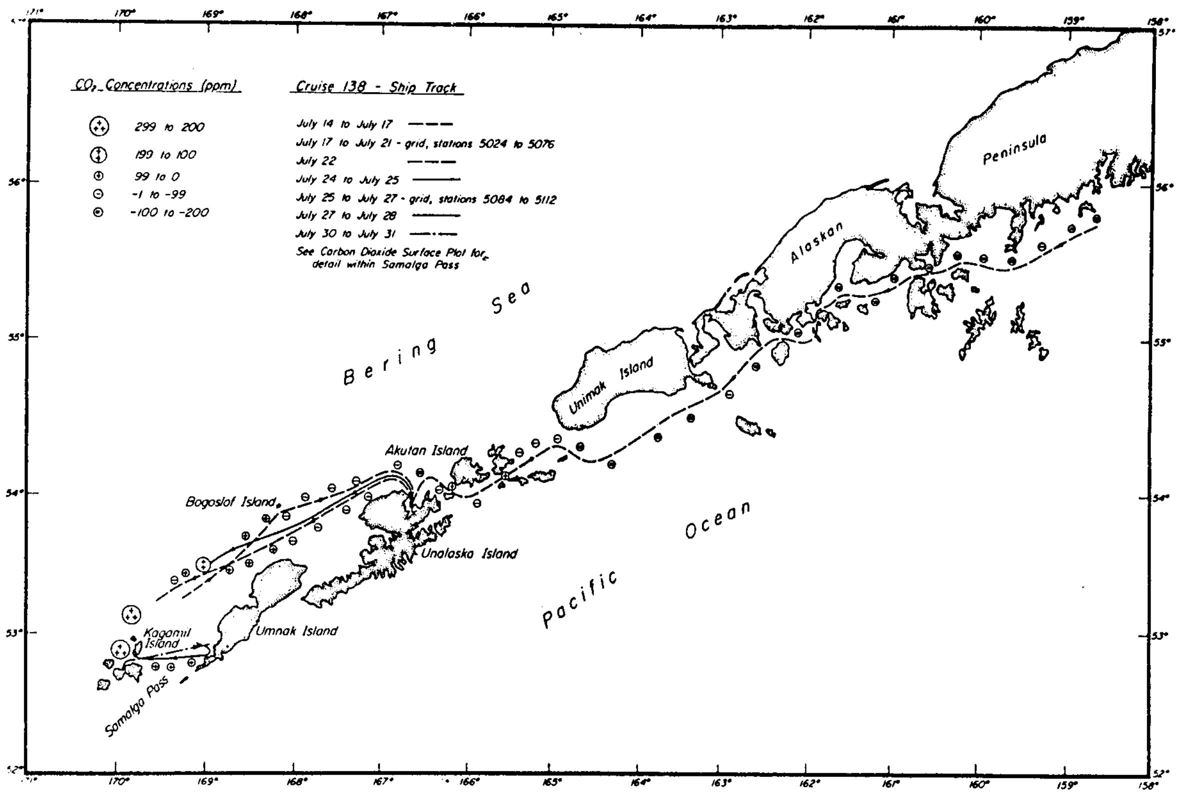


Figure 4F-13. The pCO_2 values relative to air for southwest Alaska Peninsula and eastern Aleutian Islands showing cruise tracks to Samalga Pass (from Kelley and Hood 1974).

Pass. The values among the Krenitzen Islands are only slightly positive and due to tidal mixing, but the values near Samalga Pass (Fig. 4F-14) are so large that this water could only be derived from 150- to 200-m depths. Hood and Kelley (1976) used CO_2 exchange rates through the sea surface to calculate the rate of vertical transport of deep water to the surface. They estimated a vertical flow rate of 3.1×10^{-3} cm/s which would deliver 4.8×10^6 grams of nitrate nitrogen per square kilometer/day to the surface in the region shown in Figure 4F-15.

Using oxygen depletion in the surface waters (Fig. 4F-16) as an indicator of deep water (oxygen tends to have a reverse correlation with CO_2), Swift and Aagaard (1976) studied the rate and mechanism of upwelling in the Samalga Pass area. They estimated an upper-limit vertical transport of 7×10^{-3} cm/s and concluded that this upwelling is driven from beneath by subsurface converging currents, probably related to the bottom topography.

It is well established that upwelling does occur near Samalga Pass; there are less definitive data for Amutka, Sequam and Atka passes (Kelley and Hood 1974, Swift and Aagaard 1976), but Swift and Aagaard (1976) indicate that upwelling occurs in these latter passes also. The extent of upwelling along the north side of the Aleutian Island chain, while not fully quantified, appears to be sufficient to support a rich biological community to the east of the sites of upwelling. Whether all of the upwelled water remains at the surface or, because of it s higher density, sinks beneath the water coming from the west is not clear. There is, however, sufficient biological evidence to suggest that the region west of Unimak Island, including Unimak Pass, harbors an upwelling-supported community (R.C. Dugdale, Univ. of Southern California, pers. comm.).

Chemistry

Little information on the chemical composition of waters in the vicinity of Unimak Pass--other than salinity, temperature, and limited oxygen values--is available for periods before three decades ago. Since then, nutrient dynamics has been the main focus of investigations, but this region has also had extensive studies of the carbon dioxide system,

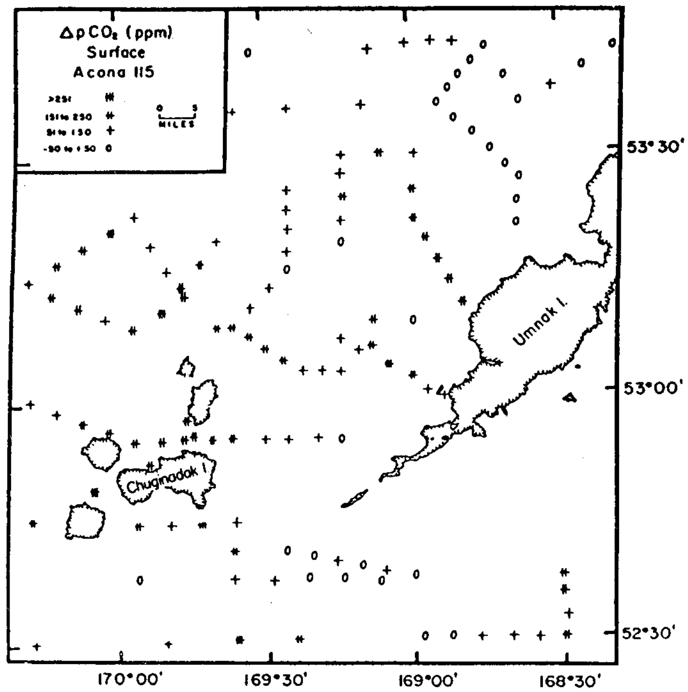


Figure 4F-14. Relative pCO_2 values with respect to air in the vicinity of Samalga Pass, July 1971 (from Kelley and Hood 1974).

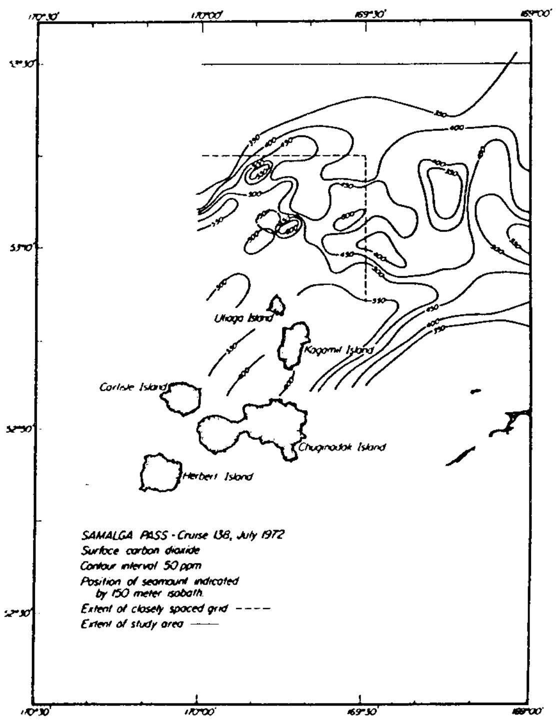


Figure 4F-15. The equilibrium concentration of CO_2 north of Samalga Pass and the Islands of Four Mountains (from Kelley and Hood 1974).

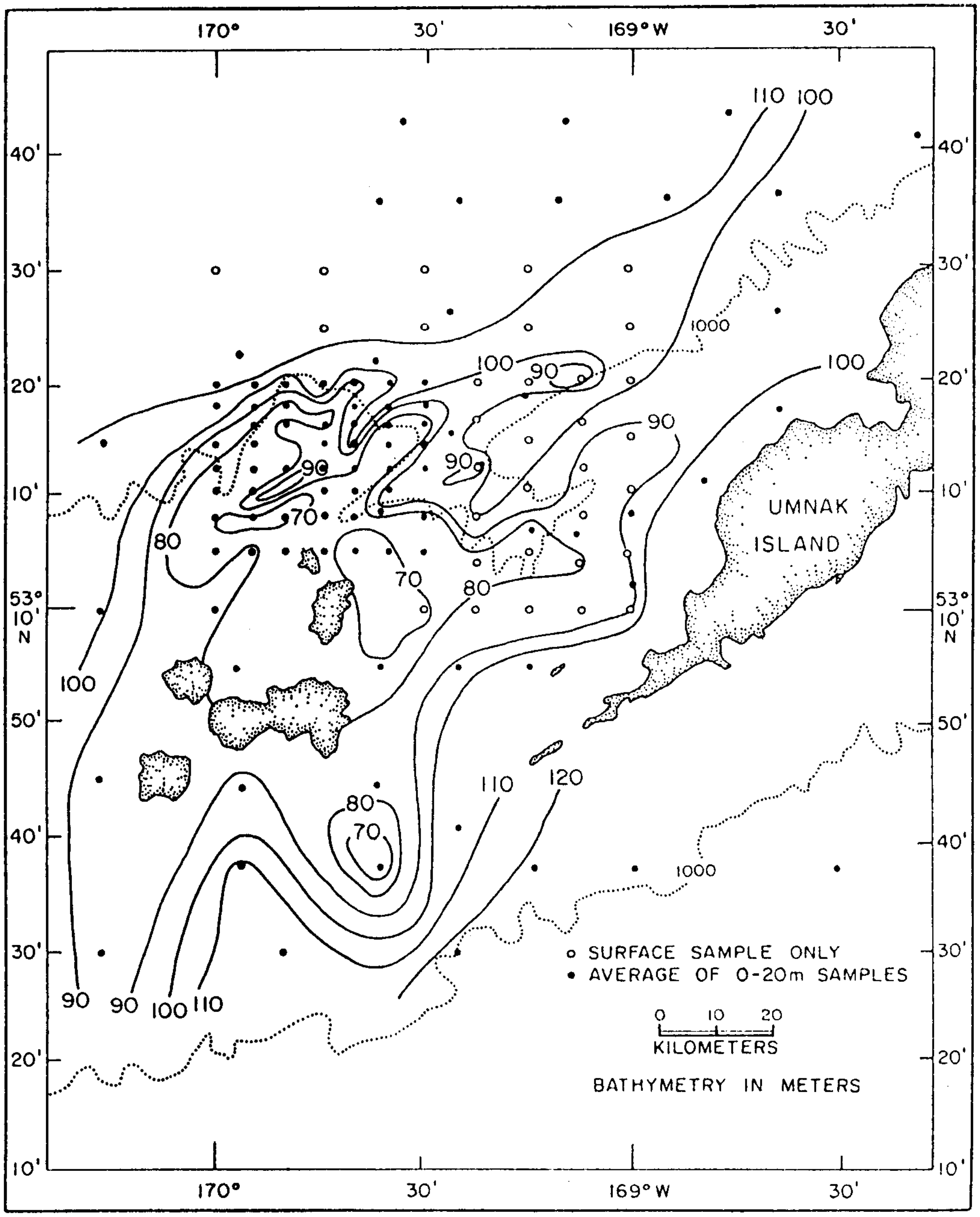


Figure 4F-16. Near-surface oxygen saturations near Samalga Pass, June-July 1971 and July 1972 (from Swift and Aagaard 1976).

background evaluation of hydrocarbon composition, and limited measurements of organic matter and suspended material.

Carbon Dioxide System. The carbon dioxide system, influenced by all forms of carbon in the water column and the interaction of this carbon with the overlying atmosphere and the sediments below, is in constant flux. The dimensions of the flux depend upon the trophic level and intensity of biological activity and the physical dynamics of the system. Since parameters within and controlled by the carbon dioxide system, i.e., partial pressure of carbon dioxide gas (pCO_2), alkalinity (A), total carbon dioxide ($S\ CO_2$) and acidity (pH), are relatively easily and accurately measured, examination of this system as a tool for understanding ecosystem dynamics is becoming increasingly important in studies of the marine environment, particularly the continental shelf and coastal regions. Partial pressures of CO_2 in the air and surface water have been extensively measured in the ocean since the International Geophysical Year (Keeling 1968) to gain understanding of the CO_2 distribution and rates of CO_2 exchange between atmosphere and ocean. These studies have provided analytical techniques and background on carbon dioxide dynamics that have been important in PROBES (Hood 1986) and other Bering Sea ecosystem studies (Hood 1981).

Beginning in 1971 (Kelley and Hood 1971), several studies have been made of the pCO_2 relationships in the Bering Sea, particularly around the Aleutian Islands where extensive upwelling occurs. Kelley et al. (1971) report on a rather complete seasonal survey of pCO_2 distribution including data in and near Izembek Lagoon. September data indicate near-equilibrium values between the atmosphere and surface waters for the Izembek Lagoon area (Fig. 4F-17). But in June the sea near Izembek Lagoon is lower than the air by as much as 90 ppm, and in October the sea exceeds the air by as much as 30 ppm. No winter data are available for this region.

These fluctuations clearly show the effect of the spring bloom in depressing pCO_2. $S\ CO_2$, which closely follows pCO_2 (Codispoti et al. 1982), would also be depressed. The bloom is followed by an increase of CO_2 to near equilibrium in September as a result of respiration and air-sea transfer of carbon dioxide. By October, there is an excess of CO_2 in

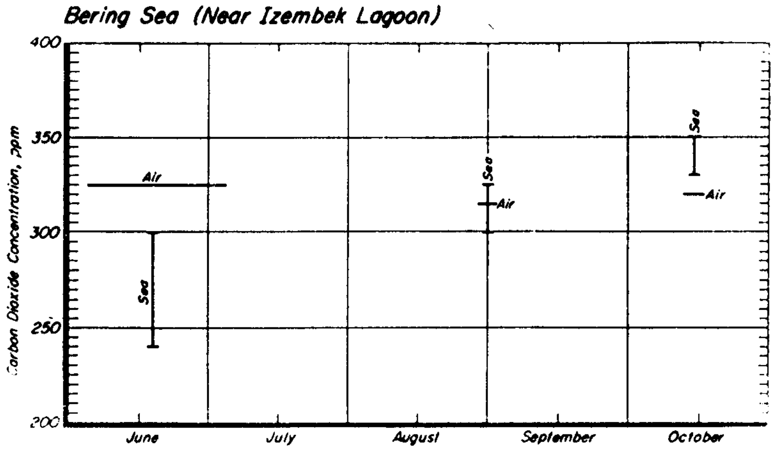


Figure 4F-17. Seasonal (late spring and fall) variations of carbon dioxide in the surface water (from Kelley et al. 1971).

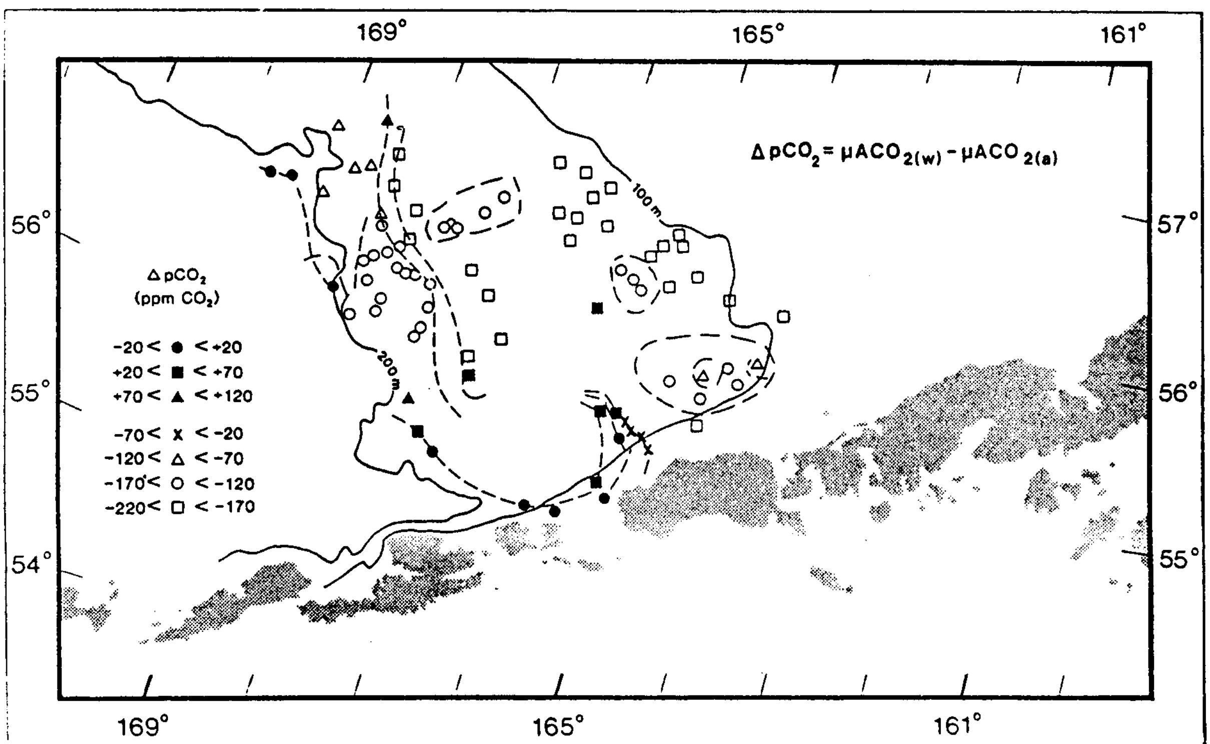


Figure 4F-18. Distribution of pCO_2 in surface water in PROBES study area north of Unimak Pass (from Hood 1971).

the water; this is caused by respiration and the upward mixing of deeper water which is rich in molecular CO_2 (Alverez-Borrego et al. 1972).

An extensive survey of carbon dioxide distribution on the eastern Bering Sea shelf, including the area immediately north of Unimak Pass, was undertaken in May 1976 (Hood 1981) (Fig. 4F-18). These data show an increase in difference in CO_2 concentration between air and water at stations eastward of Unimak Pass where pCO_2 in water was found to be near equilibrium or in excess of that in the overlying air. Unpublished data obtained in 1978 (D. Hood, pers. comm.) (Table 4F-3) also show pCO_2 concentrations in the pass at near-equilibrium values with overlying air, but the water was deficient at stations east of the pass, including sites near Amak Island (about 15 km offshore from the entrance to Izembek Lagoon). An examination of the data of Figure 4F-18 and Table 4F-3 argues against intimate contact between the Alaska Coastal Current of the Gulf of Alaska and that of the North Aleutian Shelf, and also against upwelling in the vicinity of Unimak Pass, as discussed in earlier sections.

Total carbon dioxide concentrations have not been measured in the Unimak Pass area, but extensive data have been taken in the PROBES study area to the north and east (Codispoti et al. 1982, 1986; Hood and Codispoti 1983). The seasonal changes of total CO_2, pCO_2, and NO_3 concentrations for a station (middle domain) on the PROBES line (Fig. 4F-19) should, except for timing and intensity, be somewhat similar to values in the near coastal areas near Unimak Pass.

<u>Organic Matter, Including Hydrocarbons</u>. This subject was studied in the Bering Sea by Loder (1971) who, along with Feely et al. (1981), obtained the only data specifically in the area near Unimak Pass. The location of the Loder sampling is shown in Figure 4F-20) and the data obtained are shown in Table 4F-4. In the surface waters, the dissolved organic carbon (DOC) was between 1.0 and 2.0 mgC/l, and the particulate organic matter (POC) was between 200 and 800 mgC/m^3. Lower values were found in deeper waters. Loder's data show a high correlation between absorbance of light and POC concentrations. This would infer a fairly uniform distribution in the size of particles in the water-column, thought to be larger phytoplankton. If skewness in size between stations occurred, light absorbancy would change with a given weight of material because of

Table 4F-3. Partial pressure of CO_2 in air and water near Unimak Pass in summer of 1978 (RV *Acona* cruise 261.5, 17-24 June 1978; D. W. Hood, pers. comm.).

Station	Location	Water depth (m)	pCO_2 air (ppm)	pCO_2 water (ppm)
1 18/6/78	54°18.3' N 165°27.5' W	110	334.3	235.4
2 18/6/78	54°34.3' N 165°0' W	68	332.2	313.6
3 18/6/78	54°43.9' N 164°59.5' W	66	333.2	334.0
4 18/6/78	54°28.8' N 165°36.1' W	84	334.0	312.5
5 22/6/78	54°27.0' N 165°39.5' W	135	338.0	245.0
6	Amak Island	--	332.0	261.2
7 23/6/78	55°23.3' N 163°47.2' W	76	334.0	250.0
8 23/6/78	55°21.4' N 164°4.5' W	76	334.0	250.3
9	55°15.5' N 164°17.8' W	88	332.0	337.0
10	55°9.3' N 164°31.8' W	85	333.0	325.0
11	55°2.2' N 164°44.8' W	80	335.0	323.0

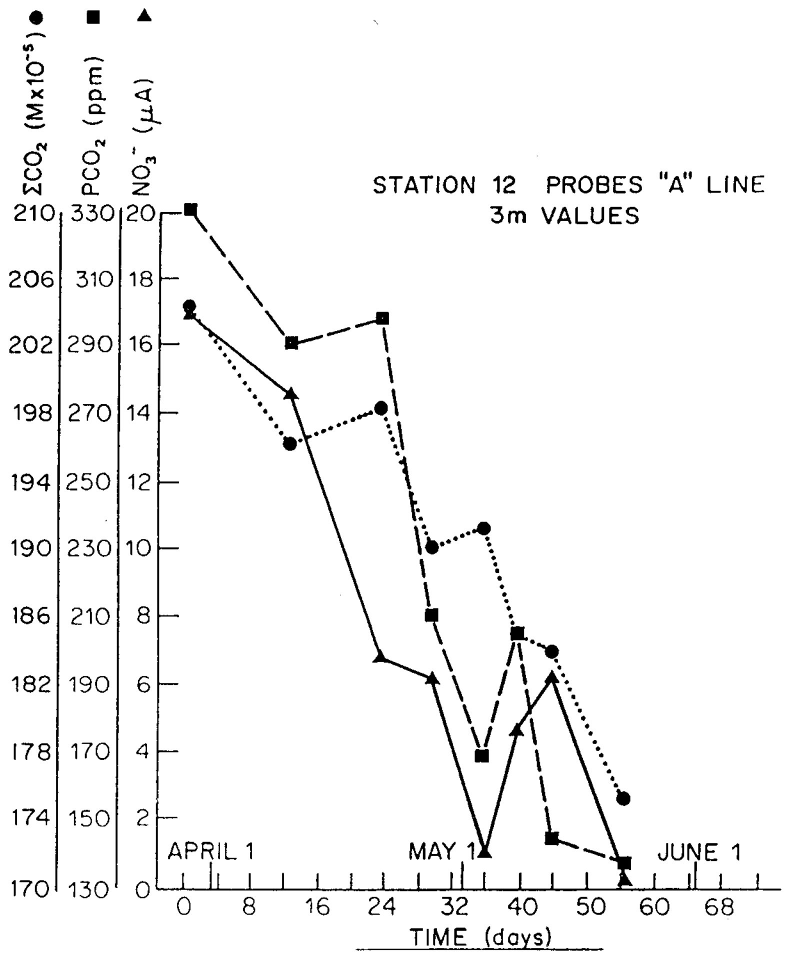


Figure 4F-19. Surface concentrations of total CO_2, pCO_2, and NO_3- over time at Station 12 on PROBES "A" line in spring of 1980 (from Hood and Codispoti 1983).

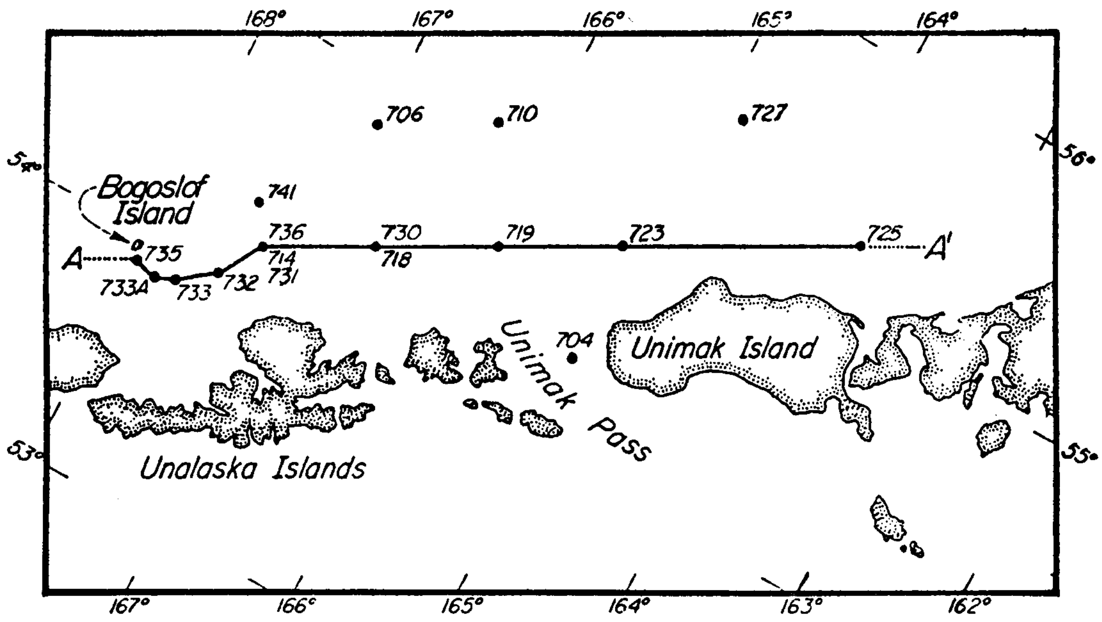


Figure 4F-20. Station locations for organic carbon sampling north of Unimak Pass during RV ACONA cruise 027 during 26 July-August 1966 (from Loder 1971).

the dominance of smaller particles in light absorbancy (Beardsley et al. 1970). Notable in the data are the high POC values found at Station 725 east of Unimak Pass, indicating unusually high phytoplankton production in this region. This finding is supported by studies of D. Schell (pers. comm.) for the area in the coastal domain just east of Izembek Lagoon.

Handa and Tanoue (1981) sampled north of the Pribilof Islands near St. Matthew Island and found POC values between 150 and 900 mgC/m^3 and DOC between 0.8 and 1.0 mg/l, agreeing favorably with Loder's data for Unimak Pass. They found C/N of 6.3 to 9.6 for the 17 samples run for this northern region with an average value of 8.3 $\pm$ 4.9. These investigators provide the only data available on the composition of the particulate organic matter in the Bering Sea.

Table 4F-4. Dissolved and particulate organic carbon concentrations in Unimak Pass area of the southeastern Bering Sea in July and August 1966 (Loder 1971).

Station	Depth (m)	% light penetration	DOC (mgC/l)	POC (μgC/l)
704	0	--	1.65	234
	10	--	1.15	164
	20	--	1.10	148
	30	--	1.10	129
	50	--	--	96
719	0	100	1.00	297
	3	50	1.30	419
	7	25	1.35	389
	12	10	1.00	283
	27	1	1.25	216
	50	--	1.30	98
	100	--	1.10	51
723	0	100	1.45	381
	3	50	1.00	303
	5	25	1.45	343
	10	10	1.60	343
	23	1	1.30	220
	50	--	1.45	135
	100	--	1.10	--
725	0	100	1.85	731
	2	50	1.00	747
	4	25	1.15	731
	7	10	1.10	746
	16	1	1.70	751
	50	--	1.50	104
727	0	100	1.10	221
	3	50	1.90	185
	8	25	1.40	180
	17	10	1.15	197
	37	1	0.70	58
	40	--	0.60	55
730	0	100	1.10	811
	3	50	1.05	468
	15	1	1.20	749

The distribution and concentrations of hydrocarbons in the surficial sediments of the continental shelf of the Bering Sea have been examined by Venkatesan et al. (1981). None of these samples were in the Unimak Pass area, but of the 32 samples taken, four were in the coastal domain and one was from the sediments of Izembek Lagoon. The general results show low concentrations of total hydrocarbons in coarse sediments and higher values in the fine materials. The hydrocarbon-to-organic carbon (HC/OC) ratio of the nearshore sediments varied between 0.0002 and 0.005, which is in the range of unpolluted sediments (Palacas et al. 1976). The total N-alkanes to organic carbon ratio was less than 0.0007 for all samples, which is much lower than that found in areas where unweathered oil is found in the sediments.

Gas chromatographic analysis revealed that allochthonous lipids were the predominant source of hydrocarbons in shelf sediments. These lipids are characterized by high molecular weight (C25-C31) N-alkanes which are derived from terrestrial sources, probably spruce-alder woodlands of the forested drainage basins. The ubiquitous presence of these predominantly odd-numbered carbon high-molecular compounds cannot be easily explained because there appears to be no continuing source of them through river input. Selective metabolism of lower-molecular-weight compounds by micro-organisms may be part of the answer.

The homologous series of isoprenoids was not found in the shelf samples. Pristane was much more abundant than phytane. Pr/pH ratios ranged from 2 to 18 suggesting that the isoprenoids are derived from biogenic materials of the marine environment rather than from petroleum (Farrington et al. 1977). Shaw and Smith (1981) examined the hydrocarbon content of 34 samples of plankton, marine birds, and marine mammal tissue on the Bering Sea shelf. These animals showed a hydrocarbon distribution which appeared to have its origin in the marine pelagic system of the region. The hydrocarbons associated with higher terrigenous plants, commonly found in the sediments, were not found in the animal tissue. Fossil hydrocarbons were not observed in any samples. Although no data are available on the higher molecular weight hydrocarbons in the immediate vicinity of Unimak Pass, there is no apparent reason to expect their presence to be different from that found on the Bering Sea shelf.

Lower molecular alkanes (C1-C4) are found in crude oil and natural gas and their presence has been investigated in the eastern Bering Sea shelf (Cline 1981). Methane is by far the most abundant. In addition to its presence in petroleum, methane is produced through fermentation of simple organic compounds or in hydrogen reduction of CO_2 by anaerobic micro-organisms (Reeburgh and Heggie 1977); it may also be produced by organisms living in anoxic microenvironments (Scranton and Brewer 1977). Despite it s probable origin in sediments, it is found in ocean surface water (Swimmerton and Lamontague 1974).

The results of Cline's analysis of low-molecular-weight hydrocarbons in Bristol Bay are shown in Table 4F-5 and the contour maps shown in Figure 4F-21. A methane seep appears to occur on St. Georges Bank about 60 miles north of Unimak Pass but background values of only 100 to 200 ppm appear in the pass area.

Nutrients. Nutrient analyses in the immediate vicinity of Unimak Pass have been limited. Koike et al. (1979, 1982) made a transect through the pass occupying stations and obtained simultaneous measurements of temperature, salinity, nitrate, ammonium, and chlorophyll (Fig. 4F-22). During the transect the ship moved at a constant speed of about 11 kts, thus the tidal currents (about 1 kt) can be neglected. Near the Aleutian Islands, nitrate concentrations were high (>10 ug atoms N/l) and chlorophyll-a concentrations were relatively low. A decrease in nitrate westward of Unimak Pass was accompanied by an increase in chlorophyll-a. Highest concentrations of chlorophyll-a were observed at Location B, 17 km north-northwest of Akun Island, where nitrate concentrations were minimal.

Although ammonium concentrations exhibited a complex pattern, they tended to decrease westward of Unimak Pass. A small increase in ammonium accompanied the high concentrations of chlorophyll-a at Location B. With an estimated flow of 5 cm/s through the pass, the source water would travel the 40 km between Location C and Location B (off Akun Island) in about 230 hrs. Salinity and temperature between the two stations are essentially unaltered, but nitrate concentrations decreased from 15 μg atoms N/l to 1 μg atom N/l, thus indicating a utilization rate of about 60 ng atoms N/l/hr. This value falls within the range of that for the eastern Bering Sea shelf.

It is tempting to extrapolate the extensive data and process studies of the PROBES program in the eastern Bering Sea to the Unimak Pass area. This transfer of information is questionable for several reasons. First, the dominant water motion everywhere on the southeastern shelf is due to tidal currents. Typical amplitudes of the diurnal current are 10 to 20 cm/sec (Shumacher and Kinder 1983). From considerations of the kinetic energy in various frequency bands, the shelf is divided into three dynamic regimes. These coincide with the depth domains of 0 to 50 m, 50 to 100 m,

Table 4F-5. Average surface (a) and near-bottom (b) concentrations (nl/l, STP) of methane, ethane, ethene, propane, and propene for various water depth intervals, southeastern Bering Sea (Cline 1981).

CRUISE	DOMAIN		METHANE Mean	METHANE Range	ETHANE Mean	ETHANE Range	ETHENE Mean	ETHENE Range	PROPANE Mean	PROPANE Range	PROPENE[1] Mean	PROPENE[1] Range
	Coastal	a	64	45-94	-	-	0.9	0.3-17	-	-	0.5	0.2-11
	(<50 m)	b	59	45-98	-	-	1.0	0.7-1.8	-	-	0.4	0.1-0.6
Sept.-Oct.,	Middle Shelf	a	60	42-83	-	-	0.8	0.3-1.6	-	-	0.4	0.1-1.4
1975	(50-100 m)	b	99	65-163	-	-	1.7	1.2-2.7	-	-	0.6	0.3-1.3
	Outer Shelf	a	76	40-200	-	-	0.5	0.2-0.8	-	-	0.3	0.3-0.4
	(100-200 m)	b	380	100-615	-	-	1.1	0.7-1.6	-	-	0.3	0.2-0.4
	Coastal	a	112	74-153	0.9	0.6-1.5	3.8	3.0-4.7	0.4	0.3-0.6	1.4	1.0-2.5
	(<50 m)	b	114	73-153	1.0	0.5-2.5	3.4	2.3-4.4	0.4	0.2-0.6	1.2	0.7-1.6
June-July,	Middle Shelf	a	85	52-134	0.6	0.3-1.5	2.9	1.9-4.7	0.3	0.2-0.6	1.1	0.6-1.7
1976	(50-100 m)	b	115	62-165	1.3	0.5-2.5	2.2	1.1-4.0	0.5	0.3-0.6	0.5	0.2-1.0
	Outer Shelf	a	140	53-276	1.1	0.4-2.1	2.3	1.8-2.8	0.4	0.2-0.7	0.7	0.5-1.1
	(100-200 m)	b	269	164-440	0.9	0.6-1.1	1.2	0.8-1.8	0.3	0.2-0.4	0.3	0.1-0.9

[1]Due to analytical difficulties encountered during the Sept.-Oct. 1975 cruise, concentrations of ethene and propene include ethane and propane respectively.

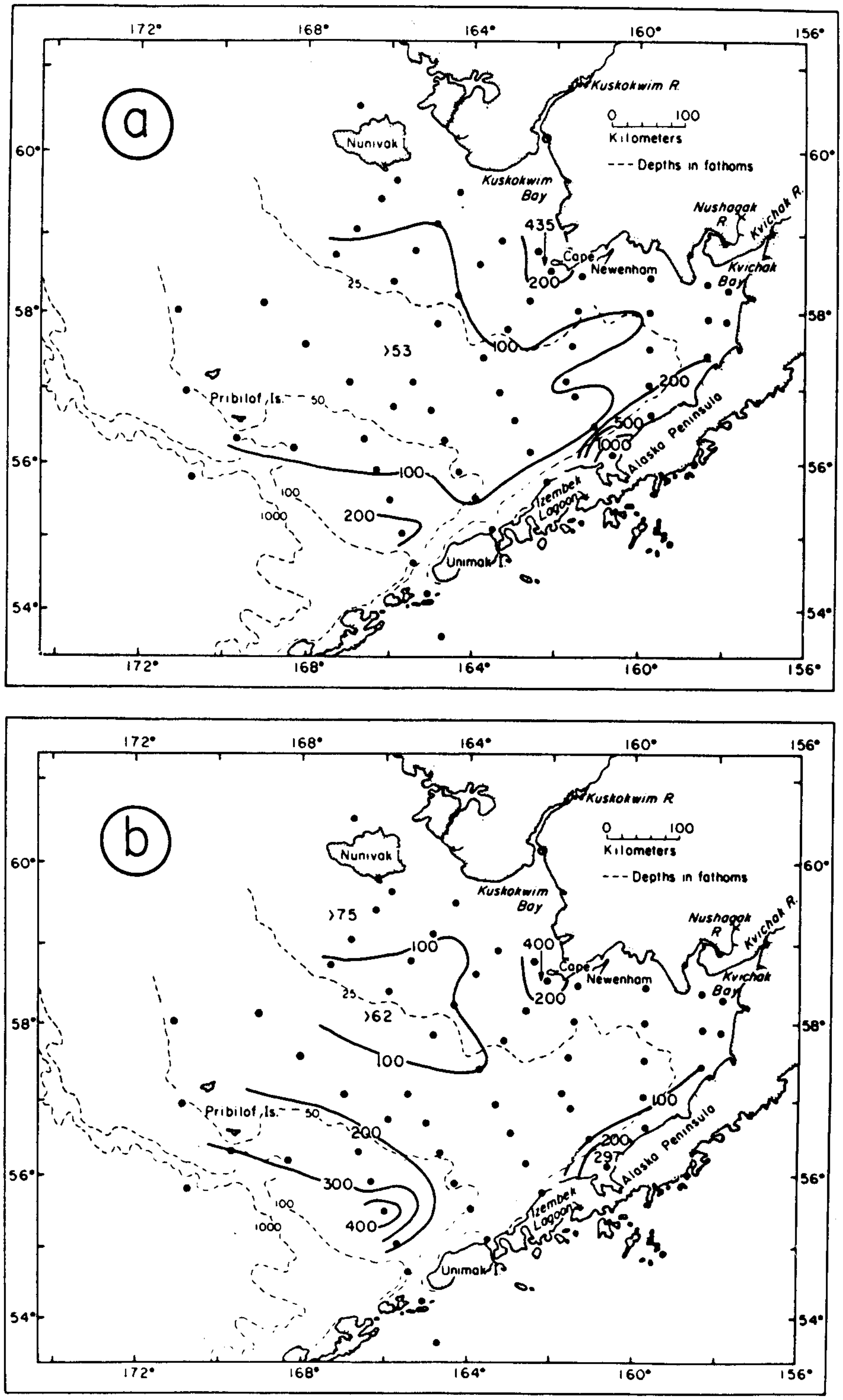


Figure 4F-21. Surface (a) and near-bottom (b) distribution of dissolved methane (nl/l, STP) in July 1976 in the southeastern Bering Sea. Near-bottom samples were taken within 5 m of the bottom (from Cline 1981).

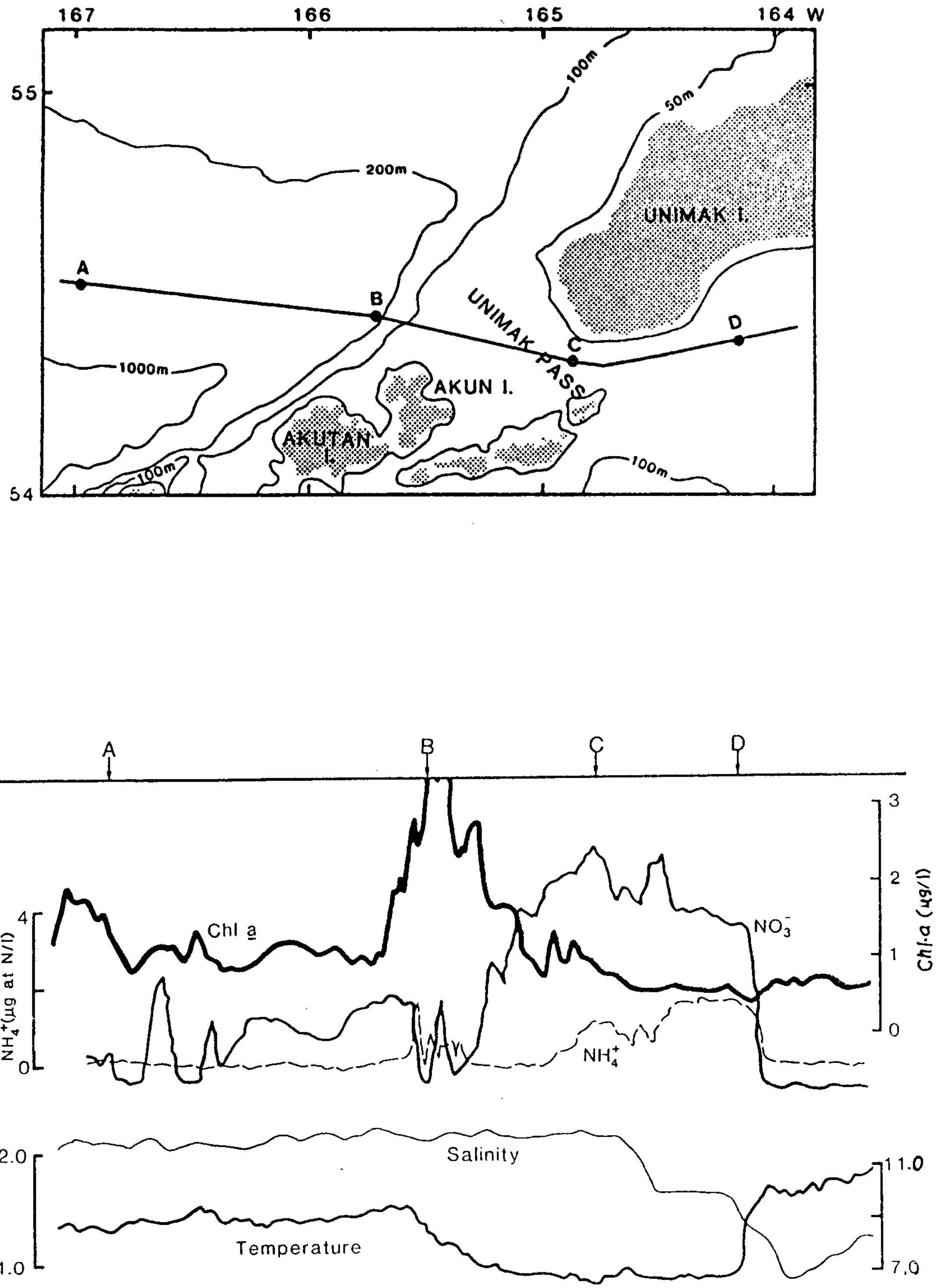


Figure 4F-22. Horizontal variations of nitrate, ammonium, chlorophyll-a, temperature, and salinity (below) in the surface waters at stations near Unimak Pass (above) on 30 July 1978 (from Koike et al. 1982).

and 100 m to the shelf break and therefore the hydrographic domains of Figure 4F-7. On the shelf these domains cover a distance of as much as 600 km, whereas at the pass the 200 m contour (the outer boundary of the outer domain) is only 40 km from the center of Unimak Pass. Therefore the pass is much more influenced by the continental slope regime than is the broad eastern shelf. Second, the nature of the subtidal flow in the outer domain is different than on the shelf. In the outer domain about one-half of the subtidal flow energy is associated with mesoscale frequencies (periods of 2 to 10 days) and one-half with longer periods. In the central and coastal domains, two-thirds the energy is at higher frequencies and only one-third at longer time scales. Finally, these features of the Bering Sea are further influenced by flow from the Gulf of Alaska through Unimak Pass into the Bering Sea, mainly from the Alaska Coastal Current.

Whitledge et al. (1986) summarized the data obtained on the PROBES program for the eastern Bering Sea shelf (Fig. 4F-23). Station 1 represents the continental slope domain and Station 19 the coastal domain. Similar data are not available for the Unimak Pass area, but it is expected that the nutrient dynamics in the pass area would resemble more the continental slope domain than the coastal domain.

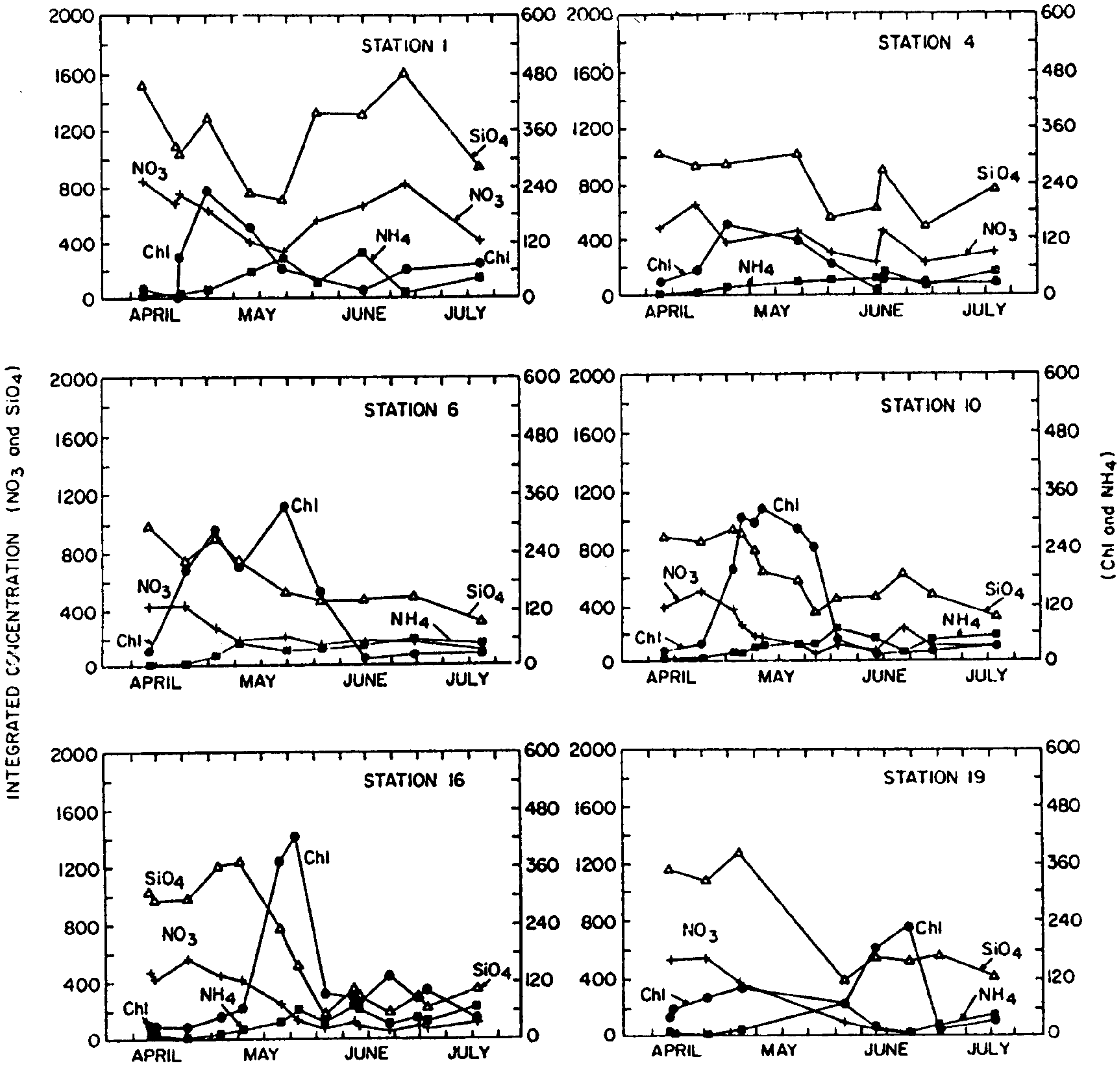


Figure 4F-23. Seasonal concentrations of nitrate, ammonium, silicate (mg-atoms/m^2), and chlorophyll-a (mg/m^2) over the upper 40 m for six stations with water depths of 1500 m (station 1), 138 m (station 4), 126 m (station 6), 90 m (station 10), and 45 m (station 19) on the PROBES main line in the southeastern Bering Sea, 1981 (from Whitledge et al. 1986).

G. GEOLOGY AND GEOCHEMISTRY

by Joe Truett

Geological characteristics of the eastern Aleutians have direct influences on potential oil and gas development activities in the region, particularly because of the high potential for volcanism and for earthquakes and associated tsunamis (Davies and Jacob 1979). Further, some characteristics of the sedimentary and geochemical regimes influence the distributions and abundances of the biota.

In this section we discuss the geologic origin and history, crustal motion, contemporary sedimentary regimes, and geochemistry of the eastern Aleutian area. The focus is on the marine environment; descriptions of terrestrial environments are not included unless they contribute importantly to understanding the geology of the marine environment.

Burk (1965) noted two decades ago that the Aleutian Islands area had received very little geological field investigation and that much structural speculation had been based on bathymetric charts of the region. Some new work has been done since that time, but geological aspects of the marine environments in the area remain relatively unknown.

Geologic Origin and Characteristics

The eastern Aleutian Islands area is young and geologically active. The Aleutian Ridge itself developed no earlier than late Cretaceous time (about 60 million years before present) (Nelson et al. 1974). Much of the present emergent and submerged features were formed in Quaternay and post-Tertiary times as a result of movement of the earth's crustal plates and associated volcanism. The Aleutian area in general, including the eastern part, is one of the most active zones of subduction (sliding of one crustal plate under another), volcanism, and earthquake activity in the world (Davies et al. 1981).

Subduction of the Pacific Plate beneath the North American Plate (Fig. 4G-1) is responsible for the topographic features of the eastern Aleutians. The northern edge of the Pacific Plate dips beneath the North American Plate, creating the Aleutian Trench on the south side of the island chain at the juncture of the plates, and uplifting the southern

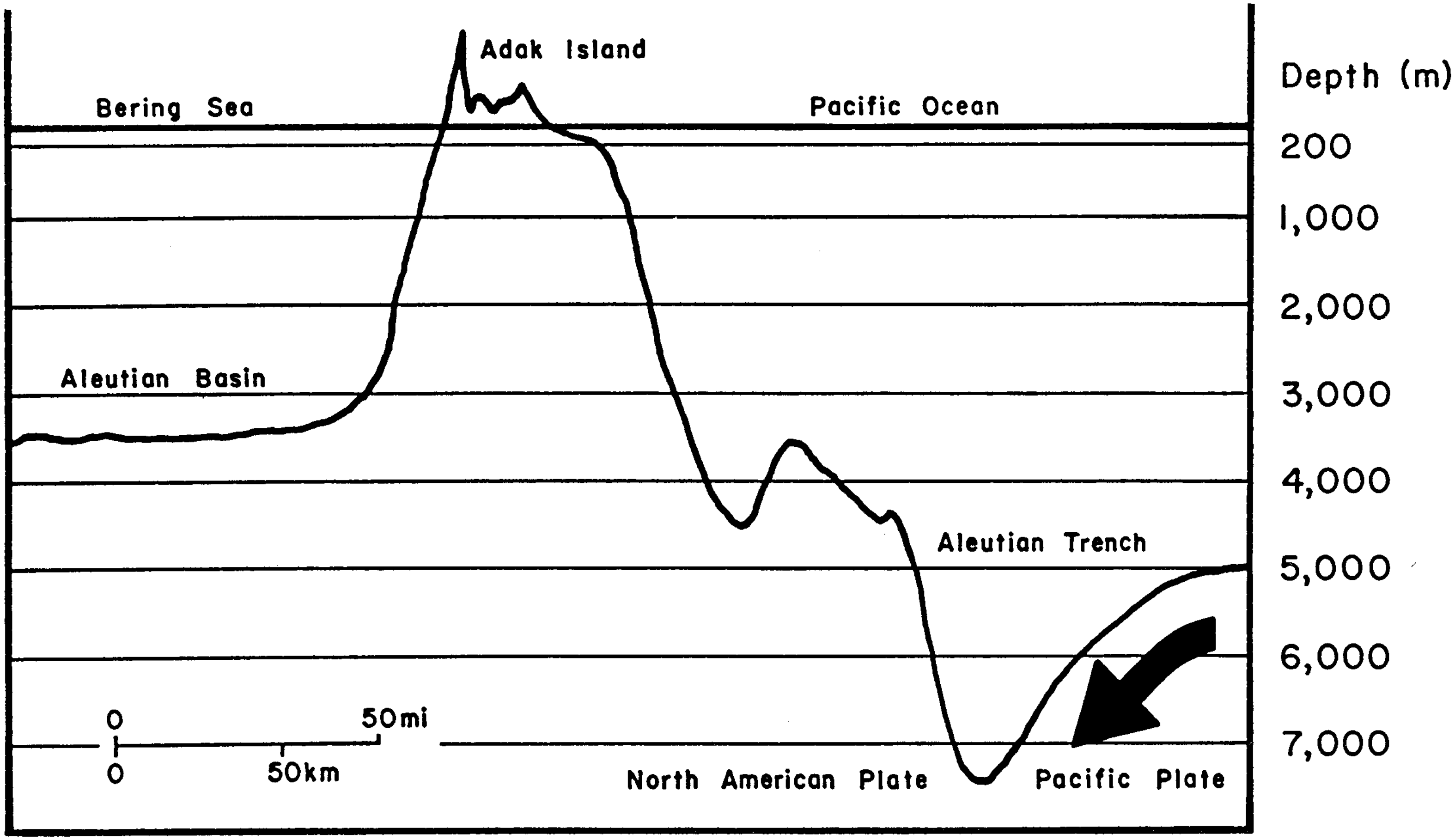


Figure 4G-1. Cross-section of the Aleutian chain, Alaska, showing general topographic configuration. Arrow shows direction of movement of the Pacific Plate (after Morgan 1980).

edge of the North American Plate to give rise to the volcanoes that form in the Aleutian Island chain (Morgan 1980). Volcanism and associated features such as lava flows and cinder cones, typical of places on the earth where crustal plates meet, continue to alter both the emergent and submerged formations. Crustal movement and volcanism remain active in the area; the seismic "Ring of Fire" along the Aleutian chain has frequent earthquakes and volcanic eruptions (Tetra Tech 1979). Bogoslof Island, for example, rose above sea level about 50 km north of Umnak Island in historic time, changing its location and shape several times since (Morgan 1980). It remains one of the most active volcanic sites in the Aleutians.

The eastern Aleutians have a narrow, submerged shelf that is bounded on the southern side by the Aleutian Trench and on the north side by the Aleutian Basin (Figs. 4G-1, 4G-2). The Aleutian Trench is 50 to 100 miles wide with a maximum depth of over 8000 m (Morgan 1980); on its south side is the abyssal plain of the Pacific Ocean (Jones et al. 1971). The Aleutian Basin, a northern embayment of the Pacific Ocean that became isolated by the development of the Aleutian Ridge (Nelson et al. 1974), is relatively shallow (2000 m) rising in the northeastern corner of our study area to the 200 m edge of the broad Bering shelf. The proximity of deep ocean basins to the eastern Aleutians has important implications for the sediment regime, hydrography, and biological production of the area, as we have seen in earlier sections.

Volcanism and Seismicity

Because the eastern Aleutians are so geologically active, biological communities and human activities in the area can be drastically affected. Volcanic activity creates and destroys emergent features important to birds and mammals. Earthquakes can be hazards to navigation and shore-based facilities associated with man's activities.

Volcanism

Volcanic activity built the Aleutian Islands; it has thus been a dominant force in shaping biological habitats. Cliffs for seabird colonies, beaches for marine mammal haulouts, and substrates for marine

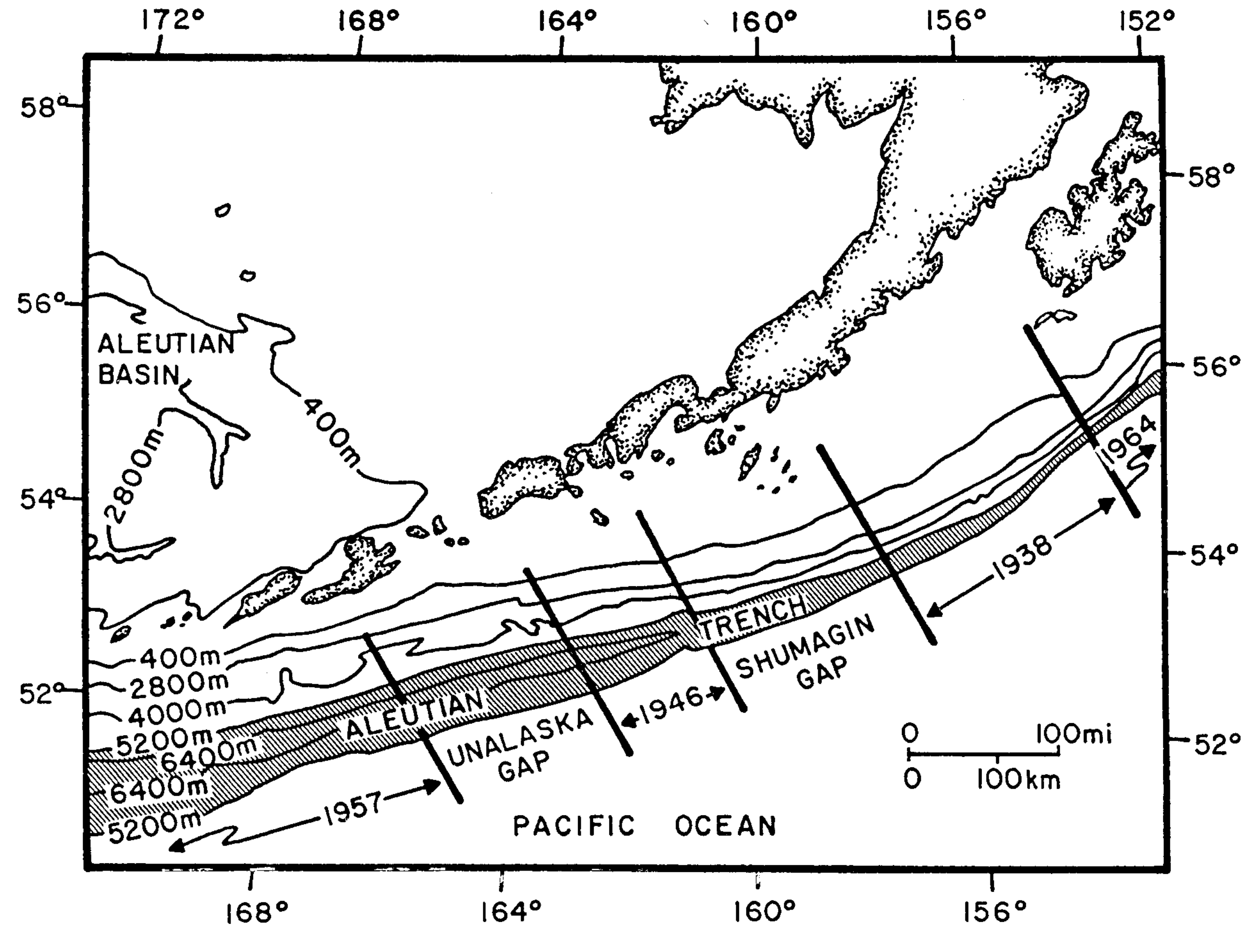


Figure 4G-2. Tectonic map for the eastern Aleutian Islands, Alaska, showing aftershock zones along the Aleutian Trench and dates for great earthquakes. Shumagin and Unalaska seismic gaps are indicated.

benthic communities were all built partly by volcanic activity (Morgan 1980, Hein et al. 1978). Volcanic activity is still actively changing these habitats, on a scale of human lifetimes. Nearly a score of volcanoes, several of which have been active in the last few centuries, are found in the eastern Aleutian study area (Fig. 4G-3) (Morgan 1980).

Perhaps the most active volcanic site in or near our study area is Bogoslof Island; seasonally it harbors many nesting birds and hauled-out mammals and has undergone drastic changes in size and shape in historic times (Morgan 1980). At this site in 1778, Captain James Cook first discovered this island and called it "Ship Rock"; 18 years later volcanic activity thrust forth another peak just southeast of Ship Rock. Ten years later, more eruptions added to the newly-emerged rock, and in 1826 the island measured two miles long, three-quarters of a mile wide, and 350 feet high. Subsequent eruptions in 1883, 1886, and 1906 further altered the island. Today Bogoslof remains active and continues to harbor many birds and mammals.

Seismicity

Volcanic activity in itself has fewer short-term environmental effects than do earthquakes and associated tsunamis (tidal waves). The consequences of these can be disastrous, both to biota and to human life and property. The potential for earthquakes and tsunamis to trigger oil spills may be large in the eastern Aleutians.

The Aleutian Islands are in a zone of extreme earthquake activity. The entire British Columbia-to-western-Aleutian length of the interface between the North American and Pacific plates is seismically very active; from 1938 to 1979 seven earthquakes of magnitude 7.6 or larger occurred along this interface. The rupture zones, seismic movements, and magnitudes of several of these shocks are among the largest known anywhere in the world (Davies et al. 1981).

Damage caused by such quakes to coastal biota and facilities onshore and at sea has the potential to be large. For example, on 1 April 1946 an earthquake of magnitude 7.4, centered in the area immediately southeast of Unimak Pass, shook the eastern Aleutians (Sykes 1971, Morgan 1980, Davies et al. 1981). It sent a tidal wave (tsunami) more than 30 m high to the

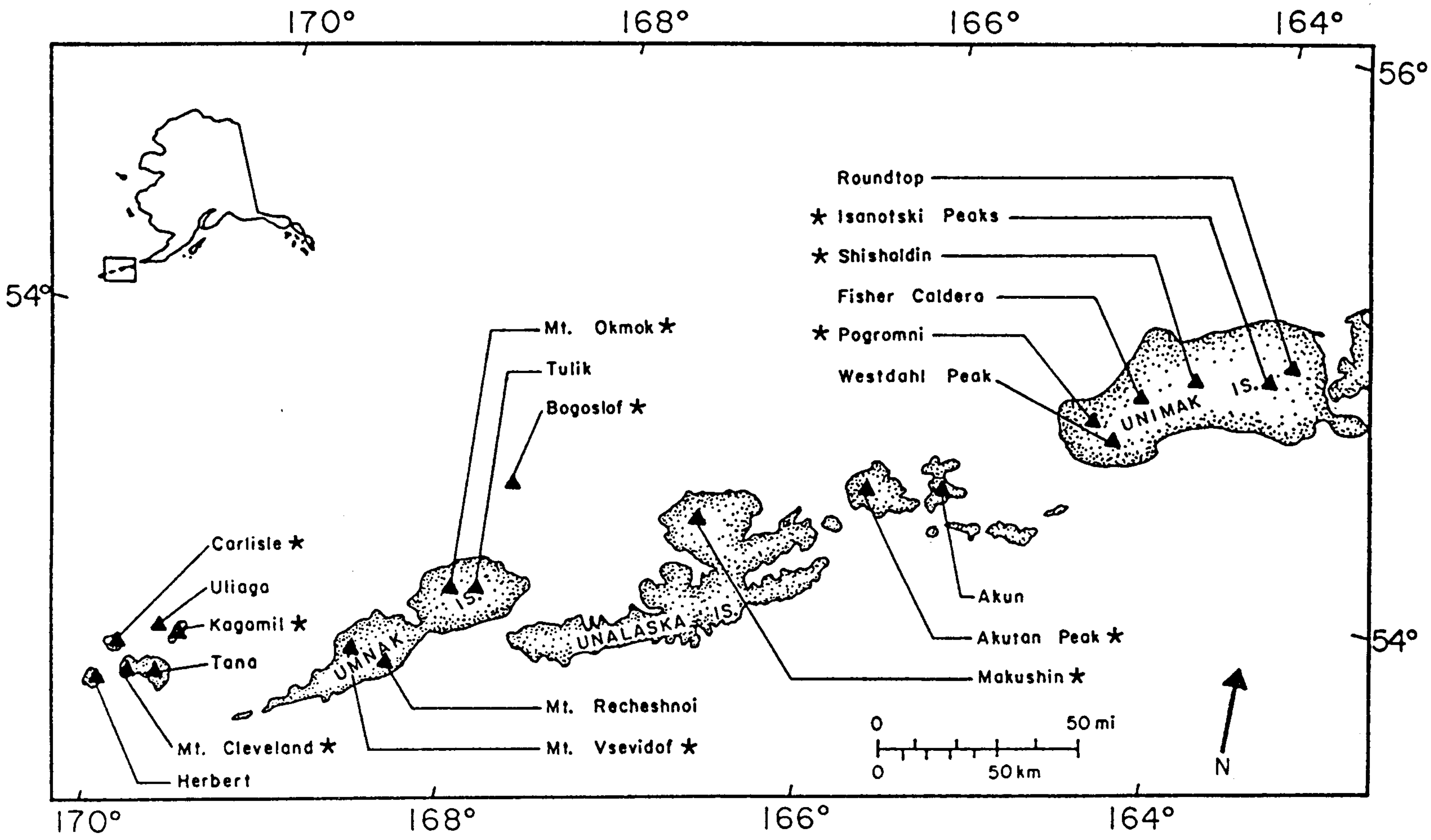


Figure 4G-3. Major volcanoes of the eastern Aleutian Islands, Alaska. Asterisks indicate volcanoes believed to have been active since 1760 (from Morgan 1980).

nearby shore, obliterating Scotch Cap lighthouse on the southwest tip of Unimak Island and killing five people; the scarcity of humans in the region prevented greater loss of life. Five hours later, this tsunami reached Hawaiian shores, killing 159 people and causing $25 million damage; it is rated as the worst natural disaster in Hawaiian history.

Recent investigations (Sykes 1971, Davies et al. 1981, Davies and Jacob 1979) have identified a major seismic "gap" ("Shumagin Gap") east of Unimak Pass (Fig. 4G-2). (A seismic gap is a segment of the plate boundary that has not ruptured recently relative to when adjacent segments have ruptured. Theory predicts that future large earthquakes are more likely to occur in gaps than elsewhere.) Over 80 years have elapsed since the Shumagin Gap last ruptured in a great earthquake. Given known repeat times for earthquakes in locations along the plate boundary, a high probability exists for a great (magnitude 7.8 or greater) earthquake to occur within the Shumagin Gap within the next decade or two. This gap is one of the few areas in the United States where pressures leading to a great earthquake are likely to be observed within a reasonable span of time (Davies et al. 1981).

Another possible seismic gap ("Unalaska Gap") has been identified (Davies et al. 1981) near (southeast of) Unalaska Island (Fig. 4G-2). An earthquake occurring in the Shumagin Gap could rupture Unalaska Gap also. Alternatively, the Shumagin Gap alone, or in combination with ruptures at Unalaska or other nearby gaps, could rupture in a series of very large earthquakes instead of a single great shock. Any of these earthquakes could generate wave heights of several tens of meters along shorelines near the rupture areas (Davies et al. 1981).

Sedimentary Regimes

Seafloor Sediments

The nature of bottom sediments usually influences the distributions and abundances of benthic animals and their predators. There have been few investigations of sedimentary regimes in the eastern Aleutian study area, but some conclusions may be drawn from the data that do exist.

Sedimentary strata from terrigenous sources underlie most of the continental shelf of the eastern Bering Sea (Nelson et al. 1974), but the narrow shelf to either side of the eastern Aleutian Islands is probably covered largely with volcanic rocks and sedimentary debris derived locally from such rocks (Burk 1966, Morgan 1980). Apparently little geological field investigation has taken place in much of the eastern Aleutians (Burk 1966); most maps of sediment size distribution of the Bering Sea shelf (e.g., Sharma 1974, 1979; Burrell et al. 1981; Gardner et al. 1979) terminate north of Unimak Pass and east of Unalaska Island. But indications are that sediments on the narrow shelf are relatively coarse, mainly volcanic (Favorite et al. 1977). Recurring volcanic activity, locally steep bottom topography, and high-energy water motion in shallower areas suggest further that coarse sediments and/or bedrock underlie much of the shallow water among the islands. Undoubtedly, finer-grained sediments are common on the floor of the Aleutian Basin; mean grain size appears generally to be inversely proportional to depth in this region (Baker 1983).

In the intertidal zones, substrates are largely bedrock or boulders. Gravel and sand occur sparingly in protected areas on most of the islands; sandy intertidal areas are most common on the west end of Unimak Island and around Umnak Island. Mud in intertidal areas is almost non-existent (Sears and Zimmerman 1977).

Suspended Material

Research on suspended particulates in the study area has been conducted primarily in the northeastern portion near Unimak Pass, as parts of studies of the southeastern Bering Sea shelf and the northern Gulf of Alaska. Little information exists for other parts of the study area, though apparent relationships between hydrographic variables and particulate concentrations warrant some extrapolations of data from adjacent areas.

Feely et al. (1980, 1981) and Feely and Cline (1977) show that, along the north side of the Alaska Peninsula, surface and water-column suspended matter concentrations decrease rapidly with distance seaward from the coast (Fig. 4G-4). (Concentrations everywhere increase near the bottom, presumably the result of resuspension.) This rapid attenuation seaward is caused by the circulation pattern: the relatively clear Alaska Stream water coming into the Bering Sea mainly through the passes in the western Aleutians moves northeastward along the Aleutian Chain and the Alaska Peninsula; the water nearest the Alaska Peninsula coast is turbid Alaska Coastal Current water that has come through the eastern part of Unimak Pass from the southern side of the peninsula (see also Schumacher et al. 1982 and "Physical and Chemical Processes", this volume).

Extrapolation of these apparent hydrographic/suspended material relationships farther west in the study area suggests that waters to the west of Unimak Pass probably contain lower concentrations of suspended material than do those in Unimak Pass proper. Whether turbidities decline with distance seaward of the islands is not known, but because of coastal input and turbulence-driven resuspension of bottom sediments, coastal waters would be expected to be more turbid than the deep waters seaward of the coast, especially under conditions of high winds or peak freshwater discharge.

Relatively high turbidities observed north of Unimak Pass and Unimak Island have sometimes been attributed to enhanced primary productivity caused by upwelling in the area (Feely et al. 1980, Sharma et al. 1974). That these turbid water plumes are observed in summer at the peak of plankton bloom (Fig. 4G-5) but not in fall after the bloom has declined (Fig. 4G-4) lends support to this idea.

Little information exists about the organic-inorganic composition of suspended particulates in or near the study area. Given the probable limited input of terrigenous material from the islands, the coarseness of bottom sediments on the narrow shelf bordering the islands, and the drastic summer increases in total suspended material near Unimak Pass (apparently caused by plankton blooms), it appears likely that biological material (plankton) dominates the suspended matter in the study area.

Geochemistry

Studies of the geochemistry of environments near and within the study area focus on concentrations and characteristics of heavy metals and

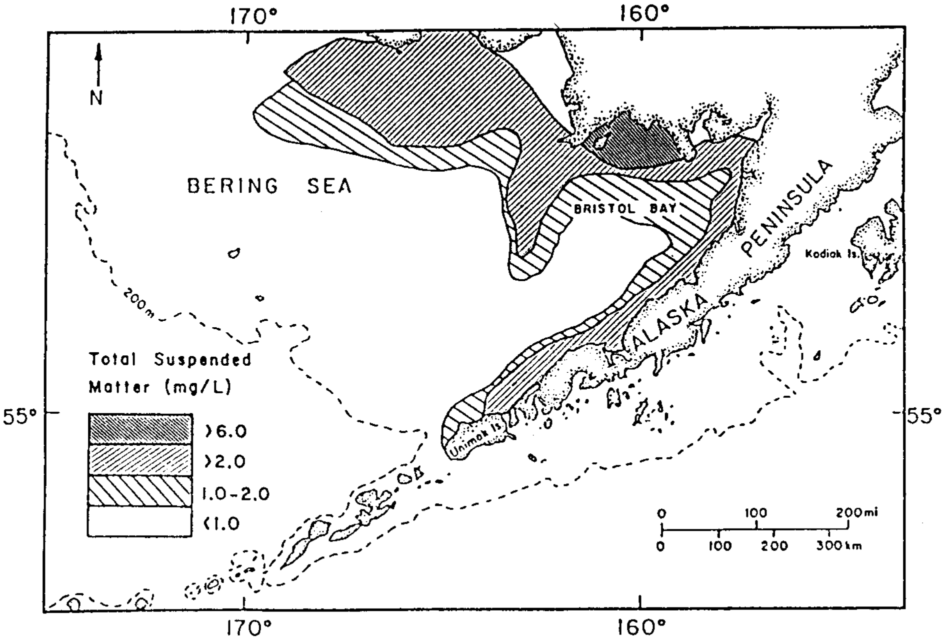


Figure 4G-4. Distribution of total suspended matter at the surface in the southeastern Bering Sea (Cruise AP-4-MW-76B-V11, 12 September-5 October 1975) (from Feely et al. 1980).

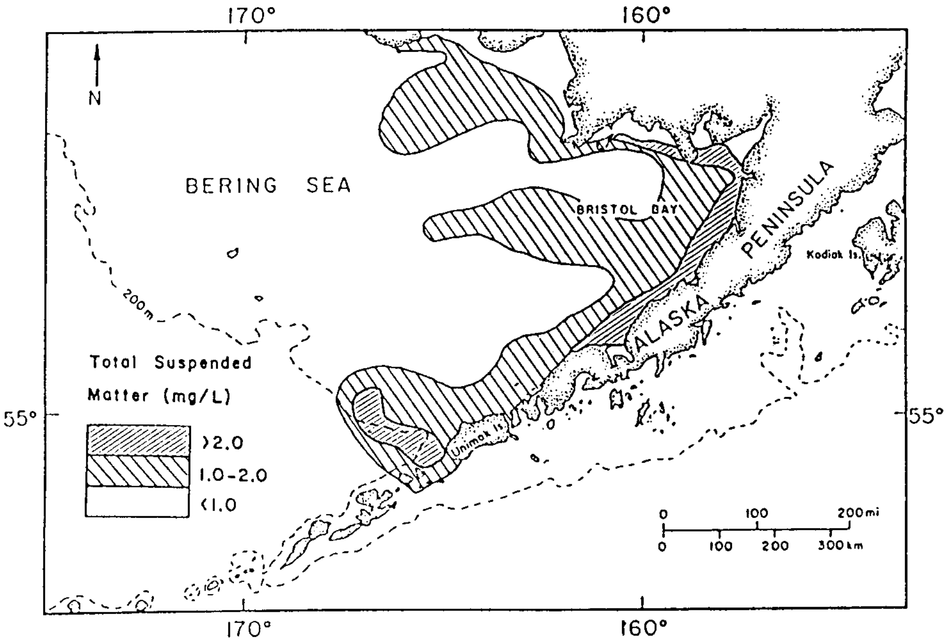


Figure 4G-5. Distribution of total suspended matter at the surface in the southeastern Bering Sea (Cruise RP-4-MW-76B-V11, 24 June-9 July 1976) (from Feely et al. 1980).

hydrocarbons. Most of these studies have sample sites in or near only the extreme northeastern part of the study area near Unimak Pass. Hydrocarbons have already been discussed in the section "Physical and Chemical Processes", this volume. Heavy metals are addressed below.

Similarly to studies of other environmental components, the few existing investigations of heavy metals in sediments, seawater, and biota (Burrell et al. 1981, Robertson and Abel 1979) were sited primarily in the shelf waters of the southern Bering Sea and northwestern Gulf of Alaska. Only a few samples have been taken from the study area, and these cluster around Unimak Pass proper. Detailed evaluations of the few Unimak Pass sampling stations are not presented in published reports, and indeed might be misleading because of the small number of samples.

But conclusions about heavy metal distributions in Alaska shelf waters in general have some utility in assessing probable metal concentrations in the environment and the biota of the study area. Robertson and Abel (1979) found that heavy metal concentrations in Alaskan shelf sediments are typical of those in other shelf areas of the world. Patchy distributions of some metals appear to be related to patchy sedimentary conditions (Robertson and Abel 1979). Burrell et al. (1981) found heavy metal contents in southeastern Bering Sea sediments to correlate with fineness of mean grain size. Robertson and Abel (1979) found concentrations in suspended particulates to vary considerably through the tidal cycle and among replicate samples. They found dissolved vanadium to be relatively uniform in shelf waters, but variable among species of organisms sampled, with Neptunia, for example, showing much higher levels than either fish or intertidal plants and bivalves. It seems likely that similar temporal, spatial and biological variations in heavy metal content would occur in the eastern Aleutians area.

5. EASTERN ALEUTIAN ISLANDS VS. NORTH ALEUTIAN SHELF: A COMPARISON

In the following paragraphs we provide an overview of the apparent similarities and differences between the eastern Aleutians area and the North Aleutian Shelf (NAS) environments. Information for this overview is largely from the discussions of components and processes in the previous sections, and from an interdisciplinary study now being completed on the NAS (LGL 1986).

Major differences between the two areas in terms of the distributions and abundances of biota are caused largely by differences in physical properties of the two environments. These properties include both processes and structural components; the most important are water sources and movement patterns, presence/absence of topographic anomalies at strategic points, and subsea topographic configuration and substrate types. Important vertebrates and invertebrates are affected by these properties directly, and also indirectly through the food chain.

A. WATER SOURCES AND MOVEMENT PATTERNS

The eastern Aleutian Islands are bathed primarily (except at the far eastern edge) with Alaska Stream water and with other ocean water upwelled from depth; the NAS is dominated by the Alaska Coastal Current and other water masses that have had long previous residence times on the shelf. The consequences of these differences to the biota are drastic. As an upwelling-supported system, the eastern Aleutians have higher primary, secondary, and tertiary production levels. They tend to be populated with more oceanic types of zooplankton than does the NAS, which hosts mainly shelf forms, especially toward inner Bristol Bay. The eastern Aleutian waters are warmer in winter, attracting many fish species that avoid such cold areas in winter as the NAS. It is likely that the NAS is "seeded" with planktonic eggs and larvae brought in through Unimak Pass by the Coastal Current; these and other materials transported by the Coastal Current would largely bypass the eastern Aleutian area. The large mass and original warmth of the eastern Aleutian waters prevent sea ice from invading the area in winter; sea ice often covers parts of the NAS.

B. EMERGENT TOPOGRAPHIC FEATURES

Tremendous numbers of animals use the eastern Aleutian area (as the place where farthest eastward passes are available) for passage between the Pacific Ocean and the Bering Sea. The NAS has no such passes; migrants between the North Pacific and central or northern parts of the Bering Sea would need to take a circuitous route in order to pass through the NAS. At least one mammal (the gray whale), probably several shorebird and waterfowl species, and perhaps many zooplankters at the mercy of the Alaska Coastal Current, take this circuitous route, but most species do not. Thus the eastern Aleutians area hosts many more species and individuals simply by virtue of the emergent topography. Further, habitat suitable for seabird nesting is abundant on the eastern Aleutian Islands but not on land adjacent to the North Aleutian Shelf; thus more seabirds would tend to use the eastern Aleutian waters simply because they are closer to nest sites, even if other factors were equal.

C. SUBSEA TOPOGRAPHY AND SUBSTRATES

Subsea topographic configurations affect the distribution and abundance of important biota in two ways--indirectly, by influencing circulation and upwelling patterns that affect food webs, and directly, by affording various habitats for benthic or demersal organisms. Having already discussed the indirect consequences (i.e., water movements, upwelling) of different topographies between our areas of interest, we concentrate here on how topography (together with substrate type) directly causes biota to be different between the two areas.

The eastern Aleutians area has shorelines that frequently drop steeply into the sea, a narrow shelf, steep and varied subsea topography both on and off the shelf, and coarse substrates ranging from bedrock and boulders to silt. Cephalopods, some groundfishes, and many inshore species of fish, invertebrates, and plants prefer these steep slopes and/or rough and coarse substrates to the gently sloping topography and finer-grained substrates found on the North Aleutian Shelf. Existing data suggest that fewer species (of mainly different kinds) prefer the NAS benthic environment.

Many benthic invertebrate species and some fishes sort themselves by depth. In the eastern Aleutians, where depth generally increases much more rapidly with horizontal distance than on the NAS, change in community composition with distance seaward of the coast is much more rapid than on the NAS.

D. THE BIOTA

As implied by the above discussions of physical differences between the eastern Aleutian environment and that on the NAS, the distributions and abundances of the biota, as well as the species compositions, are frequently very different between the two areas. The eastern Aleutians area has generally greater densities and diversities of marine mammals, birds, fishes, and invertebrates, though some exceptions exist. It has greater annual primary production caused by the richer nutrient supply to the system.

The differences are so great and so obvious that it is sometimes difficult to see the similarities, but there are some. Probably most species that are common in one area are also common in the other, though densities tend to be higher in, and more species unique to, the eastern Aleutians. The Alaska Coastal Current that swings through Unimak Pass and then along the North Aleutian Shelf tends to blend the water properties and transported organisms, and perhaps their predators, between the Unimak Pass area and the NAS. Likewise, evidence suggests that the effect of upwelling that occurs on the north side of the eastern Aleutians probably carries onto the NAS for considerable distances. The very proximity of the two areas promotes this blending effect, despite the major differences that are caused by the extreme dissimilarities of physical properties.

6. IMPLICATIONS FOR IMPACTS OF OIL AND GAS DEVELOPMENT

A. INTRODUCTION

Unimak Pass is a potentially important marine transportation corridor for development and production of petroleum that might be discovered in the Bering and Chukchi seas. The potential also exists for petroleum to be discovered very near the eastern Aleutian Islands, mainly in areas to the east and north. Should either or both of these possibilities come about, oil could be introduced into the waters of the eastern Aleutians by spills from vessels or by well blowouts. Even should oil not be spilled, considerable increases in levels of ship traffic through the eastern Aleutians could result in adverse effects to some animals. In this section we discuss the implications of these consequences of development (herein called OCS activities) to the biota of the eastern Aleutian area. The main emphasis will be on the effects of oil in the marine environment, though effects of ships moving through the area will be addressed where it appears to be potentially important.

As noted earlier in this report, there are significant marine hazards in the eastern Aleutians that could increase to above normal the probability that oil spills would occur. Earthquakes, storms, and associated marine disturbances (i.e., tsunamis, waves, and storm tides) could potentially affect marine or shore-based facilities. Frequent stormy weather, poor visibility, and extensive rocky coasts could increase the probability of oil tanker accidents.

In the discussions that follow, we attempt to focus on the most important potential interactions between the biota and OCS activities. Exhaustive reviews of the sensitivities and general vulnerabilities of the important species and species groups in the area will not be presented; these have already been presented in several other recent publications (e.g., Hameedi 1982, Jarvela 1984, Pace 1984, Thorsteinson 1984, Truett 1984, Laevastu et al. 1985). Rather, we rely on these publications, in combination with the information summarized in the preceding sections of this report, to discuss the most critical potential impacts and the information needed to address these impacts.

B. THE PHYSICAL ENVIRONMENT

In addition to the probable effects of the physical environment in promoting oil spills (noted above), there are three aspects of the abiotic environment that imply much about the potential effects of spilled oil--the effect of the environment in concentrating OCS activities and animals in the same place, its effect in moving spilled oil about in the ocean, and its effect in dispersing and weathering oil.

Overlap of OCS Activities and Animals

Unimak Pass, as the easternmost pass of any size between the Pacific Ocean and the Bering Sea, is the favored way of passage for both men and animals. Thus it forces otherwise dispersed animals and OCS activities to come together in space, setting the stage for potential interactions at an intensity not possible in other places. Depending on the timing of OCS activity in relation to animal activity in the pass, the concurrent presence of many animals with oil spills and frequent ship passage is possible. At no other location in the Bering Sea or North Pacific Ocean does the probability of such intense interaction between OCS activity and animals seem as likely. Mammals and birds, as the most sensitive groups, are most at risk.

Oil Trajectories

The likelihood that spilled oil in the marine environment will reach concentrations of mammals and birds depends on the amount and location of the spill in relation to the animals, and on the horizontal trajectory of the oil. As we have seen, many of these animals tend to concentrate in the immediate Unimak Pass area. Oil spilled north or east of the pass will probably move northeastward or northwestward and is not likely to reach the pass at any time of year (see Schumacher 1982, Manen and Pelto 1984). However, oil spilled in Unimak Pass itself will likely be coincident in space, and perhaps in time, with concentrations of mammals or birds in the pass. Further, the vast majority of existing simulated oil trajectories released in the pass (Spaulding et al. 1986) reached land in the immediate vicinity of the pass within short periods (mean time of 72 hr). Many simulated spills southeast of the pass moved to the pass area. Thus oil spilled in or near (especially southeast of) Unimak Pass poses significant risks to concentrations of animals in the pass or on adjacent coasts.

Oil Dispersal and Weathering

The weather in the eastern Aleutian Islands is frequently stormy (Morgan 1980) and the shores thus subject to very high energies from wave action, except in protected locations. Shorelines in the study area tend to be largely exposed, and composed of bedrock, sand or gravel. Most sites are judged to be less sensitive to (i.e., quickly cleansed of) oil spills, in comparison with more sheltered types of shoreline (RPI 1986). Relative to other areas in the Bering Sea or Gulf of Alaska, spilled oil would probably be rapidly mixed in the water column and cleansed from shores. Because oil normally has greater adverse effects the longer it persists, the dispersal and weathering potential of the eastern Aleutians would probably help protect the biota from spills.

We have seen that the greatest biomass and diversity of important species and their food web components in the eastern Aleutians occur in pelagic rather than benthic habitats. Given the relatively rapid flushing of pelagic habitats by water masses moving through the area, oil in the water column is likely to persist for only short times. Thus the physical character of the circulation diminishes the potential for adverse effects of oil spills on most of the biota by reducing the potential for temporal overlap of animals and oil.

C. THE BIOTA: SUSCEPTIBILITY TO IMPACT

The susceptibility of the biota to adverse impact from OCS activities depends on the vulnerability of populations and the sensitivity of individuals. The vulnerability of the biota is the likelihood that significant portions of regional populations will interact with OCS activities. The sensitivity is the level of response of individuals to the activities. Together these determine the extent to which regional populations are likely to be adversely affected by OCS activities.

We have already noted that the vulnerabilities of some of the populations are likely to be relatively high, given the concentrating effect of Unimak Pass on both animals and OCS activities. Concentrations of animals also occur in areas away from Unimak Pass proper: sea lions, sea otters, and seals tend to congregate densely in some areas; seabirds and wintering waterfowl likewise assemble in large flocks in the marine environment. The likelihood that spilled oil or other OCS activities will reach these other areas of animal concentration is not clear; additional information on the spatial and temporal distributions of animals as related to OCS activities is needed.

Sensitivities of animals to oil in the environment and to other activities varies among species and life stages. Several recent publications have extensively reviewed the sensitivities to oil and other activities of Bering Sea mammals (Braham et al. 1982, Davis and Thomson 1984, Armstrong et al. 1984, Pace 1984, Jarvela 1984), birds (Strauch and Hunt 1982, Roseneau and Herter 1984, Armstrong et al. 1984, Pace 1984), and fish and shellfish (Curl and Manen 1982; Thorsteinson and Thorsteinson 1982, 1984; Laevastu et al. 1985). Though the sensitivities of many animals, especially marine mammals, are not well known, we will accept the general consensus about relative sensitivities among species.

The following discussions focus on how the unique characteristics of the eastern Aleutians area, in conjunction with the distributions, vulnerabilities, and sensitivities of the animals, make some groups and species of major concern with respect to oil and gas development. The major focus is on the potential effects of spilled oil. Information about the general vulnerabilities and sensitivities of the biota is derived from the publications referenced in the previous paragraph and will not be elaborated upon or referenced further in this section.

Mammals

The susceptibility of many of the mammal species to adverse effects of OCS activities depends largely on their sensitivity to oil, about which little is known. Consensus suggests that mammals that insulate themselves largely with fur (fur seal, sea otter) respond more adversely to being oiled than do the other species, which are insulated with subcutaneous blubber. The literature also suggests that very young animals are probably more sensitive than older ones.

In general, the vulnerabilities of mammals depend on the proportions of regional populations harbored by the eastern Aleutians, the tendency for the animals to congregate in areas where OCS activities might occur, and the probability that the animals could detect and avoid oil in the environment.

One species, the northern fur seal, is judged to be highly sensitive as well as vulnerable. Oiled seals might suffer or succumb because of loss of the insulative value of their fur. Large percentages of the total population of fur seals congregate in the Unimak Pass area in spring and fall during migration passage, and an oil spill in the pass at peak migration could oil a relatively large number. Further, the seals spend much of their time at the sea surface where they would come into direct contact with an oil slick.

The Steller sea lion population is relatively vulnerable, and individuals are perhaps relatively sensitive when young. A large proportion of the population hauls out in large congregations and pups in the eastern Aleutians. Though adults are probably not very sensitive to oil, the young might be. Further, the sea lion population is currently declining for unknown reasons; possibly the individuals are responding to some environmental stress. They might thus be more sensitive than usual to additional stress imposed by OCS activities.

The sea otter is thought to be relatively sensitive to being oiled; oiled fur loses much of its insulative value. However, the proportion of the Aleutian Islands-Alaska Peninsula population that occupies the eastern Aleutians is small, indicating a regional population that is relatively invulnerable to OCS activities that occur in the study area.

The majority of the 17,000 eastern Pacific gray whales move through Unimak Pass in spring and fall; the population is thus relatively exposed to OCS activities occuring in the pass during these times. Whether they would be particularly sensitive to oil spills or ship traffic is speculative. Most information suggests that they would be less sensitive than the above three species.

The remainder of the mammals using the eastern Aleutians would probably be relatively secure as populations from appreciable impact caused by OCS development. Most appear to be not particularly sensitive to oil, and at any rate most are sufficiently dispersed that localized OCS activities would affect only small proportions of the populations.

Birds

Birds in general are the most highly sensitive group of vertebrates to being oiled. Oil may drastically impair the insulative and buoyancy values of feathers, frequently causing mortality if birds remain in water. Because marine birds are especially dependent on their use of the aquatic environment and the water surface, they are likely to come into direct contact with spilled oil. Birds also occasionally collide with ships, suffering dramatic mortalities, but the population-level consequences of such accidents are probably always small.

The most susceptible of the birds to adverse impact from oil spills are the alcids. Because alcids spend much of their time swimming on the water and diving for food, and because they congregate in large abundance in the study area, they are particularly vulnerable to OCS activities. Whiskered Auklets, Crested Auklets, Tufted Puffins, and murres are of particular concern.

Whiskered Auklets are highly vulnerable as a population. A large proportion of the total population uses the area year-round, concentrating to feed among the islands. However, characteristics of their feeding habitat may make them less vulnerable than they might be otherwise. They feed in tide rips and other areas of extreme water motion. Oil is likely to be quickly dispersed in such localities, reducing the amount of time that it would be hazardous to the birds.

Crested Auklets, Tufted Puffins, and murres are probably somewhat less vulnerable than Whiskered Auklets. They are mainly seasonal in their presence (Crested Auklets and murres are common in winter, Tufted Puffins in spring to fall). Further, though these birds use the area in relatively large numbers, they also occur elsewhere in abundance. But like Whiskered Auklets, they would be highly sensitive to oil encountered on the sea surface.

Next to alcids, shearwaters are probably of greatest concern. They sometimes congregate in the Unimak Pass area in tremendous numbers, at which times they spend much time on the water's surface. Many are molting at this time, which undoubtedly increases both their vulnerability and their sensitivity.

Least susceptible to impact are the storm-petrels, fulmars, kittiwakes, and gulls. They spend most of their time aloft, feeding mainly by pattering along the water and seizing objects from the surface. It is not likely that oil spills or other activities would affect significant proportions of their populations.

Fish and Invertebrates

Discussions about the potential effects of spilled oil on fish and invertebrates should be prefaced by the general findings and opinions of Laevastu et al. (1985). These authors performed an exhaustive evaluation of the potential effects of oil development on the commercial fish and shellfish of the eastern Bering Sea. They concluded that the largest oil spills conceivable would have only minor effects at most on the eastern Bering Sea populations of fish and shellfish. Very locally, and in nearshore habitats, effects could be relatively large. Small proportions of the total fish could be tainted. It is likely that the same conclusions apply to the eastern Aleutians area.

In the eastern Aleutians area as elsewhere, eggs and larval stages are most susceptible to impact because they are relatively sensitive to oil and because it is difficult or impossible for them to actively avoid oil with which they come in contact. Given this relative sensitivity of early life stages, the points of concern about oil effects on the various groups of fish and shellfish are as follows.

The most vulnerable stage in the life cycle of salmon occurs primarily in the spring when smolts migrate downstream and inhabit coastal waters. Smolts are dependent on estuarine habitats for feeding and adjustment to new salinity regimes as they leave fresh water and enter the ocean. As summer progresses, these juveniles disperse farther offshore where they are less vulnerable to site-specific disturbances. Bax (1985) and Laevastu et al. (1985) examined the vulnerabilities of Bristol Bay sockeye salmon to oil spills. Their worst-case estimates of mortality (13% juveniles, 5% adults) and tainting (6% juveniles, 2% adults) are unrealistically high when applied to the Unimak study area because salmon there are much more widely dispersed than they are in Bristol Bay, and thus far fewer would be affected. The small local stocks of salmon in the eastern Aleutians, however, would be more adversely affected (than fish migrating offshore) in a worst-case scenario.

In the event of an oilspill, herring could be the most vulnerable of the commercially important species because their spawning, incubation and nursery stages all occur in shallow shoreline environments where oil might collect and persist for relatively long periods. However, spawning stocks of herring in the Unimak area are small compared to other stocks in the eastern Bering Sea. As summer progresses, juvenile herring move offshore where they are less vulnerable. Post-spawning adult herring from Bristol Bay stocks migrate into the study area to feed in summer and fall, but they are expected to be relatively secure from large-scale effects.

Groundfish are probably less vulnerable to OCS effects than are other fishes because they inhabit deep benthic environments. It is possible that an oil spill could damage the pelagic eggs, larvae, and/or juvenile stages of these species in surface waters, particularly in the case of pollock, which spawn northwest of Unimak Pass (February to June). But because of the widespread abundance of these early-life stages, population-level effects would be small.

Inshore fishes inhabit shallow coastal environments such as rocky reefs and kelp beds. Rockfish, greenlings and sculpin are among the most abundant members of this community. Since many dwell year-round in inshore habitats, their complete life cycle, from eggs to adults, could be affected by contaminants that might collect and persist in sheltered nearshore areas. Adverse impacts on these species would be more likely to occur in summer than in winter, when many inshore fish move into deeper water.

Food Web Components

The likelihood that OCS activities will significantly affect the important species via effects on food web components is extremely small.

In the first place, many of the important species, particularly the birds and mammals, are probably more susceptible to impact than are the prey species (largely fishes and invertebrates) they consume. Second, adverse impacts on food-web components are unlikely to be more than local. Given the rapid transport of zooplankton, the relatively rapid movements of other prey, and the high mobility of the consumers themselves, these local effects on food webs are not likely to substantially reduce food available to the consumers, much less to be measurable as changes in consumer populations.

7. CONCLUSIONS: A GRAPHIC PRESENTATION

In this section we use two methods to summarize information about components and processes in the eastern Aleutian ecosystem and to present conclusions about similarities with adjacent areas and implications for oil and gas development. First we present and discuss a generalized food-web model that shows major energy pathways to the species important in the area. Second, by use of graphic and word models, we illustrate physical and biological phenomena (including trophic links) that control the distributions and abundances of the important species populations and affect their vulnerability to OCS activities.

A. FOOD WEBS

The major base of the eastern Aleutian Islands food web is phytoplankton production fueled largely by nutrients upwelled from deep ocean (Pacific and probably Bering) basins (Fig. 7-1). Production by benthic algae and eelgrass are locally important, but the total impact of this nearshore production on the ecosystem is probably small.

The most important secondary production link in the food web is comprised of pelagic zooplankton, mainly copepods and euphausiids. These groups, together with hyperiid amphipods that prey on them, support probably the vast majority of the vertebrate biomass in the eastern Aleutian waters. They support tremendous numbers of fish, birds, and mammals either directly or through forage fishes, pollock, and salmon as an intermediate link.

Some species, including shrimps, crabs, octopuses, groundfishes, inshore fishes, sea otters, and cormorants, may depend heavily on a benthic food web. Even so, much of this benthic productivity could be derived from phytoplankton that has settled. Evidence from recent studies on the adjacent North Aleutian Shelf (LGL 1986) suggests that eelgrass, and by inference perhaps benthic algae, probably supports a small proportion of the total biomass of important benthic-feeding species.

It is clear from examining this food web diagram and from reviewing the discussions in the previous sections that there are a few major food web components about which almost nothing is known in and surrounding the study area. Important links that are conspicuous as unknowns are forage fishes (sand lance, capelin, herring), cephalopods (squids and octopuses), euphausiids, and hyperiid amphipods. All these except perhaps octopuses are highly dependent on the pelagic, upwelling-supported food web.

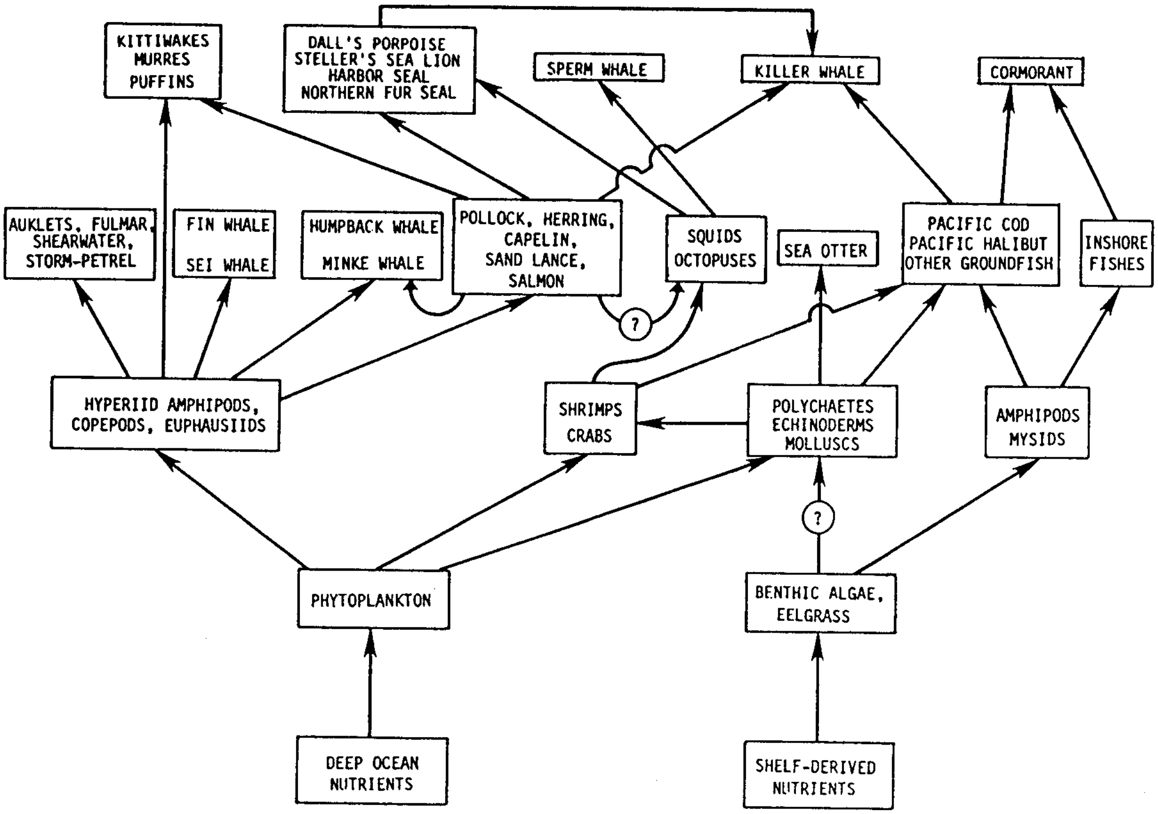


Figure 7-1. Simplified food web of the marine ecosystem of the eastern Aleutian Islands, Alaska, showing major pathways of nutrient and energy flow to species important to man. Linkages suggested by the literature to be relatively minor are not shown.

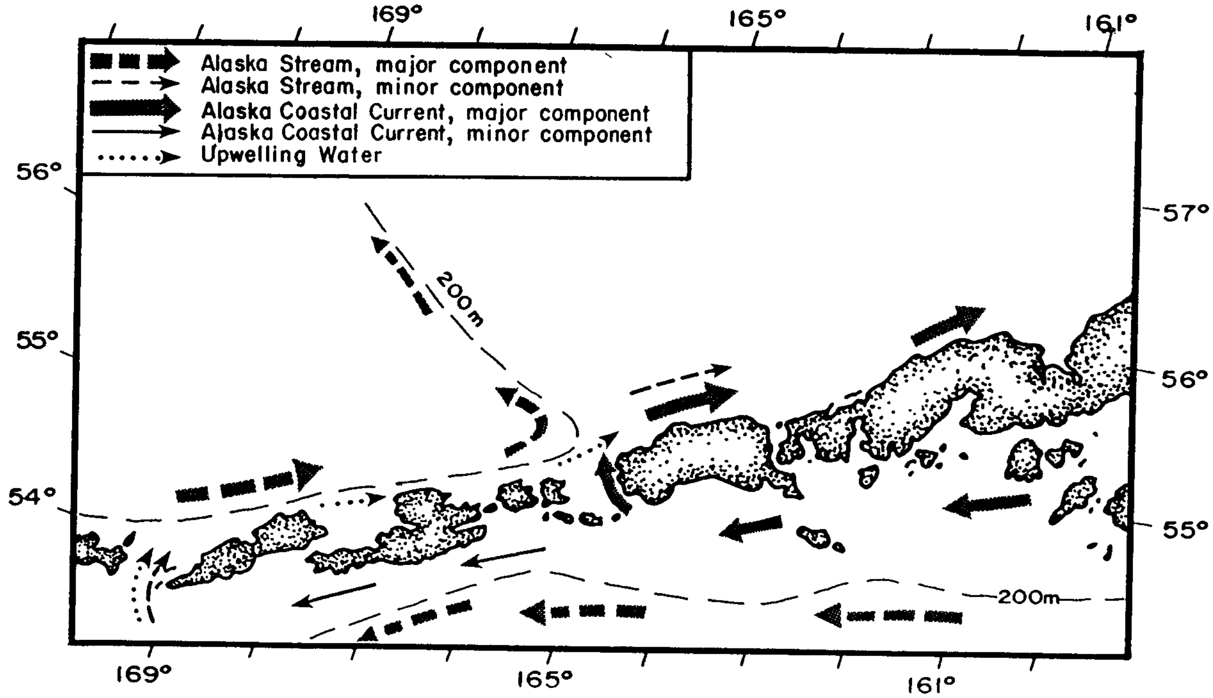
B. IMPORTANT PHYSICAL AND BIOLOGICAL PHENOMENA

A review of the above sections suggests that the distributions and abundances of important species in the eastern Aleutians are largely dependent on relatively few processes and components. In this section we identify and discuss the processes and components that seem particularly important in determining species distributions and abundances and in affecting vulnerabilities of the various species to oil and gas development.

A series of page-length charts follows; each chart describes an important process, habitat component, species, or species group in the eastern Aleutians area. Processes and components are interpreted in terms of their effects on the important biota. Processes, components, and important species and species groups are compared between the eastern Aleutians and the nearby North Aleutian Shelf. Vulnerabilities of the biota to OCS activities are noted.

Items are presented in the following sequence:

(1) Circulation and Upwelling
(2) Transport of Eggs and Larvae
(3) Water Temperature Distributions
(4) Ice Regime
(5) Topographic Characterization
(6) Substrate Type and Depth
(7) Productivity of Inshore Habitats
(8) Zooplankton Communities
(9) Cephalopod Abundance
(10) Crab Abundance
(11) Groundfish Abundance
(12) Herring Migration and Abundance
(13) Salmon Migration
(14) Bird and Mammal Feeding Concentrations
(15) Bird and Mammal Migration Corridors



CIRCULATION AND UPWELLING

IMPORTANT PROCESSES

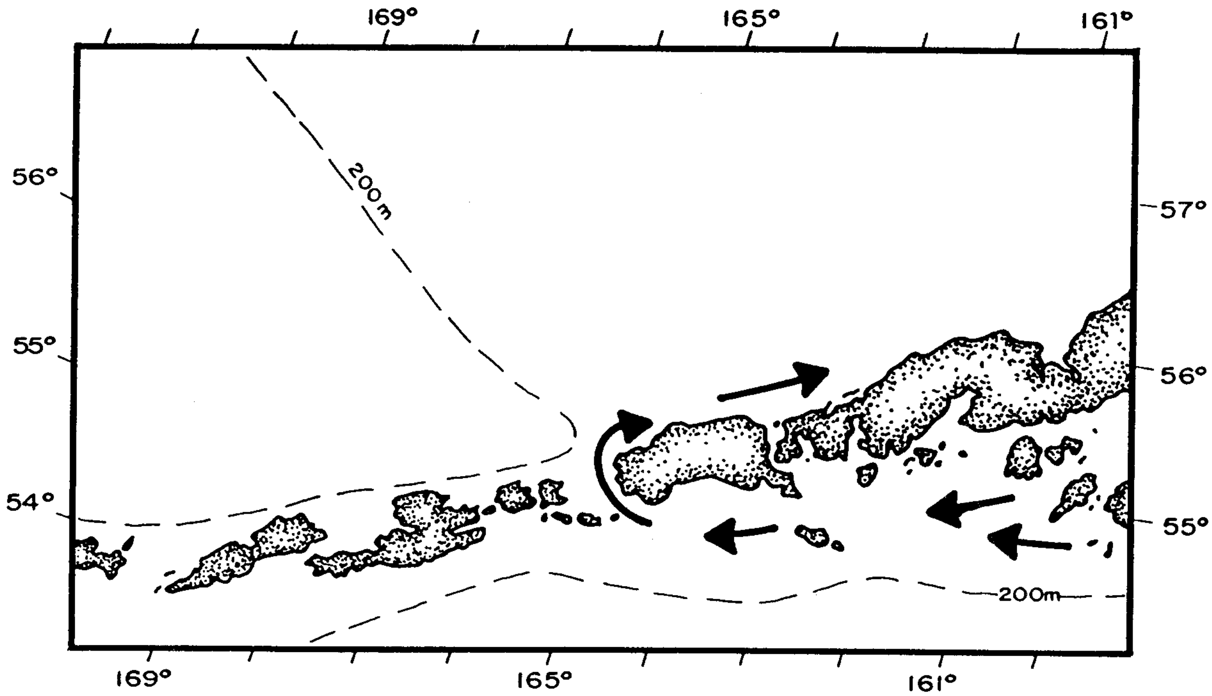
- A major component of the Alaska Coastal Current moves through Unimak Pass, thence east along the north side of the Alaska Peninsula.
- Most Alaska Stream water moves into the Bering Sea through the far western Aleutian passes.
- Upwelling brings deep, nutrient-rich Pacific water to the surface in Samalga and perhaps other passes. This water moves eastward along the north side of the Aleutians.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Circulation patterns in the eastern Aleutians are very different from those on the North Aleutian Shelf, but because water flows from one area into the other, water qualities are probably somewhat similar.
- As water moves downstream (east) from Unimak Pass, its physical and biological qualities gradually change because of impacts from terrestrial and deep shelf environments and biological activity.

CONSEQUENCES TO BIOTA

- Biological productivity of the eastern Aleutian area probably depends largely on upwelled nutrients from deep ocean basins and relatively less on nutrients brought in by the Alaska Coastal Current and the Alaska Stream.



TRANSPORT OF EGGS AND LARVAE

IMPORTANT PROCESSES

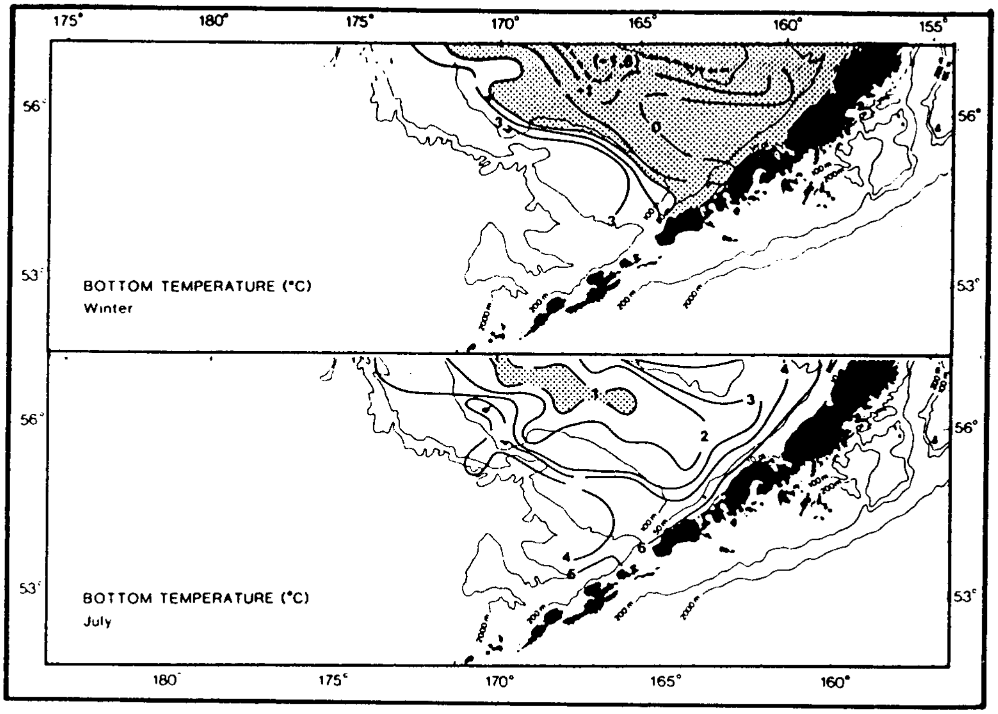
- The Alaska Coastal Current may transport large numbers of eggs and larvae of important invertebrates and fish from the Gulf of Alaska into the Bering Sea.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- The North Aleutian Shelf could be a downstream recipient of much of the material transported by the coastal current through Unimak Pass.

CONSEQUENCES TO BIOTA

- This postulated transport could serve to annually "inoculate" Bering Sea habitats with invertebrate/fish early life stages produced in the Gulf of Alaska.



WATER TEMPERATURE DISTRIBUTIONS

(Figure from Ingraham 1981)

IMPORTANT COMPONENT

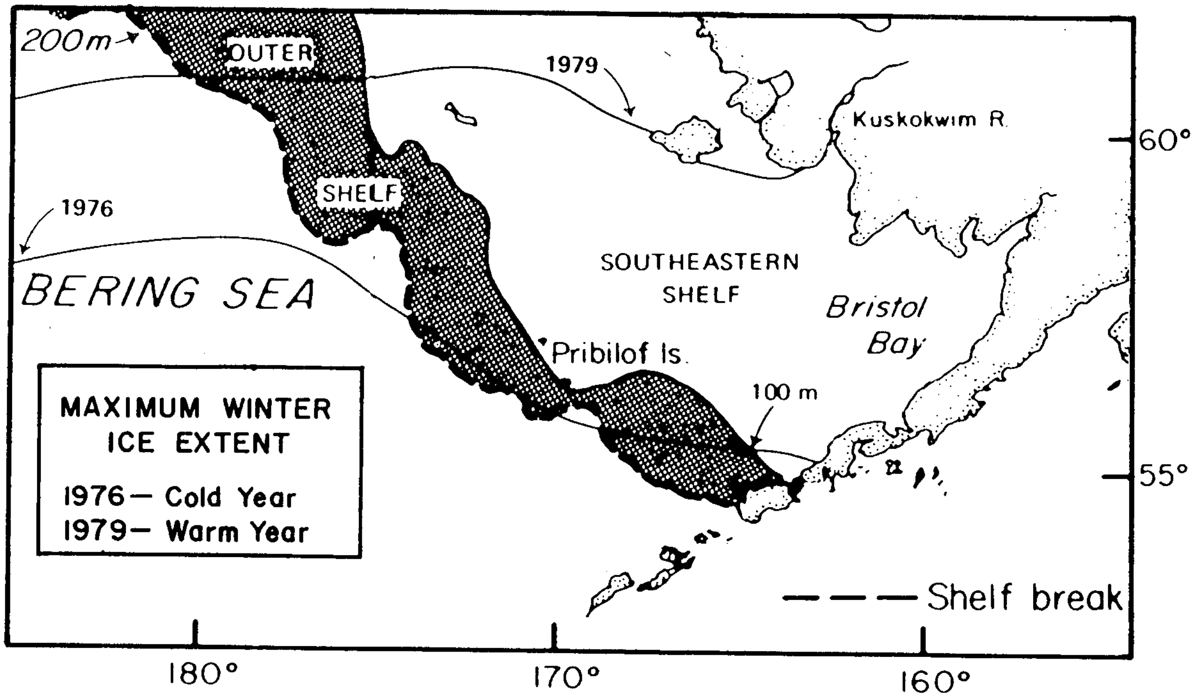
- Water temperatures vary spatially and seasonally in and near the eastern Aleutians.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Water temperature in the eastern Aleutian passes fluctuates less among seasons than it does on the NAS.
- Winter water temperatures, particularly sub-surface temperatures, remains 2°-3°C above zero in the eastern Aleutians, but typically drops to 0°C or below on the NAS.

CONSEQUENCES TO BIOTA

- Temperature influences how fish distribute themselves, especially in winter.
- Breeding times and places for fishes and invertebrates are strongly dependent on water temperature.



ICE REGIME

(Figure from Niebauer 1981)

IMPORTANT COMPONENT

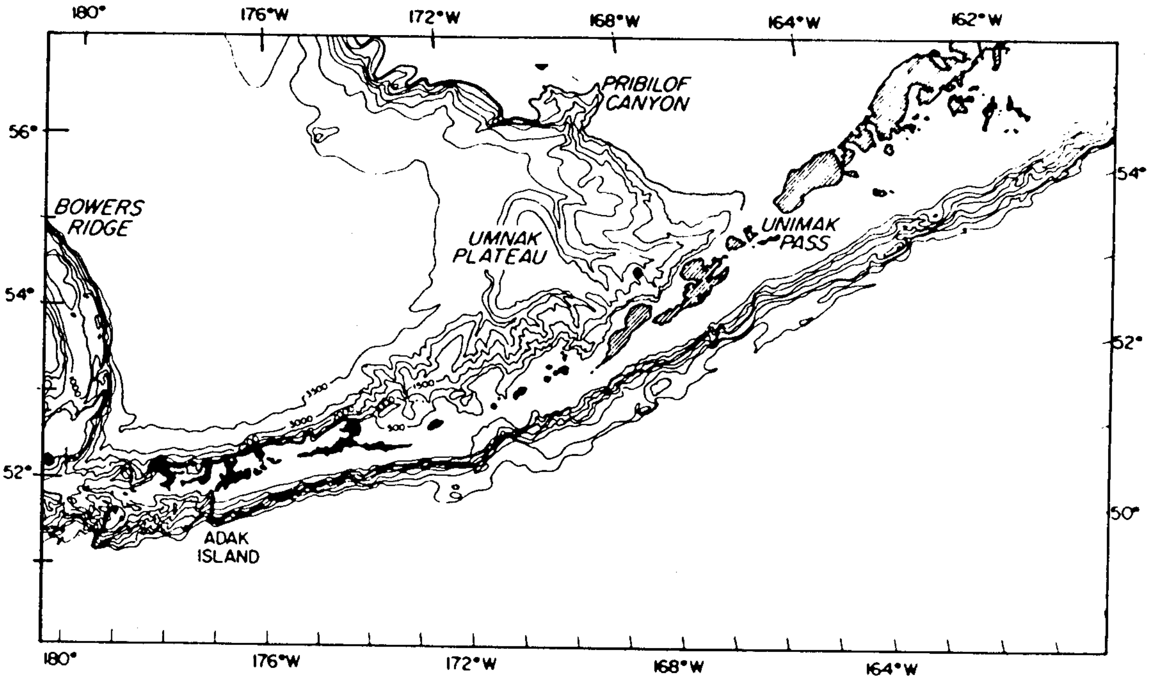
- Maximum extent of sea ice in winter varies, sometimes approaching Unimak Pass from the north.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Sea ice almost never invades the eastern Aleutian study area but affects most of the North Aleutian Shelf in some years.

CONSEQUENCES TO BIOTA

- Sea otters are limited in their northward distribution in winter by the presence of sea ice; they are thus common in the Unimak Pass and Unimak Island area but become scarce toward the northeastern end of the NAS.
- Walruses become scarce southward of the maximum extent of sea ice, thus are more common on the NAS than in the eastern Aleutians.



TOPOGRAPHIC CHARACTERIZATION

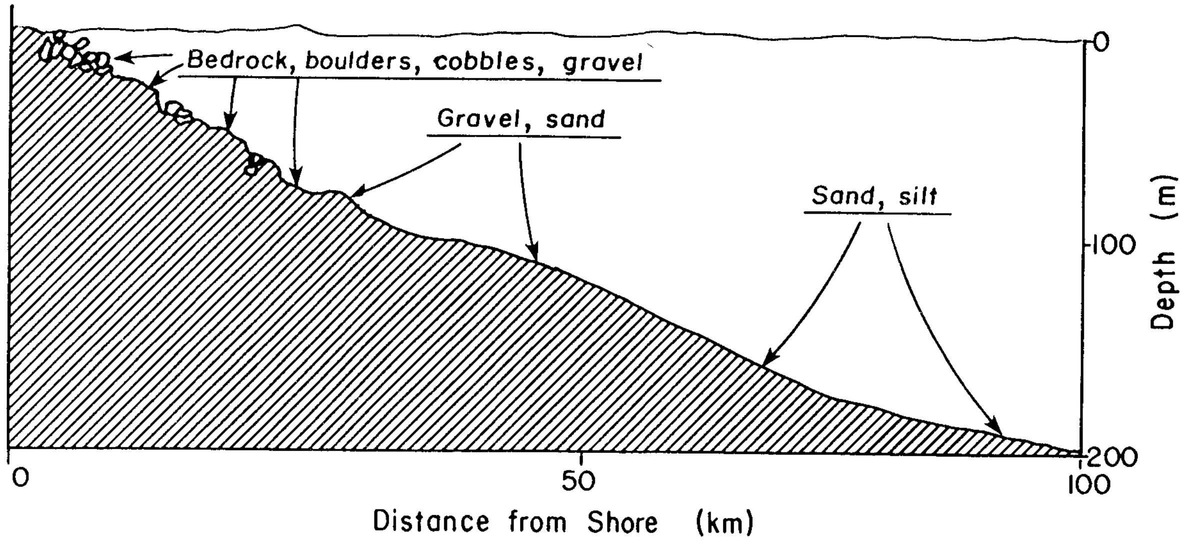
(Subsea topography from Kinder 1981)

IMPORTANT COMPONENT

- Subsea topographic configurations vary greatly from place to place in the eastern Aleutians; steep and variable topography is common.
- The study area contains the farthest eastward ocean passes between the North Pacific Ocean and Bering Sea.

CONSEQUENCES TO BIOTA

- Steep slopes in the eastern Aleutians provide ecological "edges" and a variety of microhabitats for vertebrates and invertebrates.
- Presence of the shelf edge near and within the study area promotes upwelling and biological enrichment.
- Presence of ocean passes at a strategic place between the North Pacific and Bering Sea promotes concentration points for migrating animals and transported materials.



SUBSTRATE TYPE AND DEPTH

IMPORTANT HABITAT COMPONENT

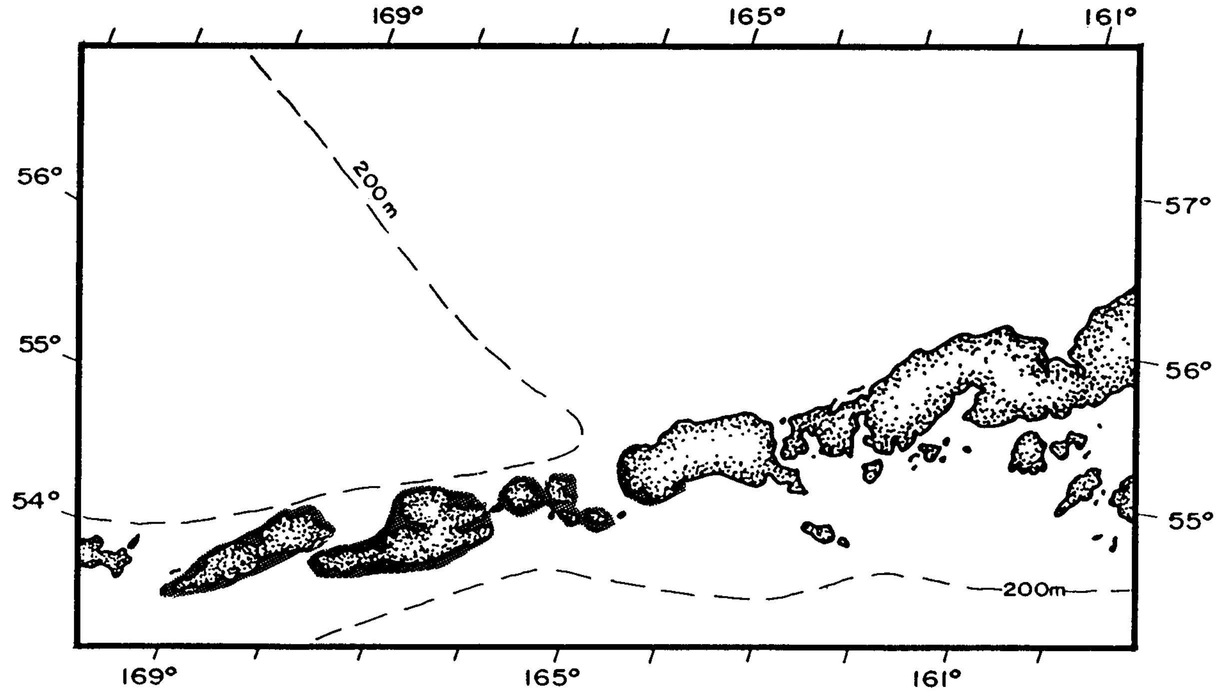
- Substrate types range from bedrock and boulders in shallow areas to fine-grained silt in deep areas.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Bedrock, boulders and cobbles are more common as substrates in shallow areas of the eastern Aleutians than they are on the NAS, and the water deepens more rapidly in the eastern Aleutians with distance from shore.

CONSEQUENCES TO BIOTA

- Different benthic biological communities live in different substrate types and water depths. Rocky, gravelly substrates common in shallow waters of the eastern Aleutians host vegetation, invertebrate, and fish communities that are rare or non-existent on the NAS.



PRODUCTIVITY OF INSHORE HABITATS

IMPORTANT PROCESSES

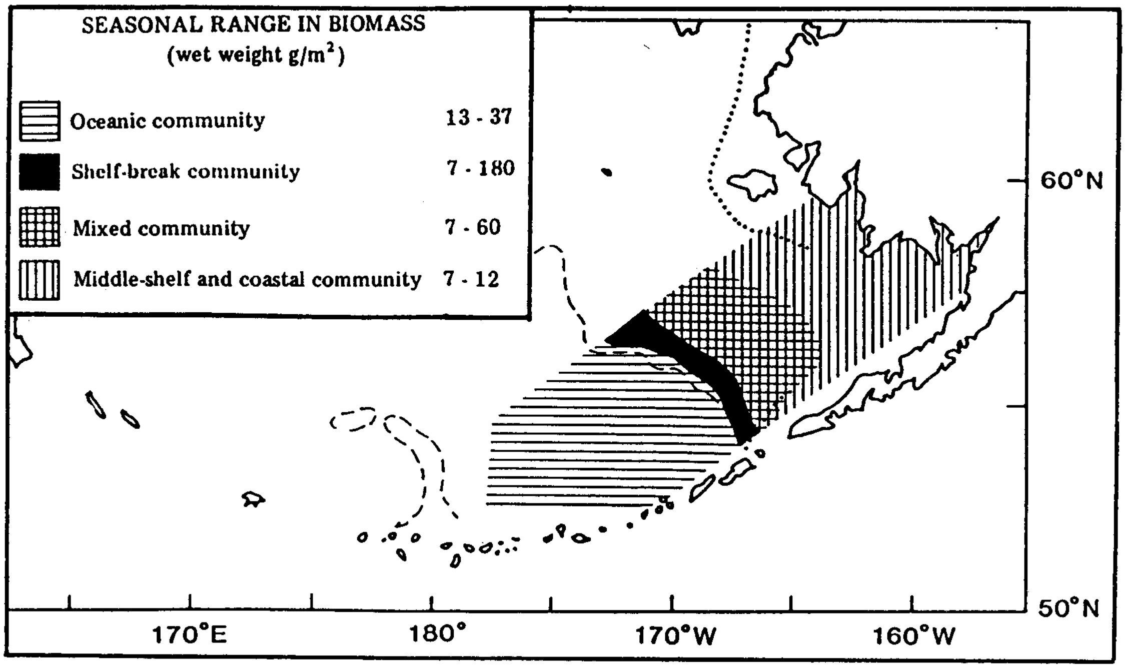
- The primary and secondary productivity in inshore habitats (bays and other shallow coastal waters) may contribute significantly to support of regionally-important populations.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Inshore production on the North Aleutian Shelf (e.g., Izembek Lagoon) contributes a small proportion of the total shelf production; whether the same is true of the eastern Aleutians is not known.

CONSEQUENCES TO BIOTA

- The consequences of inshore production could be significant to some species.



ZOOPLANKTON COMMUNITIES

(Map from Cooney 1981)

USE OF UNIMAK PASS AREA

- There are two distinctive communities of copepods and euphausiids, with a zone of mixing between them.
- Biomass of copepods is highest (but most variable) on the outer Bering Shelf near Unimak Pass where upwelling enhances phytoplankton production.

IMPORTANT HABITATS

- Relatively warm and deep waters of the oceanic-outer shelf area provide good overwintering habitat for oceanic species of copepods, thereby facilitating high year-round standing stocks.

IMPORTANT TROPHIC LINKS

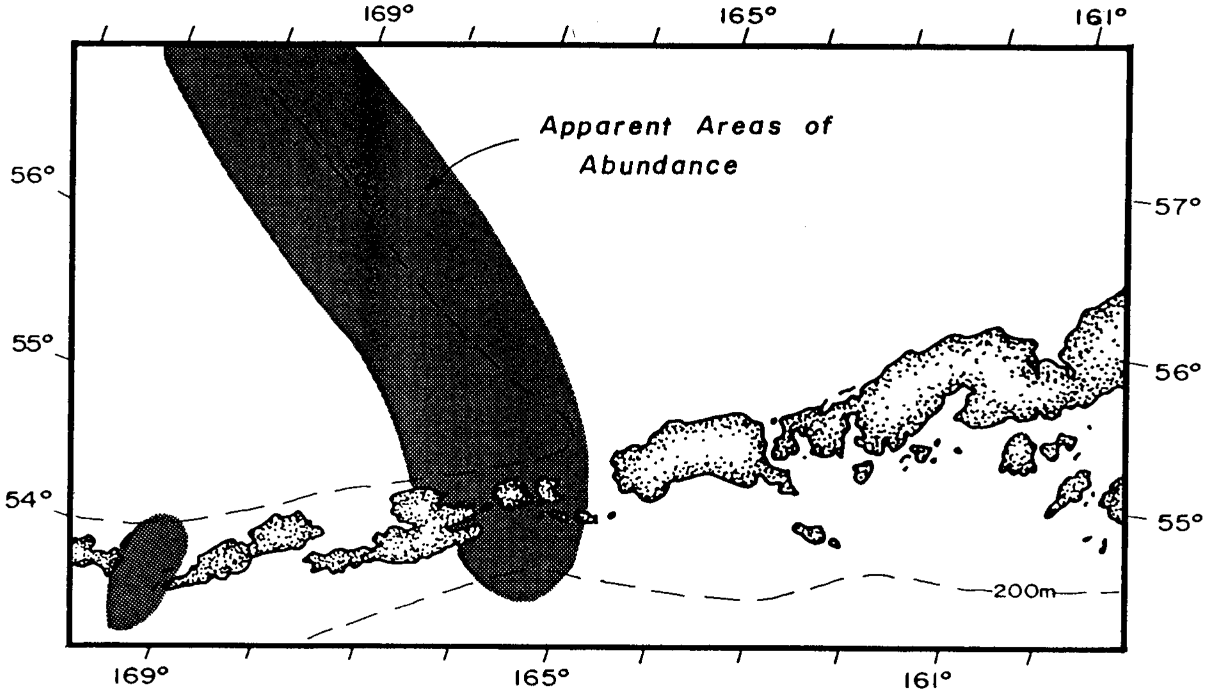
- Zooplankton are major foods of seabirds, fish and marine mammals.
- Copepods and euphausiids eat phytoplankton, though euphausiids can switch to zooplankton (copepods, crustaceans) and fish (eggs and larvae) when phytoplankton levels are low.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- These two areas have basically dissimilar zooplankton community compositions (and perhaps biomasses), with one major exception--because both the nearshore NAS and the eastern parts of Unimak Pass proper are dominated by Alaska Coastal Current water, their zooplankton communities are probably similar.

VULNERABILITY TO OIL AND GAS ACTIVITY

- Zooplankton populations are probably relatively invulnerable (except locally)because of their widespread distribution and abundance.



CEPHALOPOD ABUNDANCE

USE OF UNIMAK PASS AREA

- Squid and octopus distributions are concentrated along the shelf break and other areas with steep or diverse topography.

IMPORTANT TROPHIC LINKS

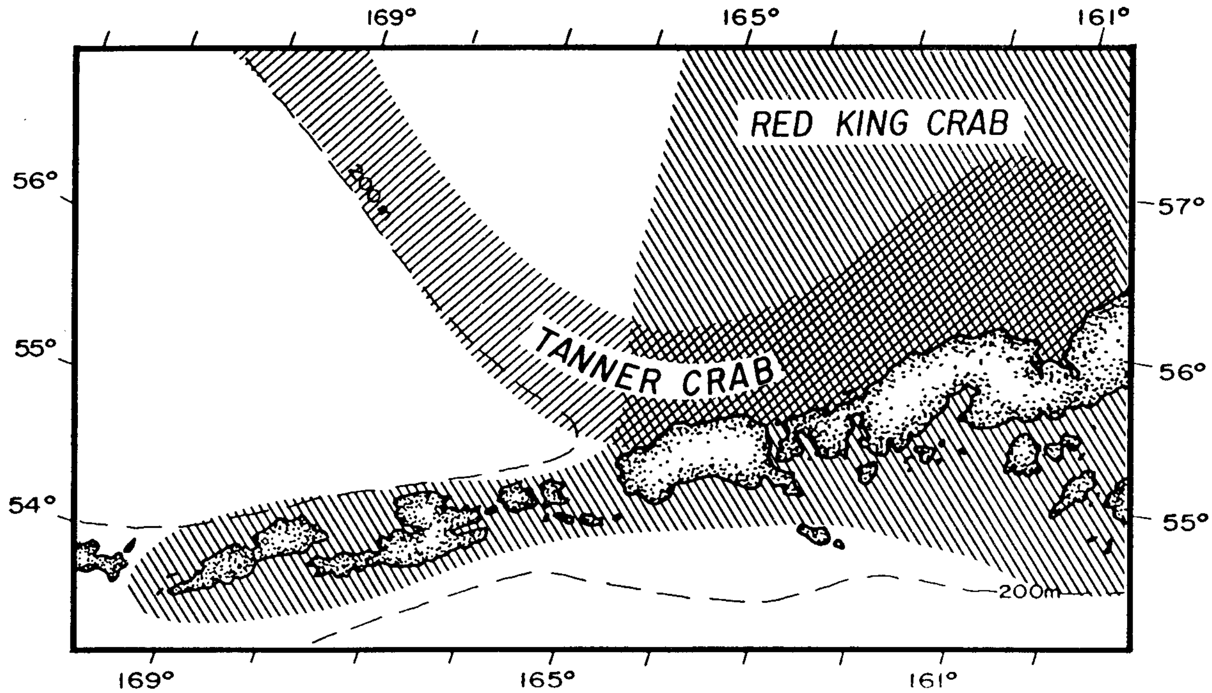
- Squid are eaten by whales, seals and salmon.
- Young squid eat small planktonic crustaceans and fish larvae; adults consume other planktonic crustaceans and each other.
- Octopus eat benthic invertebrates (crabs, molluscs).

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Squids and octopuses are much more abundant along the shelfbreak and among the islands than along the shallow and relatively flat-bottomed North Aleutian Shelf.

VULNERABILITY TO OIL AND GAS ACTIVITY

- Populations of cephalopods are probably relatively invulnerable because of their widespread distribution.



CRAB ABUNDANCE

USE OF UNIMAK PASS AREA

- King, Tanner and Dungeness crabs are distributed throughout the eastern Aleutians area, but the former are most abundant. King and Tanner crabs are deeper-water species than Dungeness.

IMPORTANT HABITATS

- Mating and rearing areas for red king crabs occur near some Aleutian islands.

TROPHIC LINKS

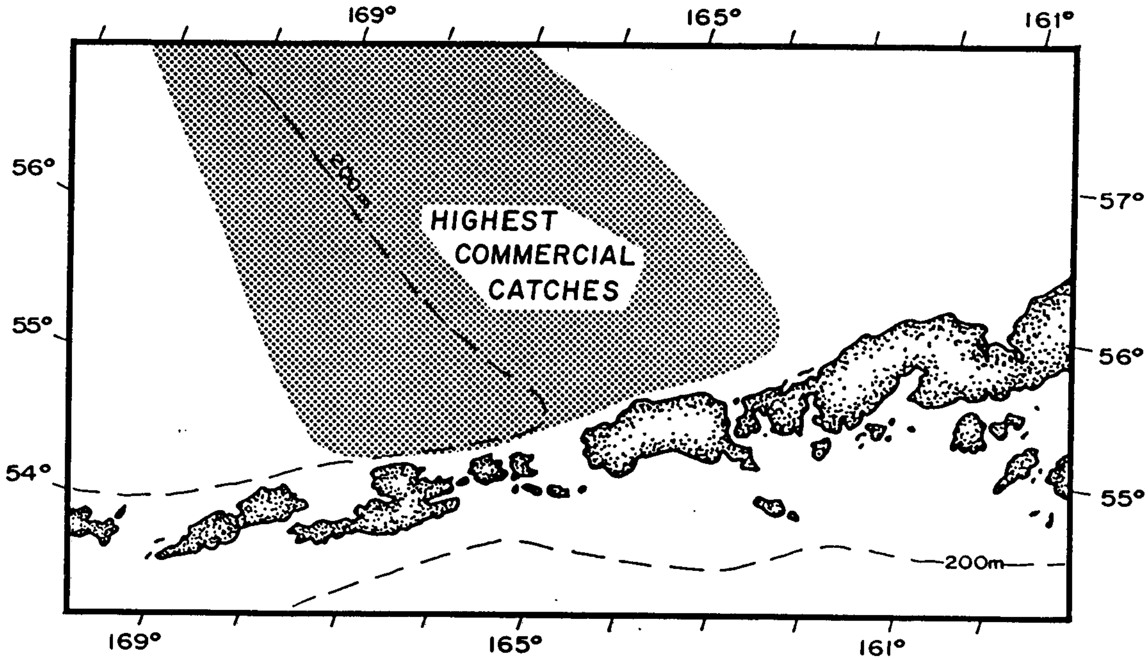
- Crabs are harvested by man and eaten by bottomfishes and sea otters.
- Red king and Tanner crab foods include (for crab larvae) diatoms, copepods, other zooplankton; (for juveniles) polychaetes, sand dollars, bivalves, oligochaetes, etc.; (and for adults) polychaetes, molluscs, crustaceans and brittle stars. Dungeness crab adults consume more fish.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Tanner crabs are more abundant on the shelf to the east of the Aleutians but red king crabs are generally abundant in both areas.

VULNERABILITY TO OIL AND GAS ACTIVITY

- Potential mortalities of planktonic larvae or newly settled juveniles would probably be local in extent and thus regionally not significant.



GROUNDFISH ABUNDANCE

USE OF UNIMAK PASS AREA

- Numerous groundfish species are distributed throughout this region and use the area for spawning, feeding, migrating and/or overwintering. Dominant species (walleye pollock and Pacific cod) are also distributed throughout, but highest commercial catches occur along shelf breaks.

IMPORTANT HABITATS

- Nearshore areas are important habitats for juveniles of some species.
- Continental shelf breaks on north and south sides of Aleutians serve as feeding, spawning and/or overwintering areas for many species.

IMPORTANT TROPHIC LINKS

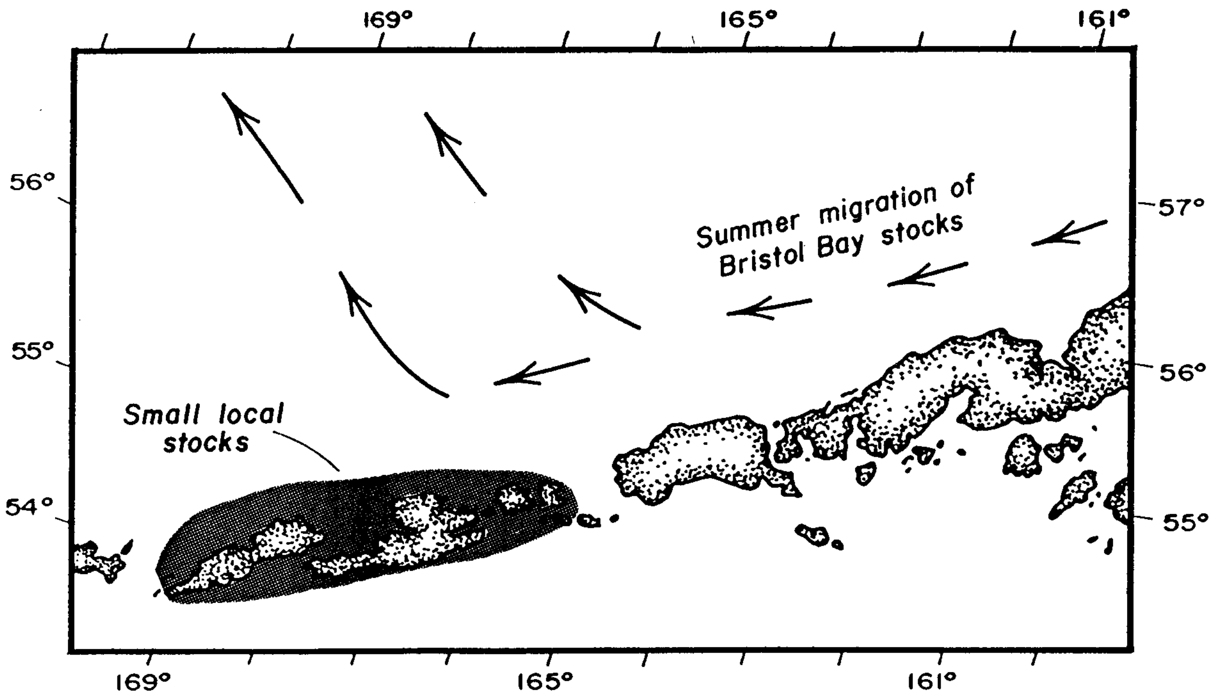
- Pollock larvae eat copepods; juveniles eat copepods, euphausiids, and amphipods; adults eat euphausiids, small pollock and fish.
- Pacific cod juveniles eat copepods and other zooplankton; adults eat pollock, shrimp, crabs, etc.
- Flatfishes eat primarily benthic and epibenthic invertebrates, but adults sometimes eat forage fish.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Pollock and Pacific cod are much more abundant in deeper waters near the shelf break than in the shallow waters along the North Aleutian Shelf. Yellowfin and rock soles are probably more abundant on the NAS, but good comparative data are lacking.

VULNERABILITY TO OIL AND GAS ACTIVITY

- Pelagic eggs and larvae would be sensitive to oil spills but the overall impact would be small due to abundance and widespread distribution of eggs and larvae.



HERRING MIGRATION AND ABUNDANCE

USE OF UNIMAK PASS AREA

- Major stocks of Bristol Bay herring (Togiak stocks) migrate here for summer feeding.
- Relatively small local stocks use the area for spawning and rearing.

IMPORTANT HABITATS

- Spawning and nursery areas around Unalaska Island.
- Major summer feeding area north of Unimak Pass.

IMPORTANT TROPHIC LINKS

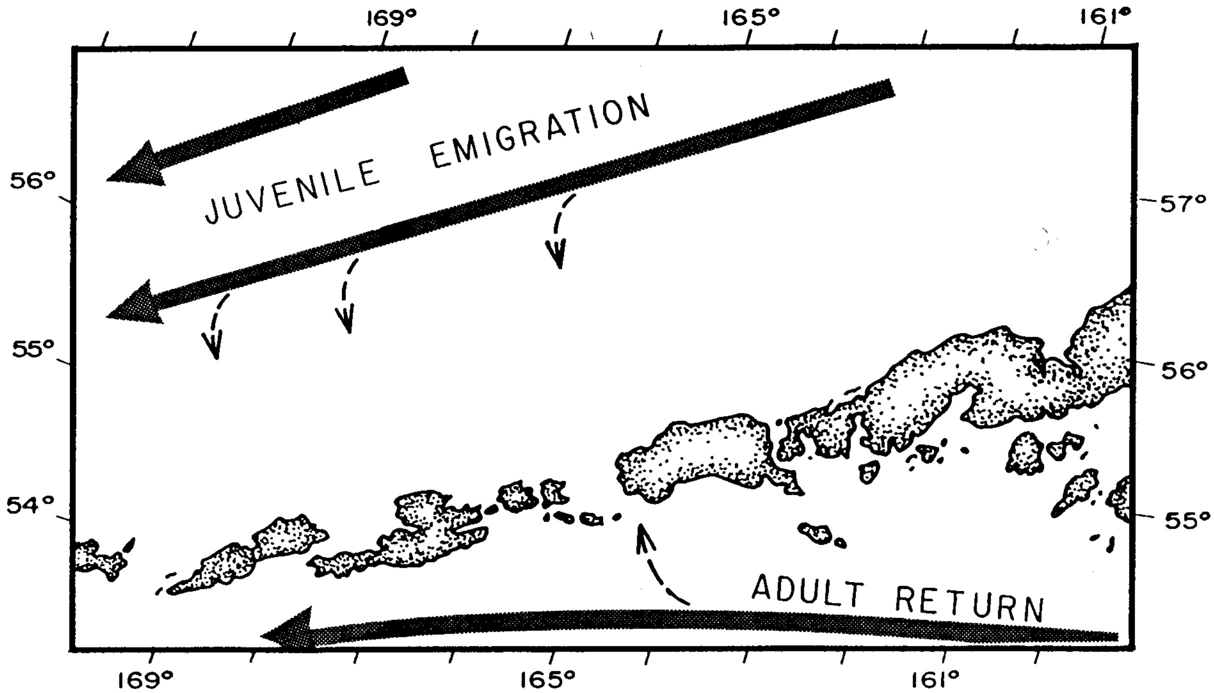
- Herring are prey of many seabirds, marine mammals and other fishes.
- Larval herring consume copepods, other small zooplankton and diatoms; juveniles eat copepods, amphipods, euphausiids, and other zooplankton; adults eat euphausiids, fish fry, copepods and other zooplankton.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Relatively small spawning stocks occur in both areas, but apparently much more summer feeding occurs near the Aleutian study area.

VULNERABILITY TO OIL AND GAS ACTIVITY

- There could be possible loss of a year-class of a local stock to an oil spill, but the overall threat to survival of population is low.



SALMON MIGRATION

USE OF UNIMAK PASS AREA

- Relatively small populations of local stocks, primarily pink salmon, use coastal waters for feeding and migrating.
- Bristol Bay stocks migrate through Aleutian passes to and from the North Pacific Ocean.

IMPORTANT HABITATS

- Nearshore areas on the north side of Unalaska Island host and provide food for newly smolted juveniles.
- Presence of island passes is important for migrating salmon.

IMPORTANT TROPHIC LINKS

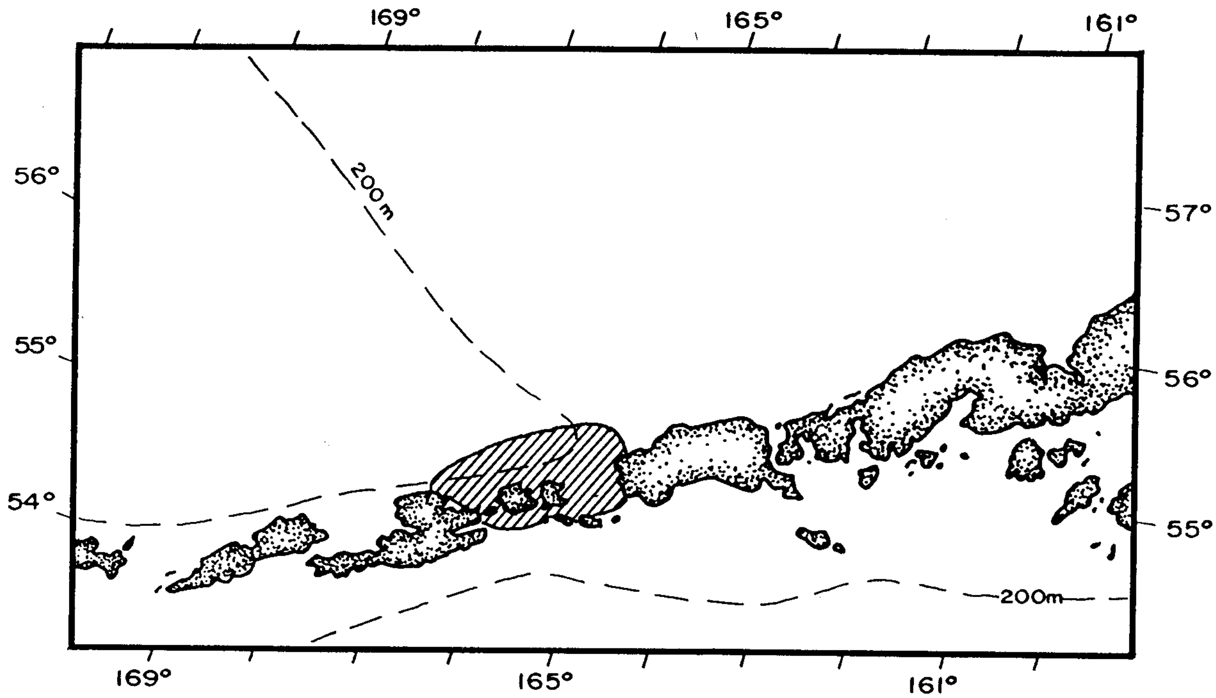
- Fry consume copepods, euphausiids and amphipods; juveniles eat sand lance, euphausiids, amphipods, copepods and mysids; adults eat euphausiids, fish and mysids.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- The two areas are generally similar in their uses by salmon.

VULNERABILITY TO OIL AND GAS ACTIVITY

- Smolts of local stocks are vulnerable during the brief period that they are dependent on estuarine habitats, but complete loss of a year-class is unlikely except very locally.
- Oil could possibly taint fish flesh in local areas and thus affect the commercial fishery.



BIRD AND MAMMAL FEEDING CONCENTRATIONS

USE OF UNIMAK PASS AREA

- Many birds (e.g., Short-tailed Shearwater, Northern Fulmar, Whiskered Auklet, Crested Auklet), and marine mammals (e.g., minke, humpback, and fin whales) concentrate mainly north and west of the Unimak Pass area to feed.

IMPORTANT HABITATS

- Concentrations seem to frequently occur near or east of the shelf edge.

IMPORTANT TROPHIC LINKS

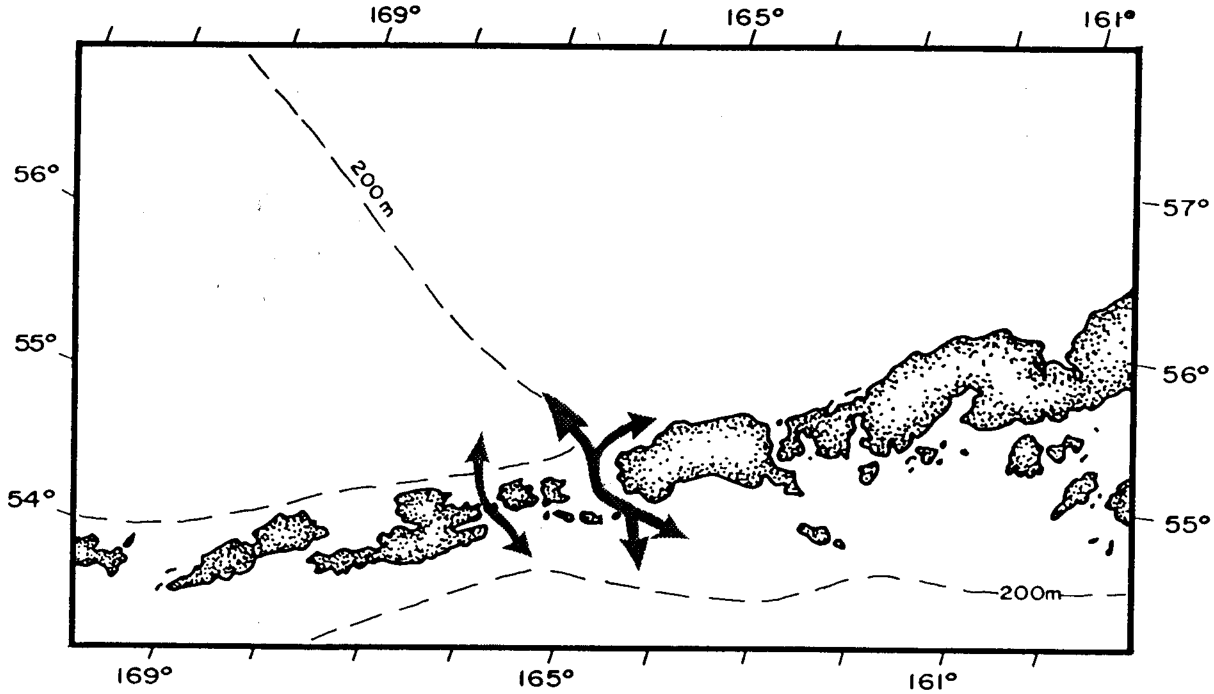
- Most of the species that concentrate in this area are zooplanktivorous, at least while they are in the area.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- Large concentrations of birds and mammals such as are found in the eastern Aleutians are not present on the North Aleutian Shelf.

VULNERABILITY TO OIL AND GAS ACTIVITY

- These areas of concentration are in or near potential Unimak Pass shipping lanes.



BIRD AND MAMMAL MIGRATION CORRIDORS

USE OF UNIMAK PASS AREA

- Many birds (e.g., shearwaters, fulmars, kittiwakes, murres, Steller's eider) and marine mammals (e.g., fur seal and several whale species) funnel through Unimak and adjacent passes during spring and fall migrations.

IMPORTANT HABITATS

- The presence of the passes as the farthest east gateways between the North Pacific Ocean and the Bering Sea is a major consideration.
- The coincident concentrations of prey in the area may enhance its utility as a passageway.

IMPORTANT TROPHIC LINKS

- The area in and near (especially north and west of) the passes appears to be a rich feeding area for migrating vertebrates.

COMPARISON: EASTERN ALEUTIAN PASSES VS. NORTH ALEUTIAN SHELF

- The North Aleutian Shelf has no comparable function as a constricted passageway for many species, except for gray whales.

VULNERABILITY TO OIL AND GAS ACTIVITY

- The areas of concentration in the passes coincide with potential shipping lanes.

8. ADEQUACY OF THE DATABASE

This section evaluates the adequacy of the existing database to provide reasonable predictions about potential impacts of OCS activities on the important species. Information supporting this evaluation is from previous sections, particularly the preceding one on the implications for impacts of oil and gas development.

It is apparent from previous sections that the potential for adverse impact hinges on the simultaneous occurrence of OCS activities and sensitive organisms in time and space. It is also obvious that the database does not describe spatial and temporal distributions of the biota in sufficient detail for impacts of activities to be predicted. (We did not review in depth the existing information on spatial and temporal distributions of OCS activities. Two important areas of understanding can be productively addressed by further study--(1) the seasonal and spatial distributional and use patterns of organisms that are both important to man and susceptible to significant adverse impact, and (2) their relationship to the timing, spatial extent, and nature of expected OCS activities. It is unlikely that further studies of the sensitivities of species or their expected responses to OCS activities can be similarly productive at this point.

Focusing on these information needs, we first develop in the following paragraphs hypotheses about potential impacts. Then we identify the kinds of information needed for testing these hypotheses.

A. HYPOTHESES FOR TESTING

In our opinion, up to three major hypotheses might be productively tested to provide the information most needed to predict the effects of oil and gas development activities on important species in the eastern Aleutians area. All the hypotheses are focused on predicting spatial and temporal distributions of birds and mammals. These hypotheses are related; Hypothesis 1 (below) is the key hypothesis.

Hypothesis 1: Sensitive life stages of important species (i.e., selected birds and mammals) will be present in abundance at the same times and places as OCS activities (oil spills, vessel traffic, etc.) that are likely to have important adverse effects. A key part of testing this hypothesis is developing a capacity to predict bird and mammal distributions, and distributions of OCS activities, in time and space. If predicting bird and mammal distribution is relatively easy to do, testing Hypotheses 2 and 3 cannot be justified.

Hypothesis 2: Birds and mammals that concentrate to feed at specific localities do so because their fish or invertebrate prey is concentrated there. Testing this hypothesis might provide a tool to better predict bird and mammal distributions, if prey distributions are relatively easy to predict.

Hypothesis 3: Densities of zooplanktonic prey are correlated with circulation and upwelling patterns that enrich the euphotic zone and/or physically concentrate the zooplankton. The need to test this hypothesis hinges on demonstrating that prey distributions influence bird and mammal distributions (Hypothesis 2). It is the lowest priority for testing, and in any case would be difficult to justify testing until Hypotheses 1 and 2 have been thoroughly tested.

B. INFORMATION NEEDS FOR TESTING HYPOTHESES

Data needed to test these hypotheses are of several kinds. Information on OCS activities and on distributions and abundances of important species are necessary for testing Hypothesis 1. Information on prey distributions (best collected simultaneously with information on consumer distributions), could help address Hypothesis 2. Information on physical processes, best collected coincidentally with data on prey distributions, could help respond to Hypotnesis 3. A summary of suggested information needs follows; note again that needs for testing Hypothesis 1 are top priority.

Hypothesis 1

The following types of information are needed to help test Hypothesis 1:

(1) Expected times and places of oil spills in the vicinity of Unimak Pass. (The probable trajectories of spilled oil for localities in and near Unimak Pass have already been investigated.)

(2) Expected times, levels, and locations of ship traffic through the Unimak Pass area.

(3) Seasonal distribution and abundance patterns of northern fur seals, Steller sea lions (especially juveniles), and sea otters in the eastern Aleutian Islands.

(4) Seasonal distribution and abundance patterns of the abundant alcids (auklets, puffins, murres), especially in winter.

Hypothesis 2

If testing of Hypothesis 1 does not provide a capability to accurately predict seasonal distributional patterns of the mammals and birds of interest, then collection of the following information to test Hypothesis 2 may be warranted:

(1) Bird and mammal distribution in relation to the seasonal distributional patterns of forage fish important in their diets (e.g., herring, capelin, sand lance).

(2) Bird, fish, and mammal distribution in relation to the seasonal distributional patterns of the cephalopods, euphausiids, and copepods important in their diets.

Hypothesis 3

Should Hypothesis 3 need to be tested, the following kinds of information needs are suggested:

(1) Correlation between primary productivity distributional patterns and zooplankton abundance.
(2) Influence of microscale physical phenomena (tide rips, fronts) in concentrating euphausiids and copepods.
(3) Seasonal and spatial patterns of upwelling in passes between the islands and on the adjacent shelf.
(4) Correlations between upwelling patterns and observed bird, mammal, fish, and zooplankton abundance.

9. LITERATURE CITED

ADFG (Alaska Dep. Fish & Game). 1983. Legislative report, 1982 Aleutian Islands salmon stock assessment study (1983 supplement). Div. Comm. Fish., Juneau. 17 pp.

ADFG (Alaska Dep. Fish & Game). 1985a. Alaska habitat management guide, Southwest Region. Vols. 1-4. Div. Habitat, Juneau.

ADFG (Alaska Dep. Fish & Game). 1985b. Westward region shellfish report to the Alaska Board of Fisheries. Div. Comm. Fish. Kodiak.

ADFG (Alaska Dep. Fish & Game). 1985c. Alaska habitat management guide, Southwest Region, map series. ADFG, Habitat Div., Anchorage.

ADFG (Alaska Dep. Fish & Game). 1986. South Peninsula tagging study, ATA 87-0174. Div. Comm. Fish., Juneau.

Ainley, D.G. and G.A. Sanger. 1979. Trophic relations of seabirds in the northeastern Pacific Ocean and Bering Sea. U.S. Fish Wildl. Serv., Wildl. Res. Rep. 11:95-122.

Alaska Maritime National Wildlife Refuge. 1981. Results of a bird and mammal survey in the central Aleutian Islands, summer 1980. Unpubl. Rep., Aleutian Islands Unit. 189 pp.

Alverson et al. 1964. A study of demersal fishes and fisheries of the northwestern Pacific Ocean. H.R. MacMillan Lectures in Fisheries. Univ. British Columbia, Inst. Fish., Vancouver. 190 pp.

Alton, M.S. 1974. Bering Sea benthos as a food resource for demersal fish populations. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea. Univ. Alaska, Inst. Mar. Sci., Occas. Pub. No. 2, Fairbanks. pp. 257-277.

Alverez-Borrego, S., L.I. Gordon, L.B. Jones, P.K. Park and R.M. Pytkowitz. 1972. Oxygen-carbon dioxide-nutrients relationships in the southeastern region of the Bering Sea. J. Oceanogr. Soc. Japan 28:71-93.

Angell, J. and J. Korshover. 1982. Comparison of year average latitude, longitude and pressure of the four centers of action with air and sea temperature, 1899-1978. Monthly Weather Rev. 110:300-303.

Armstrong, D.A. 1983. Cyclic crab abundance and relationship to environmental causes. In: W.S. Wooster (ed.), From year to year: Interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. of Washington, Sea Grant Program. pp. 102-110.

Armstrong, D.A., L.K. Thorsteinson and C.A. Manen. 1984. Coastal habitats and species. In: L.K. Thorsteinson (ed.), The North Aleutian Shelf environment and possible consequences of offshore oil and gas development. U.S. Dep. Commer., NOAA, OMPA, Juneau, AK. pp. 35-114.

Armstrong, D.A., L.S. Incze, D.L. Wencker and J.L. Armstrong. 1983. Distribution and abundance of decapod larvae in the southeastern Bering Sea with emphasis on commercial species. Final Rep. to U.S. Dep. Commer., by Univ. Washington School of Fisheries, Seattle. 388 pp.

Arneson, P.D. 1977. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 2:1-95.

Arneson, P.D. 1980. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP.

Arsen'ev, V.S. 1967. Currents and water masses of the Bering Sea. Izd. Nauka, Moscow. (Transl. 1968 by U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA). 135 pp.

Ashmole, N.P. 1971. Sea bird ecology in the marine environment. In: D.S. Farner and J.R. King (eds.), Avian biology, Vol. 1. Academic Press, New York. pp. 223-286.

Atkinson, C. 1955. A brief review of the salmon fishery in the Aleutian Islands area. Int. North Pacific Fish. Comm. Bull. 1:93-104.

Bailey, E.P. and J.L. Trapp. 1984. A second wild breeding population of the Aleutian Canada Goose. Am. Birds 38:284-286.

Bailey, K. and J. Dunn. 1979. Spring and summer foods of walleye pollock in the eastern Bering Sea. Fish. Bull. 77:304-308.

Baker, E.T. 1981. North Aleutian Shelf transport experiment. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 6:329-390.

Baker, E.T. 1983. Suspended particulate matter distribution, transport, and physical characteristics in the North Aleutian Shelf and St. George Basin lease areas. Draft final rep. to U.S. Dep. Commer., NOAA, OCSEAP. 134 pp.

Bakkala, R. 1981. Pacific cod of the eastern Bering Sea. Rep. by U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA. 49 pp.

Bakkala, R. 1984. Research and commercial fisheries data bases for eastern Bering Sea groundfish. In: B. Melteff and D. Rosenberg (eds.), Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea. Univ. Alaska, Alaska Sea Grant Rep. 84-1. pp. 39-66.

Bakkala, R. and L. Low (eds.). 1983. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1982. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-42. 187 pp.

Bakkala, R. and L. Low (eds.). 1984. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1983. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-53. 189 pp.

Bakkala, R. and L. Low (eds.). 1985. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands Region in 1984. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83. 196 pp.

Bakkala, R., J. Traynor, K. Teshima, A. Shimada and H. Yamaguchi. 1985. Results of cooperative U.S.-Japan groundfish investigations in the eastern Bering Sea during June-November 1982. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-87. 448 pp.

Bakkala, R., V. Wespestad and H. Zenger. 1983. Pacific cod. In: R. Bakkala and L. Low (eds.), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1982. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC. 187 pp.

Banister, J. and E. Mitchell. 1980. North Pacific sperm whale stock identity: Distributional evidence from Maury and Townsend charts. Rep. Int. Whal. Comm. (Special Issue) 2:219-230.

Barabash-Nikiforov, I. 1938. Mammals of the Commander Islands and the surrounding sea. J. Mammal. 19:423-429.

Barnes, C.A. and T.G. Thompson. 1938. Physical and chemical investigations in the Bering Sea and portions of the North Pacific Ocean. Univ. Washington Publ. Oceanogr. 3:35-79 + Appendix pp. 1-164.

Barton, L. 1979. Finfish resource surveys in Norton Sound and Kotzebue Sound. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 4:75-313.

Barton, L. and D. Steinhoff. 1980. Assessment of spawning herring and capelin stocks at selected coastal areas in the eastern Bering Sea. North Pacific Fish. Manage. Council, Anchorage, AK. Council Doc. No. 18. 63 pp.

Barton, L., V. Wespestad. 1980. Distribution, biology and stock assessment of western Alaska's herring stocks. In: Proceedings of the Alaska Herring Symposium. Alaska Sea Grant Rep. 80-4. pp. 27-53

Bax, N. 1985. Simulations of the effects of potential oil spill scenarios on juvenile and adult sockeye salmon migrating through Bristol Bay, Alaska. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Proc. Rep. 85-03. 128 pp.

Beardsley, G.F. Jr., H. Pak and K. Carder. 1970. Light scattering and suspended particles in the eastern equatorial Pacific Ocean. J. Geophys. Res. 75:2837-2845.

Beikman, H.M. 1975. Preliminary geologic map, Alaska Peninsula and Aleutian Islands. U.S. Geol. Surv. Map MF-674.

Bell, R. and G. St. Pierre. 1970. The Pacific halibut. Int. Pacific Halibut Comm., Tech. Rep. 6. 24 p.

Bellrose, F.C. 1976. Ducks, geese and swans of North America. Stackpole Books, Harrisburg, PA. 544 p.

Berzin, A.A. 1959. O pitanii kashalota v Beringovom More (On the feeding of sperm whales (Physeter catodon) in the Bering Sea). Izv. TINRO 47:161-165. In Russian. (Transl. by Univ. Washington College of Fisheries, Seattle, 1979, 9 pp.)

Berzin, A.A. 1971. Kashaot (The sperm whale). Izd. Pishch. Prom., Moscow. In Russian. (Transl. by Israel Program Sci. Transl., 1972, NTIS No. TT 71-50152, 394 p.)

Berzin, A.A. and A.A. Rovnin. 1966. The distribution and migrations of whales in the northeastern part of the Pacific, Chukchi and Bering seas. Izvestia TINRO 58:179-207.

Best, E. 1981. Halibut ecology. In: D.W. Hood and J. Calder (eds.), The eastern Bering She shelf: Oceanography and resources. U.S. Dep. Commer., NOAA, OMPA, Univ. Washington Press, Seattle. Vol. 1. pp. 495-508.

Best. E. and W. Hardman. 1982. Juvenile halibut surveys, 1973-1980. Int. Pacific Halibut Comm. Tech. Rep. 20. 38 pp.

Betesheva, E.I. 1961. Pitanie promyslovykh kitov Prikuril'skogo raiona (Food of commercial whales in the Kurile region). Tr. Inst. Morfol. Zhivotnykh Akad. Nauk SSSR 34:7-32. In Russian. (Abstr. transl. in Biol. Abstr. 43(1), entry 469.)

Bigg, M.A. 1985. Arrival of northern fur seals, Callorhinus ursinus, on St. Paul Island, Alaska. Fish. Bull. 84:383-394.

Birkeland, K.G. 1926. The whalers of Akutan. Yale Univ. Press, New Haven, CT. 171 pp.

Black, R.F. 1974a. Geology and ancient Aleuts, Amchitka and Umnak Islands, Aleutians. Arctic Anthropology 11:126-140.

Black, R.F. 1974b. Late-Quaternary sea-level changes, Umnak Island, Aleutians--their effects on ancient Aleuts and their causes. Quaternary Research 4:264-281.

Black, R.F. 1975. Late-Quaternary geomorphic processes--effects on the ancient Aleuts of Umnak Island in the Aleutians. Arctic 28:159-169.

Black, R.F. 1976. Geology of Umnak Island, eastern Aleutian Islands, as related to the Aleuts. Arctic and Alpine Research. 8:7-35.

Blackburn, J., P. Rigby and D. Owen. 1980. An observer program for the domestic groundfish fisheries in the Gulf of Alaska and Bering Sea/Aleutian Islands. North Pacific Fish. Manage. Council, Council Document No. 16. Anchorage, AK. 50 pp.

Bourne, W.R.P. 1976. Seabirds and pollution. In: R. Johnson (ed.), Marine pollution. Academic Press, New York. pp. 403-502.

Brower, W.A., H.F. Diaz, A.S. Prechel, H.W. Searby and J.L. Wise. 1977. Climatic atlas of the outer continental shelf waters and coastal regions of Alaska, Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 2:1-443.

Bradstreet, M.S.W. 1985. Feeding studies. In: S.R. Johnson (ed.), Population estimation, productivity, and food habits of nesting seabirds at Cape Peirce and the Pribilof Islands, Bering Sea, Alaska. Rep. by LGL Ecol. Res. Assoc., Inc., to U.S. Dep. Int., MMS, Anchorage, AK. pp. 257-306.

Braham, H.W. 1977. California gray whale (*Eschrichtius robustus*) spring migration in Alaska. In: Proc. (abstracts), Second Conf. Biol. Mar. Mammals, San Diego, 12-15 December 1977. pp. 59.

Braham, H.W. 1984a. Distribution and migration of gray whales in Alaska. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale, (*Eschrichtius robustus* Lilljebord, 1861). Academic Press, New York.

Braham, H.W. 1984b. The status of endangered whales: an overview. Marine Fish. Rev. 46:2-6.

Braham, H.W. and M.E. Dahleim. 1982. Killer whales in Alaska documented in the platforms of opportunity program. Rep. Int. Whal. Comm. 32:643-646.

Braham, H.W., R.D. Everitt, B.D. Krogman, D.J. Rugh and D.E. Withrow. 1977. Marine mammals of the Bering Sea: Preliminary analyses of distribution and abundance, 1975-76. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA. 90 pp.

Braham, H.W., R.D. Everitt and D.J. Rugh. 1980. Northern sea lion population decline on eastern Aleutian Islands. J. Wildl. Manage. 44:25-33.

Braham, H.W., C.H. Fiscus and D.J. Rugh. 1977. Marine mammals of the Bering and southern Chukchi seas. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 1:1-99.

Braham, H.W., L.L. Jones, G.C. Bouchet and A.T. Actor. 1983. Distribution of sightings of Dall's and harbor porpoise in the eastern North Pacific. Document SC/35/SM18 presented to the IWC Scientific Committee. Cambridge England. June-July 1983. 9 pp.

Braham, H.W. and R.W. Mercer. 1978. Seasonal distribution and relative abundance of marine mammals in the Gulf of Alaska. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 1:15-30.

Braham, H.W., G.W. Oliver, C. Fowler, K. Frost, F. Fay, C. Cowles, D. Costa, K. Schneider and D. Calkins. 1982. Marine mammals. In: M.J. Hameedi (ed.), Proceedings of the synthesis meeting: St. George environment and possible consequences of planned offshore oil and gas development, 28-30 April 1981, Anchorage, AK. U.S. Dep. Commer., NOAA, OMPA. pp. 55-81.

Brannian, L. 1984. Recovery distribution of chum salmon tagged in the North Pacific offshore of the Alaska Peninsula and eastern Aleutian Island chain. Alaska Dep. Fish & Game, Info. Leaflet 237. 30 pp.

Brueggeman, J.J., R.A. Grotefendt and A.W. Erickson. 1983. Endangered whale surveys of the Navarin Basin, Alaska. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP by Envirosphere Company, Bellevue, WA. 124 pp.

Brueggeman, J.J., T.C. Newby and R.A. Grotefendt. 1985. Seasonal abundance, distribution and population characteristics of blue whales reported in the 1917 and 1939 catch records of two Alaska whaling stations. Rep. Int. Whal. Comm. 35:405-411.

Brueggeman, J.J., T.C. Newby and R.A. Grotefendt. 1986. Catch records of the twenty North Pacific right whales from two Alaska whaling stations, 1917-39. Arctic 39:43-46.

Burk, C.A. 1965. Geology of the Alaskan Peninsula-Island arc and continental margin. Geol. Soc. Amer. Mem. 99, Part 1. 250 p.

Burk, C.A. 1966. The Aleutian Arc and Alaska continental margin. In: Continental margins and island arcs. Geol. Surv. of Canada Pap. 66-15. pp. 206-215.

Burrell, D.C., K. Tommos, A.S. Naidu and C.M. Hoskin. 1981. Some geochemical characteristics of Bering Sea sediments. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 305-319.

Bychkov, V.A. 1967. (On killer whale attacks on fur seals off Tyuleniy Island). Zool. Zhur. 46:149-150. In Russian. (Transl. unknown, in files U.S. Dep. Commer., NOAA, NMML, NMFS, Seattle, WA)

Byers, F.M., Jr. 1959. Geology of Umnak and Bogoslof islands, Aleutian Islands, Alaska. U.S. Geol. Surv. Bull. 1028-L:267-369.

Byrd, G.V. 1973. Expedition to Bogoslof and Amak Islands, with notes on other eastern Aleutian Islands, June 24 through July 8, 1973. Trip report, Aleutian Islands National Wildlife Refuge, U.S. Fish and Wildlife Service, Adak, Alaska. 36 pp.

Byrd, G.V., G.J. Divoky and E.P. Bailey. 1980. Changes in marine bird and mammal populations on an active volcano in Alaska. Murrelet 61:50-62.

Byrd, G.V. and D.D. Gibson. 1980. Distribution and population status of whiskered auklet in the Aleutian Islands, Alaska. Western Birds, 11:135-140.

Byrd, G.V., D.D. Gibson and D.L. Johnson. 1974. The birds of Adak Island, Alaska. Condor 76:288-300.

Cahn, A.R. 1947. Notes on the birds of the Dutch Harbor area of the Aleutian Islands. Condor 49:78-82.

Caldwell, D.K. and M.C. Caldwell. 1969. Addition of the leatherback sea turtle to the known prey of the killer whale Orcinus orca. J. Mammal. 40:636.

Calkins, D.G. 1978. Feeding behavior and major prey species of the sea otter, Enhydra lutris, in Montague Strait, Prince William Sound, Alaska. Fish. Bull. 76:125-131.

Carlson, H. 1980. Seasonal distribution and environment of Pacific herring near Auke Bay, Lynn Canal, Southeastern Alaska. Trans. Am. Fish. Soc. 109:71-78.

Chikuni, S. 1975. Biological study of the population of the Pacific Ocean perch in the North Pacific. Bull. Far Seas Fish. Res. Lab. 12:1-119.

Cimberg, R.L., D.P. Costa and P.A. Fishman. 1984. Ecological characterization of shallow subtidal habitats in the North Aleutian Shelf. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 44(1986):437-646.

Clarke, M. 1978. Some aspects of the feeding biology of larval walleye pollock in the southeastern Bering Sea. M.S. Thesis, Univ. Alaska, Fairbanks. 44 pp.

Cline, J.D. 1981. Distribution of dissolved low molecular weight hydrocarbons in Bristol Bay, Alaska. In: D.W. Hood, and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 435-444.

Codispoti, L.A., G.E. Frederich, R.L. Iverson and D.W. Hood. 1982. Temporal changes in the inorganic carbon system of the southeast Bering Sea during spring 1980. Nature 296:242-245.

Cooney, R.T. 1978. Environmental assessment of the southeastern Bering Sea: Zooplankton and micronekton. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 1:238-337.

Cooney, R.T. 1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 947-974.

Crawford, T. 1981. Vertebrate prey of Phoecoenoides dalli (Dall's porpoise) associated with the Japanese high seas salmon fishery in the North Pacific Ocean. M.S. Thesis, Univ. Washington, Seattle.

Cupp, E. 1937. Seasonal distribution and occurrence of marine diatoms and dinoflagellates at Scotch Cap, Alaska. Scripps Inst. of Oceanogr. Tech. Ser. 4:71-100.

Curl, H.E., Jr. and C.A. Manen. 1982. Shellfish resources. In: M.J. Hameedi (ed.), Proc. of a synthesis meeting: The St. George Basin environment and possible consequences of planned offshore oil and gas development. Anchorage, AK., 28-30 april 1981. U.S. Dep. Commer., NOAA, BLM, Anchorage.

Dagg, M. 1982. Zooplankton feeding and egg production in the southeast Bering Sea. Component 4b. In: PROBES: Processes and Resources of the Bering Sea shelf. Nat. Sci. Found. Office of Polar Programs, Final Prog. Rep. Vol. 1. 735 pp.

Dahlheim, M.D. 1981. A review of the biology and exploitation of the killer whale, Orcinus orca, with comments on the recent sightings from Antarctica. Rep. Int. Whal. Comm. 31:541-546.

Davies, J.N. 1977. A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Island-Eastern Aleutian Islands region of the Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Quart. Rep. 3:465-497

Davies, J.N. and K.H. Jacob. 1979. A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Islands-eastern Aleutian Islands region of the Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 9:2-93.

Davies, J.N., L.R. Sykes, L. House and K.H. Jacob. 1981. Shumagin seismic gap, Alaska Peninsula: History of great earthquakes, tectonic setting, and evidence for a high seismic potential. J. Geophys. Res. 86:3821-3855.

Davis, R.A., and D.H. Thomson. 1984. Marine mammals. In: J.C. Truett (ed.), Proc. of a synthesis meeting: The Barrow Arch environment and possible consequences of planned offshore oil and gas development. Girdwood, AK. 30 October-1 November 1983. U.S. Dep. Commer., NOAA, MMS, Anchorage, AK.

Day, R.H. 1980. The occurrence and characteristics of plastic pollution in Alaska's marine birds. M.S. Thesis, Univ. Alaska, Fairbanks. 111 p.

Dick, M.H. and W. Donaldson. 1978. Fishing vessel endangered by crested auklet landings. Condor 80:235-236.

Dick, M. and I. Warner. 1982. Pacific sand lance Ammodytes hexapterus in the Kodiak Island group, Alaska. Syesis 15:44-50.

Dobrovol'skii, A.D. and V.S. Arsen'ev. 1959. On the question of currents of the Bering Sea (in Russian). Probl. Severa 3:3-9 (Trans. National Res. Council, Ottawa).

Dodimead, A. J., F. Favorite and T. Hirano. 1963. Review of oceanography of the subarctic Pacific region. Int. North Pacific Fish. Comm. Bull. 13. 195 pp.

Donaldson, W.E. and D.M. Hicks. 1980. Explorations for the Tanner crab Chionoecetes bairdii off the coasts of Kodiak Island, the Alaska Peninsula and Aleutian islands, 1978 and 1979. Alaska Dept. Fish & Game Tech. Data Rep. No. 50. Juneau.

Drewes, H., G.D. Fraser, G.C. Snyder and H.F. Barnett, Jr. 1961. Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska. U.S. Geol. Surv. Bull. 1028-S:583-675.

Dudnik, Y. and E. Vsoltsev. 1964. The herring of the eastern part of the Bering Sea. In: P. Moiseev (ed.), Soviet Fisheries Invest. in the northeast Pacific. Vol. 2. (Transl. Israel Prog. Sci. Transl. 1968.) pp. 225-229.

Dugdale, R.C. and J.J. Goering. 1966. Dynamics of the nitrogen cycle in the sea. Univ. Alaska Inst. Mar. Sci. Rep. R-66-2. 23 pp.

Dugdale, R.C. and J.J. Goering. 1967. Uptake of new and regenerated forms of nitrogen in primary production. Limnol. Oceanogr. 12:196-206.

Dunlop, H., F. Bell, R. Myhre, W. Hardman and G. Southward. 1964. Investigation, utilization and regulation of the halibut in southeastern Bering Sea. Int. Pacific Halibut Comm., Rep. 35. 72 pp.

Estes, J. 1986. Marine otters and their environment. Ambio 15:181-183.

Estes, J.A., R.J. Jameson and E.B. Rhode. 1982. Activity and prey election in the sea otter and influence of population status on community structure. Am. Nat. 120:242-258.

Estes, J., R.J. Jameson and A.M. Johnson. In Press. Food selection and some foraging tactics of sea otters. In: Proc. Worldwide Furbearer Conf., Univ. Maryland Press.

Everitt, R.D. and H.W. Braham. 1978. Harbor seal (Phoca vitulina Richardii) distribution and abundance in the Bering Sea: Alaska Peninsula and Fox Islands. Proc. Ak. Sci. Conf. 29:389-398.

Everitt, R.D. and H.W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Sci. 54:281-288.

Farrington, J.W., N.M. Frew, P.M. Girchwend, and B.W. Tripp. 1977. Hydrocarbons in cores of northwestern Atlantic coastal and continental margin sediments. Estuarine and Coastal Marine Science 5:793-808.

Favorite, F. 1974. Flow into the Bering Sea through the Aleutian Island passes. In: D.W. Hood, and E.J. Kelley (eds.). Oceanography of the Bering Sea. Univ. Alaska Inst. Marine Sci. Occ. Pub. No. 2, Fairbanks, AK. pp. 3-37.

Favorite, F. 1985. A preliminary evaluation of surface winds, their anomalies, effects on surface currents, and relations to fisheries. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 85-21. 54 p.

Favorite, F., A.J. Dodimead and K. Nasu. 1976. Oceanography of the subarctic Pacific region, 1960-1971. Int. North Pacific Fish. Comm. Bull. 13. 187 pp.

Favorite, F., T. Laevastu and R. Straty. 1977. Oceanography of the northeastern Pacific Ocean and eastern Bering Sea, and relations to various living marine resources. U.S. Dep. Commer., NOAA, NMFS. Northwest and Alaska Fish. Center Processed Rep. 280 pp.

Feder, H.M. and S.C. Jewett. 1980. A survey of the epifaunal invertebrates of the southeastern Bering Sea with notes on the feeding biology of selected species. Univ. Alaska Inst. Mar. Sci. Rep. R78-5. 105 pp.

Feder, H.M. and S.C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1229-1261.

Feeley, R.A. and J.D. Cline. 1977. The distribution, composition, and transport of suspended particulate matter in the northeastern Gulf of Alaska, southeastern Bering Shelf, and lower Cook Inlet. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 13:89-179.

Feeley, R.A., G.J. Massoth, A.J. Paulson and M.F. Lamb. 1980. Distribution and elemental composition of suspended matter in Alaskan coastal waters. Rep. by U.S. Dep. Commer., NOAA PMEL to NOAA/NOS. Anchorage, AK.

Feeley, R.A., G.J. Massoth, A.J. Paulson, M.F. Lamb and E.A. Martin. 1981. Distribution and elemental composition of suspended matter in the Alaskan coastal waters. U.S. Dep. Commer., NOAA Tech. Memo. ERL-PMEL-27. 119 pp.

Fiscus, C.H. 1978. Northern fur seal. In: D. Haley (ed.), Marine mammals of eastern North Pacific and arctic waters. Pacific Search Press, Seattle. pp. 153-159.

Fiscus, C.H. 1980. Marine mammal-salmonid interactions: a review. In: W.J. McNeil and D.C. Himsworth (eds.), Salmonid ecosystems of the North Pacific. Oregon State Univ. Press, Corvallis. pp. 121-132.

Fiscus, C.H. 1982. Predation by marine mammals on squids of the eastern North Pacific Ocean and the Bering Sea. Mar. Fish. Rev. 44(2):1-10.

Fiscus, C.H. and G.A. Baines. 1966. Food and feeding behavior of Steller and California sea lions. J. Mammal. 47:195-200.

Fiscus, C., G. Baines, and F. Wilke. 1964. Pelagic fur seal investigations, Alaska waters, 1962. U.S. Fish and Wildl. Serv., Spec. Sci. Rep. Fish. No. 475. 59 p.

Fiscus, C.H., H.W. Braham, R.W. Mercer, R.D. Everitt, B.D. Krogman, P.D. McGuire, C.E. Peterson, R.M. Sonntag and D.E. Withrow. 1976. Seasonal distribution and relative abundance of marine mammals in the Gulf of Alaska. U.S. Dep. Commer. NOAA, NMFS Mar. Mammal Div., Processed Rep. Seattle. 238 pp.

Fiscus, C.H., D.J. Rugh and T.R. Loughlin. 1981. Census of northern sea lions (Eumetopic jubatus) in the central Aleutian Islands, Alaska, June 17-July 15, 1979, with notes on other marine mammals. U.S. Dep. Commer., NOAA, NMFS, NMML. Seattle, WA.

Forsell, D.J. 1983a. Observations of seabirds at Aiktak Island - August 1982. U.S. Fish and Wild. Serv., Nat. Fish. Res. Center - Seattle, Migratory Bird Section, Anchorage, AK.

Forsell, D.J. 1983b. Progress report on field studies in the Aleutian Islands, Semedi Islands, and Bering Sea, 1983. U.S. Fish and Wildl. Serv., Alaska Field Station of Denver Wildlife Research Center, Anchorage, AK.

Forsell, D.J. and P.J. Gould. 1980. Distribution and abundance of seabirds wintering in the Kodiak area of Alaska. U.S. Fish Wildl. Serv., Off. Biol. Serv., Coastal Ecosystems Team, Unpubl. Rep. 125 pp.

Fowler, C.W. 1982. Interactions of northern fur seals and commercial fisheries. In: Trans. 47th N. Am. Wildl. Nat. Res. Conf. pp. 278-293.

Fredin, R. 1985. Pacific cod in the eastern Bering Sea: a synopsis. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 85-05. 58 pp.

French, R. and R. Bakkala. 1974. A new model of ocean migrations of Bristol Bay sockeye salmon. Fish. Bull. 72:589-614.

French, R., H. Bilton, M. Osako, A. Hartt. 1976. Distribution and origin of sockeye salmon (Oncorhynchus nerka) in offshore waters of the North Pacific Ocean. Int. North Pacific Fish. Comm. Bull. No. 34. 113 p.

Fried, S. and V. Wespestad. 1985. Productivity of Pacific herring (Clupea harengus) in the eastern Bering Sea under various patterns of exploitation. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):181-191.

Frost, K.J. and L.F. Lowry. 1981. Foods and trophic relationships of cetaceans in the Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 825-836.

Frost, K., L.F. Lowry and J.J. Burns. 1982. Distribution of marine mammals in the coastal zone of the Bering Sea during summer and autumn. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20(1983):365-561.

Fujii, T. 1975. On the relation between the homing migration of the western Alaska sockeye salmon and the oceanic conditions in the eastern Bering Sea. Mem. Faculty Fish., Hokkaido Univ., Japan. 22:99-192.

Fujino, K. 1960. Immunogenetic and marking approaches to identifying subpopulations of the North Pacific whales. Sci. Rep. Whales Rep. Inst. Tokyo 15:85-142.

Fujioka, J. and N. Sigler. 1984. Time-location traces of sablefish tag recoveries released by the U.S. National Marine Fisheries Service and the Fisheries Agency of Japan, 1972-83. U.S. Dep. Commer., NOAA, NMFS, Auke Bay, AK., Document 2828.

Fukuhara, F.M. 1985. Biology and fishery of southeastern Bering Sea red king crab (Paralithodes camtschatica Tilesius). U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36 Part 2 (1986):801-982. Also: Northwest and Alaska Fish. Center Processed Report 85-11.

FWS (Fish & Wildlife Service). 1974. Preliminary report of biological data on proposed harbor sites at Unalaska, Alaska. FWS, Anchorage, AK. 35 p.

FWS (Fish & Wildlife Service). 1986. Fish resources, Aleutian Islands unit. Alaska Maritime National Wildlife Refuge Comprehensive Conservation Plan. FWS (in prep.).

Gambell, R. 1977. Report to the special meeting of the Scientific Committee of sei and Bryde's whales, La Jolla, 3-13 December, 1974. Rep. Int. Whal. Comm. (Special Issue 1):1-8.

Gardner, J.V., T.L. Vallier and W.E. Dean. 1979. Sedimentology and geochemistry of surface sediments and the distribution of faults and potentially unstable sediments, St. George Basin region of the outer continental shelf, southern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. Phys. 2:181-271.

Gibson, D.D. 1985. Alaska Region. Am. Birds. 40:155.

Gill, R.E., Jr., and J.D. Hall. 1983. Use of nearshore and estuarine areas of the southeastern Bering Sea by gray whales (Eschrichtius robustus). Arctic 36:275-281.

Gill, R.E., Jr., C.M. Handel and M. Petersen. 1979. Migration of birds in Alaska marine habitats. U.S. Dep. Commer., NOAA, OCSEAP Final Rep., Biol. 5:245-288.

Gilmer, I. 1984. Alaska Peninsula-Aleutian Islands area--herring sac roe report to the Alaska Board of Fisheries. Alaska Dept. Fish & Game, Anchorage. 17 pp.

Godfrey, H., K. Henry and S. Machidori. 1975. Distribution and abundance of coho salmon in offshore waters of the North Pacific Ocean. Int. North Pacific Fish. Comm., Bull. 31. 80 pp.

Goering, J.J. and R.L. Iverson. 1981. Phytoplankton distribution of the southeastern Bering Sea shelf. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 933-946.

Gould, P.J. 1977. Shipboard surveys of marine birds. In: U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 3:193-284.

Gould, P.J. 1978. Distribution and abundance of marine birds south and east of Kodiak Island. U.S. Fish and Wildl. Serv., Off. Biol. Serv., Coastal Ecosystems Team, Anchorage, AK Unpubl. Rep.

Gould, P.J. 1982. Distribution and abundance of seabirds over marine waters of the eastern Aleutian Islands. U.S. Fish and Wildl. Serv., Anchorage, AK.

Gould, P.J., D.J. Forsell and C.J. Lensink. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. U.S. Fish and Wildl. Serv., Off. Biol. Serv., Pub. No. FWS/OBS-82/48. 294 pp.

Grant, W., R. Bakkala, F. Utter, D. Teel and T. Kobayashi. 1983. Biochemical genetic population structure of yellowfin sole, Limanda aspera, of the North Pacific Ocean and Bering Sea. Fish. Bull. 81:667-677.

Grant, W. and F. Utter. 1980. Biochemical genetic variation in walleye pollock, Theragra chalcogramma: population structure in the southeastern Bering Sea and the Gulf of Alaska. Can. J. Fish. Aquat. Sci. 37:1093-1100.

Grant, W. and F. Utter. 1984. Biochemical population genetics of Pacific herring (Clupea pallasi). Can. J. Fish. Aquat. Sci. 41:856-864.

Guzman, J. 1981. The wintering of Sooty and Short-tailed Shearwaters (genus Puffinus) in the North Pacific. Ph.D. Thesis, Univ. Calgary, Alberta.

Guzman, J. and M.T. Myres. 1982. Ecology and behavior of southern hemisphere shearwaters (Genus Puffinus) when over the outer continental shelf of the Gulf of Alaska and Bering sea during the northern summer (1975-1976). Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP. 110 pp.

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1091-1104.

Haflinger, K.E. and C.P. McRoy. 1983. Yellowfin sole (Limanda aspera) predation on three commercial crab species (Chionoecetes opilio, C. bairdii, and Paralithodes camtschatica) in the southeastern Bering Sea. Univ. Alaska Inst. Mar. Sci., Final Rep. to U.S. Dep. Commer., NOAA, NMFS, Contract No. 82-ABC-00202. 28 pp.

Hall, J.D., C.S. Harrison, J. Nelson and A. Taber. 1977. The migration of California gray whales into the Bering Sea. In: Proceedings (Abstracts) Second Conference on the Biology of Marine Mammals. San Diego, California, 12-15 December 1977. pp. 8.

Hameedi, M. (ed.). 1982. Proceedings of a synthesis meeting: the St. George Basin environment and possible consequences of planned offshore oil and gas development, Anchorage, AK, 28-30 April 1981. U.S. Dep. Commer., NOAA, OMPA. Juneau, AK.

Handa, N. and E. Tanoue. 1981. Organic matter in the Bering Sea and adjacent areas. In: D.W. Hood, and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 359-381.

Harrison, C.S. 1977. Seasonal distribution and abundance of marine birds. Part II: Aerial surveys of marine birds. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 3:285-593.

Harrison, C.S. and S.A. Hatch. 1975. Field observations on Unimak Island, Alaska, 11 to 25 August 1975. U.S. Fish and Wildl. Serv., Office of Biol. Services-coastal Ecosystems Team, Field Rep. No. 75-017; Anchorage, AK.

Harry, G.V. and J.R. Hartley. 1981. Northern fur seals in the Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 847-868.

Hart, J. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180. 740 pp.

Hartt, A. 1962. Movement of salmon in the North Pacific Ocean and Bering Sea as determined by tagging 1956-1958. Int. North Pacific Fish. Comm. Bull. 6. 157 pp.

Hartt, A. 1980. Juvenile salmonids in the oceanic ecosystem--the critical first summer. In: W. McNeil and D. Himsworth (eds.), Salmonid ecosystems of the North Pacific. Oregon State Univ. Press, Corvallis. pp. 25-58

Hatch, S.A. and M.A. Hatch. 1983. An isolated population of small Canada Geese on Kaliktagik Island, Alaska. Wildfowl 34:130-136.

Hattori, A. and J.J. Goering. 1981. Nutrient distributions and dynamics in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 975-992.

Hayes, M.L. 1983. Variation in the abundance of crab and shrimp with some hypotheses on its relationship to environmental causes. In: W.S. Wooster (ed.), From year to year: Interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. Washington Sea Grant Program, Seattle. pp. 86-101.

Hein, J.R., D.W. Scheil and J. Miller. 1978. Episodes of Aleutian Ridge explosive volcanism. Science 199:137-141.

Hessing, P. 1981. Gray whale (Eschrichtius robustus) migration into the Bering Sea observed from Cape Sarichef, Unimak Island, Alaska, Spring 1981. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20(1983):46-74.

Hickey, J.J. 1976. A census of seabirds on the Pribilof Islands. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 2:55-104.

Hofman, R.J. and W.N. Bonner. 1985. Conservation and protection of marine mammals: past, present and future. Mar. Mammal Sci. 1:109-127.

Holmes, P. 1982. 1982 Aleutian Islands salmon stock assessment study. Special report to the Alaskan Board of Fisheries. Alaska Dept. Fish and Game, Anchorage. 83 pp.

Hood, D.W. 1981. Preliminary observations of the carbon budget of the eastern Bering Sea shelf. In: D.W. Hood, and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 347-358.

Hood, D.W. (ed.). 1986. Special issue on processes and resources of the Bering Sea (PROBES). Continental Shelf Research Vol. 5 (No. 1-2). 288 pp.

Hood, D.W. and J.A. Calder (eds.). 1981. The eastern Bering Sea shelf: Oceanography and biological resources. U.S. Dep. Commer. NOAA, OMPA. Univ. Washington Press, Seattle, 2 Vols., 1339 pp.

Hood, D.W. and L.A. Codispoti. 1983. The effects of primary production on the carbon dioxide components of the Bering Sea shelf. In: J.H. McCeath (ed.), The potential effects of carbon dioxide induced climatic change in Alaska. Univ. Alaska School of Agriculture and Land Resources Management, Fairbanks.

Hood, D.W. and E.J. Kelley (eds.). 1974. Oceanography of the Bering Sea. Univ. Alaska Inst. Mar. Sci. Occ. Pub. No. 2, Fairbanks. 633 pp.

Hood, D.W. and J.J. Kelley. 1976. Evaluation of mean vertical transports in an upwelling system by CO_2 measurements. Mar. Sci. Comm. 2(6):386-411.

House, L., L.R. Sykes, J.N. Davies and K.H. Jacob. 1981. Identification of a possible seismic gap near Unalaska Island, eastern Aleutians, Alaska. In: P.G. Richards and D.W. Simpson (eds.), Earthquake prediction--An International review, Maurice Ewing Series 4, Amer. Geophys. Union, Washington, D.C. pp. 81-92.

Hubbard, J. 1964. A comparative survey of intertidal fishes of Kodiak and Umnak islands, Alaska. M.S. Thesis, Univ. Wisconsin, Madison. 139 pp.

Hughes, F.W., L.K. Coachman and K. Aagaard. 1974. Circulation, transport and water exchange in the western Bering Sea. In: D.W. Hood, and E.J. Kelley (eds.). Oceanography of the Bering Sea. Univ. Alaska Inst. Marine Sci. Occas. Pub. No. 2. Fairbanks. pp. 40-59.

Hunt, G.L., Jr., B. Burgeson and G.A. Sanger. 1981a. Feeding ecology of seabirds of the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 629-746.

Hunt, G.L., Z. Eppley, B. Burgeson and R. Squibb. 1981b. Reproductive ecology, foods and foraging areas of seabirds nesting on the Pribilof Islands, 1975-1979. U.S. dep. Commer., NOAA, OCSEAP Final Rep. Biol. 12:1-58.

Hunt, G.L., Z. Eppley and W.H. Drury. 1981c. Breeding distribution of marine birds in the eastern Bering Sea. In: D.W. Hood, and J.A. Calder (eds.). The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Walshington Press, Seattle. pp. 649-687.

Hunt, G.L., Jr., P.J. Gould, D.F. Forsell and H. Peterson, Jr. 1981d. Pelagic distribution of marine birds in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 689-718.

Hunt, G.L., Jr., J. Kaiwi and D. Schneider. 1982. Pelagic distribution of marine birds and analysis of encounter probability for the southeastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final. Rep. 16:1-160.

IPHC (Int. Pacific Halibut Comm.). 1964. Catch records of the trawl survey conducted by IPHC between Unimak Pass and Cape Spencer, Alaska, from May 1961 to April 1963. IPHC Rep. No. 36. Seattle, WA. 324 pp.

IPHC (Int. Pacific Halibut Comm.), 1980-85. Halibut trawl surveys at Unimak Island. IPHC File Data. Seattle, WA.

Isakson, J., D. Rogers and S. Parker. 1986. Fish use of inshore habitats north of the Alaska Peninsula. Rep. to U.S. Dep. Commer., NOAA, OCSEAP by Dames and Moore. 357 pp.

Jaques, F.L. 1930. Water birds observed on the Arctic Ocean and the Bering Seas in 1928. Auk 47:353-366.

Jarvela, L.E. (ed.). 1984. The Navarin Basin environment and possible consequences of planned offshore oil and gas development. U.S. Dep. Commer., NOAA, MMS, Anchorage, AK.

Jarvela, L.E., L.K. Thorsteinson and M.J. Pelto. 1984. Oil and gas development and related issues. In: L.E. Jarvela (ed.), The Navarin Basin environment and possible consequences of planned offshore oil and gas development. U.S. Dep. Commer., NOAA, MMS. Anchorage, AK.

Jones, E.J.W., J. Ewing and M. Truchan. 1971. Aleutian plain sediments and lithospheric plate motions. J. Geophys. Res. 76:8121-8127.

Kachina, T. and R. Akinova. 1972. The biology of the Korfo-Koraginski herring in the first year of life. Izv. Tikhookean. Nauchoissled, Inst. Rybn. Khoz. Okeanogra.

Kaganovakii, A. 1955. Basic traits of behavior of pelagic fishes and methods of scouting and forecasting them in Far Eastern waters. Akad. Nauk. SSSR., Tr. Soveshch. Ikhtiol. Kom. 5:26-33. (Transl. U.S. Dep. Commer., NMFS Biol. Lab., Honolulu, HI.)

Kajimura, H., R.H. Lander, M.A. Perez, A.E. York and M.A. Big. 1979. Preliminary analysis of the pelagic fur seal data collected by the United States and Canada during 1958-1974. 22nd Annu. Meet., Standing Committee North Pacific Fur Seal Comm., U.S. Dep. Commer., NOAA, NMML. Seattle, WA.

Kajimura, H., R.H. Lander, M.A. Perez, A.E. York and M.A. Bigg. 1980. Further analysis of the pelagic fur seal data collected by the United States and Canada during 1958-1974. 23rd Annu. Meet., Standing Committee North Pacific Fur Seal Comm., U.S. Dep. commer., NOAA, NMML. Seattle, WA.

Kanno, Y. and I. Hanai. 1971. Food of salmonid fish in the Bering Sea in summer of 1966. Bull. Fac. Fish., Hokkaido Univ. 22:107-128.

Kawakami, T. 1980. A review of sperm whale food. Sci. Rep. Whales Res. Inst. 32:199-218.

Kawamura, A. 1975. Whale distribution in the Bering Sea and North Pacific in the summer of 1974: results of a visual sighting study aboard the Univ. of Hokkaido training vessel Oshoro Maru. Bull. Japan Soc. Fish. Oceanogr. 25:119-128.

Kawamura, A. 1980. A review of food of Balaenopterid whales. Sci. Rep. Whales Res. Inst. 32:155-197.

Keeling, C.D. 1968. Carbon dioxide in surface ocean waters. IV. Global distribution. J. Geophys. Res. 73:4543-4553.

Kelleher, J.A. 1970. Space-time seismicity of the Alaska-Aleutian seismic zone. J. Geophys. Res. 75:5745-5756.

Kelley, J.J. and D.W. Hood. 1971. Carbon dioxide in the Pacific Ocean and Bering Sea: Upwelling and mixing. J. Geophys. Res. 76(3):745-752.

Kelley, J.J. and D.W. Hood. 1974. Upwelling in the Bering Sea near the Aleutian Islands. Tethys 6(1-2):149-156.

Kelley, J.J., L.L. Longerich and D.W. Hood. 1971. Effect of upwelling, mixing and high primary production on CO_2 concentrations in surface waters of the Bering Sea. J. Geophys. Res. 76:8687-8693.

Kennedy, W. and F. Pletcher. 1968. The 1964-65 sablefish study. Fish. Res. Bd. Can. Tech. Rep. 74. 24 p.

Kenyon, K.W. 1949. Distribution of the Pacific kittiwake in November and December of 1948. Condor 52:188.

Kenyon, K.W. 1969. The sea otter in the eastern Pacific Ocean. U.S. Fish Wildl. Serv., N. Am. Fauna No. 68. 352 p.

Kenyon, K.W. 1978. Sea otters. <u>In</u>: D. Haley (ed.), Marine mammals of eastern North Pacific and arctic waters. Pacific Search Press, Seattle. pp. 227-235.

Kenyon, K.W. and J.G. King, Jr. 1965. Aerial surveys of sea otters and other marine mammals, Alaska Peninsula and Aleutian Islands, 19 April to 9 May 1965, and bird observations, Aleutian Islands survey. Unpubl. M.S. on file at U.S. Dep. Int., FWS, Anchorage, AK. 61 pp.

Kenyon, K.W. and D.W. Rice. 1961. Abundance and distribution of the Steller sea lion. J. Mammal. 42:223-234.

Kenyon, K.W. and F. Wilke. 1953. Migration of the northern fur seal, *Callorhinus ursinus*. J. Mammal. 34:86-98.

Kessel, B. and D.D. Gibson. 1978. Status and distribution of Alaska birds. Stud. Avian Biol. 1. 100 p.

King, J.E. 1964. Seals of the world. Brit. Mus. Nat. Hist., London. 154 p.

King, J.E. 1983. Seals of the world. Brit. Mus. Nat. Hist., London. 240 pp.

Kinder, T.H. 1981. A perspective of physical oceanography in the Bering Sea, 1979. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 5-13.

Kinder, T.H. and J.D. Schumacher. 1981a. Hydrographic structure over the continental shelf of the southeastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 31-52.

Kinder, T.H. and J.D. Schumacher. 1981b. Circulaton over the continental shelf of the southeastern Bering Sea shelf. In: D.W. Hood, and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and biological resources, Vol. 1. U.S. Dep. Commer. NOAA, OMPA. Univ. Washington Press, Seattle. pp. 31-52.

Klumov, S.K. 1963. Pitaniye i gel'mintofauna usatykh kitov (mystacoceti) v osnovnykh promyslovykh rayonakh mirovogo okeana (Food and helmith fauna of whalebone whales (Mystacoceti) in the main whaling regions of the world oceans). In: Biologosheskiye Issledovaniya Morey, Vol. 71, Tr. Inst. Okeanol., Moscow, 1963. pp. 94-194, 237. In Russian. (Transl. by Transl. Bur., Dep. Sec. State, Ottawa, Ont., Canada, Fish. Res. Board Can. Transl. Ser. No. 589, 1965, 21 p.)

Knudtson, E.P. and G.V. Byrd. 1982. Breeding biology of crested, least and whiskered auklets at Buldir Island, Alaska. Condor 84:197-202.

Kodolov, L. 1983. Certain causes of sablefish (Anoplopoma fimbria) population depression. In: B. Melteff (coord.), Proceedings of the International Sablefish Symposium. March 1983. Univ. Alaska, Alaska Sea Grant Rep. 83-8. pp. 265-272.

Koike, I., K. Furuya and A. Hattori. 1979. Continuous measurements of nitrogenous compounds and chlorophyll-a in surface waters of the Bering Sea. In: Proc. 1979 Spring meeting of Oceanogr. Soc. Japan, pp. 221-222.

Koike, I., K. Furuya, H. Otobe, T. Nakai, T. Nemoto and A. Hattori. 1982. Horizontal distributions of surface chlorophyll-a and nitrogenous nutrients near Bering Strait and Unimak Pass. Deep Sea Res. 29:149-152.

Koto, H. and T. Fujii. 1958. Structure of the waters in the Bering Sea and Aleutian region. Bull. Fac. Fish., Hokkaido Univ. 9:149-170.

Kozloff, P. 1981. Fur seal investigations, 1980. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 81-2. Seattle, WA Proc. Rep. 81-2.

Laevastu, T. and F. Favorite. 1978. Numerical evaluation of marine ecosystems. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA.

Laevastu, T and C. Fiscus. 1978. Review of cephalopod resources in the eastern North Pacific. Northwest & Alaska Fisheries Center Processed Report.

Laevastu, T. and R. Marasco. 1982. Fluctuations of fish stocks and the consequences of the fluctuations to fishery and its management. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-27. 53 pp.

Laevastu, T. and R. Marasco. 1984. Some analyses of consequences of fisheries expansion in the Gulf of Alaska and eastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 84-14. 30 pp.

Laevastu, T., R. Marasco, N. Bax, R. Fredin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara and N. Pola. 1985. Evaluation of the effects of oil development on the commercial fisheries in the eastern Bering Sea (summary report). U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 85-19. 40 pp.

Lander, R.H. and H. Kajimura. 1976. Status of northern fur seals. Rep. to FAO Advisory Comm. Mar. Resour. Res., ACMRR/MM/SC/34. 50 pp.

Leatherwood, S., A.E. Bowles and R.R. Reeves. 1983. Aerial surveys of marine mammals in the southeastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 42(1986):147-490.

Leatherwood, S. and R.R. Reeves. 1978. Porpoises and dolphins. In: D. Haley (ed.), Marine mammals of eastern North Pacific and arctic waters. Pacific Search Press, Seattle. pp. 97-111.

Lebida, R., L. Malloy and C. Meacham. 1984. Eastern Aleutian Islands Pacific herring fishery and probable stock origin. Alaska Dept. Fish and Game, Anchorage. 10 pp.

Lewbel, G. (ed.). 1983. Bering Sea biology: an evaluation of the environmental data base related to Bering Sea oil and gas exploration and development. LGL Alaska Research Assoc. and SOHIO Alaska Petroleum Co., Anchorage, AK. 180 pp.

LGL (LGL Ecological Research Associates, Inc.). 1986. Environmental characterization and biological utilization of the North Aleutian Shelf nearshore zone. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP. In Prep.

Lipinski, M. 1973. The place of squids in the biological and fishery structure of the world ocean. In: M. Lipinski (ed.), B. Pryzbylska (tr.), Sympozjum Kalmarowe Gydnia: Sea Fisheries Institute. (Also available NTIS, Springfield, VA.)

Lisovenko, L. 1963. Distribution of the larvae of rockfish (Sebastodes alutus) in the Gulf of Alaska. In: P. Moiseev (ed.), Soviet Fish. Invest. in the Northeast Pacific. (Israel Prog. Sci. Transl. 1968.) pp. 217-225.

Lloyd, D.S., C.P. McRoy and R.H. Day. 1981. Discovery of northern fur seals (Callorhinus ursinus) breeding on Bogoslof Island, southeastern Bering Sea. Arctic 34:318-320.

Loder, T.C. 1971. Distribution of dissolved and particulate organic carbon in Alaskan polar, sub-polar and estuarine waters. Ph.D. Thesis, Univ. Alaska, Fairbanks. 236 pp.

Loughlin, T.R., D.J. Rugh and C.H. Fiscus. 1984. Northern sea lion distribution and abundance: 1956-89. J. Wildl. Manage. 48:729-740.

Low, L. 1976. Status of major demersal fishery resources of the northeastern Pacific: Bering Sea and Aleutian Islands. U.S. Dep. Commer., NOAA, NMFS. Northwest and Alaska Fish. Center Processed Rep. 116 pp.

Low, L., G. Tanonaka and H. Shippen. 1976. Sablefish of the northeastern Pacific Ocean and Bering Sea. U.S. Dep. Commer., NOAA, NMFS. Northwest and Alaska Fish. Center Processed Rep. 115 pp.

Lowry, L.F. 1982. Documentation and assessment of marine mammal-fishery interactions in the Bering Sea. Trans. N. Am. Wildl. Conf. 47:300-311.

Lowry, L.F. and K.J. Frost. 1981. Feeding and trophic relationships of phocid seals and walruses in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 813-824.

Lowry, L.F., K.J. Frost and J.J. Burns. 1979. Potential resource competition in the southeastern Bering Sea: Fisheries and phocid seals. Proc. Alaska Sci. Conf. 29:287-296.

Lowry, L.F., K.J. Frost and J.J. Burns. 1982a. Investigations of marine mammals in the coastal zone of western Alaska during summer and autumn. Annu. Rep. to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK. 37 pp.

Lowry, L.F., K.J. Frost, D.G. Calkins, G.L. Swartzman and S. Hills. 1982b. Feeding habits, food requirements, and status of Bering Sea marine mammals. North Pacific Fish. Manage. Council, Contract 814, Final Rep., Vol. 1. Anchorage, AK. 401 pp.

Lyubimova, T. 1963. Basic aspects of the biology and distribution of Pacific rockfish (Sebastodes alutus) in the Gulf of Alaska. In: P. Moiseev (ed.), Soviet Fish. Invest. in the Northeast Pacific. Part 1, pp. 308-318. (Israel Prog. for Sci. Transl. 1968.)

Lyubimova, T. 1965. Main stages in the life cycle of the rockfish Sebastodes alutus in the Gulf of Alaska. In: P. Moiseev (ed.), Soviet Fish Invest. in the Northeast Pacific. Part. 4. pp. 85-111. (Israel Prog. for Sci. Transl. 1968.)

Macy, P., J. Wall, N. Lampsakis, J. Mason. 1978. Resources of non-salmonid pelagic fishes of the Gulf of Alaska and eastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Vols. 1-3.

Maeda, T. 1972. Fishing grounds of the Alaska pollock. Bull. Jap. Soc. Sci. Fish. 43:39-45.

Major, R. (ed.). 1985. Condition of groundfish resources of the Gulf of Alaska region as assessed in 1984. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-80. 211 p.

Major, R., J. Ito, S. Ito and H. Godfrey. 1978. Distribution and origin of chinook salmon in offshore waters of the North Pacific Ocean. Int. North Pacific Fish. Comm. Bull. 38. 54 pp.

Major, R. and H. Shippen. 1970. Synopsis of biological data on Pacific ocean perch, Sebastodes alutus. U.S. Dep. commer., NOAA, NMFS, Circular 347. 38 pp. (Also FAO Fisheries Synopsis No. 79.)

Malloy, L. 1985. Peninsula/Aleutians management area, eastern Aleutian Islands herring food and bait fishery. Alaska Dept. Fish and Game, Kodiak. 12 pp.

Manen, C.A. and M.J. Pelto. 1984. Transport and fate of spilled oil. In: L.K. Thorsteinson (ed.), Proc. of a synthesis meeting: The North Aleutian Shelf and possible consequences of offshore oil and gas development. Anchorage, AK., 9-11 March 1982. U.S. Dep. Commer., NOAA, MMS, Anchorage.

Masaki, Y. 1977. The separation of the stock units of sei whales in the North Pacific. Rep. Int. Whal. Comm. (Special Issue 1):71-79.

Mathisen, O.A. and R.J. Lopp. 1963. Photographic census of the Steller sea lion herds in Alaska, 1956-58. U.S. Fish and Wildl. Serv. Spec. Sci Rep. Fish. 424. 20 pp.

McAlister, W.B. 1981. Estimates of fish consumption by marine mammals in the eastern Bering Sea and Aleutian Island area. U.S. Dep. commer., NOAA, NMFS, NMML, Draft Rep. Seattle, WA. 87 pp.

McBride, J., D. Fraser and J. Reeves. 1982. Information on the distribution and biology of the golden (brown) king crab in the Bering Sea and Aleutian Islands area. U.S. Dep. Commer., NOAA, NMFS Northwest and Alaska Fish. Center Processed Rep. 82-02. 22 pp.

McCullough, J. 1984. Herring sac-roe report, Alaska Peninsula-Aleutian Islands area. Rep. to Alaska Board Fish., Alaska Dept. Fish & Game, Div. Comm. Fish. 20 pp.

McDonald, J., H.M. Feder and M. Hoberg. 1981. Bivalve mollusks of the southeastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1155-1204.

McMurray, G., A.H. Vogel, P.A. Fishman, D.A. Armstrong, and S.C. Jewett. 1984. Distribution of larval and juvenile red king crabs (Paralithodes camtschatica) in Bristol Bay. U.S. Dep. commer., NOAA, OCSEAP Final Rep. 145 pp. (In Press.)

McRoy, C.P. 1968. The distribution and biography of Zostera marina (eelgrass) in Alaska. Pac. Sci. 22(4):507-513.

McRoy, C.P., D.W. Hood, L.K. Coachman, J.J. Walsh and J.J. Goering. 1986. Processes and resources of the Bering Sea Shelf (PROBES): The development and accomplishments of the project. Continental Shelf Research 5:5-22.

Miller, M. (n.d.). Fog and men on the Bering Sea. E.P. Dutton and Co. Publishers, New York, NY.

Minoda, T. and R. Marumo. 1975. Regional characteristics of distribution of phyto- and zooplankton in the eastern Bering Sea and Chukchi Sea in June-July, 1972. In: D.W. Hood and Y. Takenouti (eds.), Bering Sea oceanography: An update. Univ. Alaska Inst. Mar. Sci. Rep. No. 75-2. Fairbanks. pp. 83-95.

Mishima, S. and S. Nishizawa. 1955. Report on hydrographic investigations in the Aleutian waters and the southern Bering Sea in the early summers of 1953 and 1954. Bull. Fac. Fish., Hokkaido Univ. 6:35-124.

Mitchell. E.D. 1975a. Review of biology and fisheries for small cetaceans--report and papers from a meeting of the IWC subcommittee on small cetaceans. Montreal. April 1-11, 1974. J. Fish. Res. Bd. Canada. 32:875-1240.

Mitchell, E.D. 1979. Comments on magnitude of early catch of east Pacific gray whale (Eschrictius robustus). Rep. Int. Whal. Comm. 29:307-314.

Mizue, K. and K. Yoshida. 1965. On the porpoises caught by the salmon fishing gillnet in the Bering Sea and the North Pacific Ocean. Bull. Fac. Fish. Nagasaki Univ. 19:1-21.

Mizue, K., K. Yoshida and A. Takemura. 1966. On the ecology of the Dall's porpoise in Bering Sea and the North Pacific Ocean. Bull. Fac. Fish. Nagasaki Univ. 21:1-21.

Moiseev, P. (ed.). 1963. Soviet fisheries investigations in the northeast Pacific. Parts 1-5. (Transl. from Russian by Israel Prog. Sci. Transl. 1968.)

Morgan, L. (ed.). 1980. The beginnings. Alaska Geographic. 7(3):18-29.

Morse, D.H. and C.W. Buchheister. 1977. Age and survival of breeding Leach's storm-petrels in Maine. Bird-Banding 48:341-349.

Motoda, S. and T. Minoda. 1974. Plankton of the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on natural resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 207-241.

Murie, O. 1959. Fauna of the Aleutian Islands and Alaska Peninsula with notes on invertebrates and fishes collected in the Aleutians 1936-38. U.S. Fish and Wildl. Serv., North Amer. Fauna. 61:1-406.

Nakajima, K. 1969. Suspended particulate matter in the waters on both sides of the Aleutian ridge. J. Oceanogr. Soc. Japan. 25:239-48.

Nakamura, K., K.H. Jacob and J.N. Davies. 1977. Volcanoes as possible indicators of tectonic stress orientation--Aleutians and Alaska. Pageoph. 115:87-112.

Nasu, K. 1966. Fishery oceanography study on the baleen whaling grounds. Sci. Rep. Whales Res. Inst. Tokyo. 20:157-210.

Nasu, K. 1974. Movement of baleen whales in relation to hydrographic conditions in the northern part of the North Pacific Ocean and the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 345-361.

Natarov, V.V. 1963. Water masses and currents of the Bering Sea (in Russian). Trudy VNIRO 48:111-133 (Trans. 1968, P. 110-130 In: Soviet fisheries investigations in the northeast Pacific, Part 2. Pub. No. TT-67-51204 from National Technical Information Service, Springfield, VA).

Neave, F. 1966. Chum salmon in British Columbia. Int. North Pacific Fish. Comm., Bull. 18. 86 pp.

Neave, F., T. Yonemori, R. Bakkala. 1976. Distribution and origin of chum salmon in offshore waters of the North Pacific Ocean. Int. N. Pacific Fish. Comm. Bull. No. 35. 79 pp.

Nelson, C.H., D.M. Hopkins and D.W. Schell. 1974. Cenogoic sedimentary and tectonic history of the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 485-516.

Nelson, J. 1976. Field observations on Unimak Island 15 September to 22 October, 1976. Unpubl. field report. U.S. Fish and Wildl. Serv., Anchorage, AK.

Nemoto, T. 1957. Food of baleen whales in the northern Pacific. Sci. Rep. Whales Res. Inst. Tokyo. 12:33-89.

Nemoto, T. 1959. Food of baleen whales with reference to whale movements. Sci. Rep. Whales Res. Inst. Tokyo. 14:149-290.

Nemoto, T. 1963. Some aspects of the distribution of Calanus cristatus and C. pulchrus in the Bering and its neighboring waters, with reference to the feeding of baleen whales. Sci. Rep. Whales Res. Inst. Tokyo. 17:157-170.

Nemoto, T. 1968. Feeding of baleen whales and krill, and the value of krill as a marine resource in the Antarctic. In: Proc. Symp. Antarctic Oceanogr., Santiago, Chile, 13-16 September 1966. pp. 240-253.

Nemoto, T. 1970. Feeding pattern of baleen whales in the ocean. In: J.H. Steele (ed.), Marine food chains. Univ. California Press, Berkeley. pp. 241-252.

Nemoto, T. 1978. Humpback whales observed within the continental shelf waters of the eastern Bering Sea. Sci. Rep. Whales Res. Inst. Tokyo. 30:245-247.

Nemoto, T. and A. Kawamura. 1977. Characteristics of food habits and distribution of baleen whales with special reference to the abundance of North Pacific sei and Bryde's whales.

Nerini, M. 1984. A review of gray whale feeding ecology. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale (Eschrichtius robustus, Lilljeborg, 1861). San Francisco and New York, Academic Press.

Nerini, M., L. Jones and H.L. Braham. 1980. Feeding ecology of the gray whale (Eschrichtius robustus) in the northern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 43(1986):163-207.

Niebauer, H.J. 1981. Recent fluctuations in sea ice distribution in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 133-140.

Nikulin, P.G. 1946. O raspredelenii kitiibraznykh v moryakh, omyvayushchikh Chutskiy Poluostrov (Distribution of cetaceans in seas surrounding the Chukchi Peninsula). Izv. TINRO 22:255-257. In Russian (Transl. No. 428, 1969, 300).

Nishiwaki, M. 1966. Distribution and migration of the larger cetaceans in the North Pacific as shown by Japanese whaling results. In: K.S. Norris (ed.), Whales, dolphins and porpoises. Univ. of California Press, Berkeley. pp. 169-191.

Nishiwaki, M. and C. Handa. 1958. Killer whales caught in the coastal waters of Japan for recent 10 years. Sci. Rep. Whales Res. Inst. Tokyo 13:85-96.

Nishiyama, T. 1974. Energy requirements of Bristol Bay sockeye salmon in the central Bering Sea and Bristol Bay. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea with emphasis on renewable resources. Univ. Alaska, Inst. Mar. Sci. Occas. Pub. 2. pp. 231-343.

NMFS (National Marine Fisheries Service). 1975-81. Cruise results. R.V. Oregon Cruise Nos. OR-75-3, OR-78-3, OR-79-3, OR-80-3; RV Chapman Cruise No. CH-81-04. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Kodiak Facility, Kodiak, AK.

Nof, D. and S.H. Im. 1985. Suction through broad oceanic gaps. J. Phys. Oceanogr. 15:1721-1732.

NORPAC. 1960. Oceanographic observations of the Pacific--1955. In: The NORPAC Atlas. Univ. California, Berkeley. 8 pp. + 123 plates.

Norris, K.W. 1979. Gray whale lagoon entrance aggregations. In: Third Biennial Conf. Biol. Marine Mammals, October 7-11, 1979. Seattle, WA. (Abstr.).

North Pacific Fur Seal Commission. 1962. Report on investigations from 1958 to 1961. Presented to the North Pacific Fur Seal Commission by the Standing Scientific Committee.

North Pacific Fur Seal Commission. 1969. Report on investigations in 1964-66. Issued from the Headquarters of the Commission. Washington, D.C.

North Pacific Fur Seal Commission. 1971. Report on investigations in 1962-63. Issued from the Headquarters of the commission. Washington, D.C.

Nysewander, D.R., D.J. Forsell, P.A. Baird, D.J. Shields, G.J. Weiler and J.H. Kogan. 1982. Marine bird and mammal survey of the eastern Aleutian Islands, summers of 1980-81. U.S. Fish and Wildl. Serv., Alaska Regional Office, Anchorage.

O'Clair, C.E. 1981. Disturbance and diversity in a boreal marine community: The role of intertidal scouring by sea ice. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2: U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1105-1130.

O'Clair, C.E., J.L. Hanson, R.T. Myren, J.A. Gharrett, T.R. Merrell, Jr. and J.S. Mackinnon. 1981. Reconnaissance of intertidal communities in the eastern Bering Sea and the effects of ice-scour on community structure. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 10:109-415.

Okutani, T. 1977. World edible squids directory. Unpubl. Rep.

Okutani, T. and T. Nemoto. 1964. Squids as the food of sperm whales in the Bering Sea and Alaskan Gulf. Sci. Rep. Whales Res. Inst. Tokyo 18:111-121.

Omura, H. 1955. Whales in the northern part of the North Pacific. Norsk Hvalfangst-tidende. 44:195-213, :239-248.

Omura, H. 1958. North Pacific right whale. Sci. Rep. Whales Res. Inst. Tokyo 13:1-52.

Omura, H., S. Ohsumi, T. Nemoto, K. Nasu and T. Kasuya. 1969. Black right whales in the North Pacific. Collect. Reprints Ocean Res. Inst. 8:661-683. Univ. Tokyo.

Oshite, K. and G.D. Sharma. 1974. Contemporary depositional environment of the eastern Bering Sea. Part 2. Distribution of recent diatoms on the eastern Bering Shelf. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on natural resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 541-551.

Otto, R.S. 1981. Eastern Bering Sea crab fisheries. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1037-1066.

Otto, R.S. and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (Lithodes acquispina) in the Bering Sea and Aleutian Islands. In: Proc. Int. King Crab Symp., Jan. 1985, Anchorage, AK. pp. 123-135.

Pace, S. 1984. Environmental characterization of the North Aleutian Shelf nearshore region: Annotated bibliography and key word index. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 38(1986):475-743.

Palacas, J.G., P.M. Gerrild, A.H. Love and A.A. Robarts. 1976. Baseline concentrations of hydrocarbons in barrier island quartz sand, northeastern Gulf of Mexico. Geology 4:81-84.

Palmer, R.S. (ed). 1962. Handbook of North American Birds, Vol. 1. Yale Univ. Press, New Haven, CN. 567 pp.

Paulke, K. 1985. Biology of capelin in western Alaska. MA Thesis, Univ. Alaska, Juneau.

Pearcy, W. 1983. Abiotic variations in regional environments. In: W. Wooster (ed.), From year to year: interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. Wash., Wash. Sea Grant Pub., Seattle. pp. 30-34.

Pearson, C.A., E. Baker and J.D. Schumacher. 1980. Hydrographic, suspended particulate matter, wind and current observations during reestablishment of a structural front: Bristol Bay, Alaska. Unpub. MS, U.S. Dep. Commer., NOAA, PMEL, Seattle, WA.

Pearson, C.A., H.O. Mofjeld and R.B. Tripp. 1981. Tides of the eastern Bering Sea shelf. In: D.W. Hood, and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 1. U.S. Dep. Commer. NOAA, OMPA. Univ. Washington Press, Seattle. pp. 111-130.

Pearson, W.H., D.L. Woodruff and B.J. Higgins. 1984. Feeding ecology of juvenile king and Tanner crabs in the southeastern Bering Sea. Draft Final Rep. by Battelle Pacific Northwest Lab., to U.S. Dep. Commer., NOAA, OCSEAP. 116 pp.

Perez, M.A. and M.A. Bigg. 1981a. Modified volume: a two-step frequency-volume method for ranking food types found in stomachs of northern fur seals. Draft Rep., NMML, NMFS, NOAA. 25 pp.

Perez, M.A. and M.A. Bigg. 1981b. An assessment of the feeding habits of the northern fur seal in the eastern North Pacific Ocean and eastern Bering Sea. Rep. by U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center. 47 pp.

Phillips, M. 1976. Field observations on Unimak Island, 21 April to 27 May 1976. U.S. Fish and Wildl. Serv., Field Rep. No. FWS 6020, Anchorage, Alaska. 25 pp.

Prescott, J.H. and P.M. Fiorelli. 1980. Review of the harbor porpoise (Phocoena phocoena) in the U.S. Northwest Atlantic. Final Rep. Contract MM8AC016, to U.S. Marine Mammal Comm., Washington, D.C. 64 pp.

Quinlan, S.E. 1979. Breeding biology of storm-petrels at Wooded Islands, Alaska. M.S. Thesis, Univ. Alaska, Fairbanks. 206 p.

RPI (Research Planning Institute, Inc.). 1986. The southern coast of the Alaska Peninsula: Geomorphology and sensitivity to spilled oil. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK. 61 pp. + App.

Rae, B.B. 1973. Additional notes on the food of the common porpoise (Phocoena phocoena). J. Zool. 169:127-131.

Rauzon, M. 1976. Field observations on Unimak Island, 1 to 17 July 1976. U.S. Fish and Wildl. Serv., Office of Biol. Serv. Coastal Ecosystems, Field Report No. 76-076. Anchorage, AK.

Reeburgh, W.S. and D.T. Heggie. 1977. Microbial methane consumption reactions and their effect on methane distributions in fresh water and marine environments. Limnol. Oceanog. 22:1-9.

Reed, R.K. 1971. Nontidal flow in the Aleutian Island passes. Deep Sea Res. 18:379-380.

Reed, R.K. 1984. Flow of the Alaska Stream and its variations. Deep Sea Res. 31:369-386.

Reed, R.K., R.D. Muench and J.D. Schumacher. 1980. On baroclinic transport of the Alaskan Stream near Kodiak Island. Deep Sea Res. 86:6453-6546.

Reed, R.K. and J.D. Schumacher. 1986. Physical oceanography In: D.W. Hood and S.T. Zimmerman (eds.), The Gulf of Alaska. U.S. Dep. of Commer., NOAA, OCSEAP, U.S. Government Printing Office (in press).

Reeves, R.R., S. Leatherwood, S.A. Karl and E.R. Yohe. 1985. Whaling results at Akutan (1912-39) and Port Hobron (1926-37), Alaska. Rep. Int. Whal. Comm. 35:441-457.

Reilly, S.B. 1984. Assessing gray whale abundance. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale (Eschrichtius robustus, Lilljeborg, 1861). Academic Press, New York.

Reilly, S., D. Rice, and A. Wolman. 1982. Population assessment of the gray whale, Eschrichtius robustus, from California shore censuses, 1967-80. Fish. Bull. 81:267-279.

Rice, D.W. 1968. Stomach contents and feeding behavior of killer whales in the eastern North Pacific. Norsk Hvalfangst-Tid. 57:35-38.

Rice, D.W. 1974. Whales and whale research in the eastern North Pacific. In: W.E. Schevill (ed.), The whale problem. A status Rep. Harvard University Press, Cambridge, MA. pp. 170-195.

Robertson, D.E. and K.H. Abel. 1979. Natural distribution and environmental background of trace heavy metals in Alaskan shelf and estuarine areas. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 5:660-698.

Rogers, D. and K. Schnepf. 1985. Feasibility of using scale analysis methods to identify Bering Sea herring stocks. North Pacific Fish. Manage. Council, Council Document No. 30, Anchorage, AK. 48 pp.

Ronholt, L. 1963. Distribution and relative abundance of commercially important pandalid shrimps in the northeastern Pacific Ocean. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 449. 28 pp.

Ronholt, L., F. Shaw and T. Wilderbuer. 1982. Trawl survey of groundfish resources off the Aleutian Islands, July-August 1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-23. 84 pp.

Ronholt, L., H. Shippen and E. Brown. 1978. Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass: A historical review. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 2:1-955.

Ronholt, L., K. Wakabayshi, T. Wilderbuer, H. Yamaguchi and K. Okada. 1986. Results of the cooperative U.S.-Japan groundfish resource assessment survey in Aleutian Islands waters, June-November 1980. U.S. Dep. Commer., NOAA Tech. Memo. (In press.)

Roseneau, D.G. and D.R. Herter. 1984. Marine and coastal birds. In: J.C. Truett (ed.), Proc. of a synthesis meeting: The Barrow Arch environment and possible consequences of planned offshore oil and gas development. Girdwood, AK. 30 October-1 November 1983. U.S. Dep. Commer., NOAA/MMS, Anchorage, AK.

Roseneau, D.G. and A.M. Springer. 1982. Draft species account, murres. Rep. to U.S. Dep. Commer., NOAA, OCSEAP, Arctic Project Office, Fairbanks, AK.

Royer, T.C. 1981. Baroclinic transport in the Gulf of Alaska, Part II. A fresh water driven coastal current. J. Mar. Res. 39:251-266.

Royer, T.C. 1982. Coastal fresh water discharge in the northeast Pacific Ocean. J. Geophys. Res. 86:2017-2021.

Rugh, D.J. 1984. Census of gray whales at Unimak Pass, Alaska, November-December 1977-1979. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale (Eschrichtius robustus, Lilljeborg, 1861). Academic Press, New York. pp. 225-248.

Rugh, D.J. and H.W. Braham. 1979. California gray whale (Eschrichtius robustus) fall migration through Unimak Pass, Alaska, 1977: A preliminary report. Rep. Int. Whal. Comm. 29:315-320.

Rumyantsev, A. and M. Darda. 1970. Summer herring in the eastern Bering Sea. In: Moiseev (ed.), Soviet fisheries investigations in the northeastern Pacific. pp. 409-441. (Israel Program for Scientific Translations, 1972.)

SAI (Science Applications, Inc.). 1980. Major references--North Aleutian Shelf lease area. Rep. to U.S. Dep. Commer., NOAA, OMPA. Juneau, AK. 45 pp.

Sallenger, A.H., Jr., J.R. Dingler and R. Hunter. 1978. Coastal processes and morphology of the Bering Sea coast of Alaska. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 12:451-503.

Sallenger, A.H.,Jr., R. Hunter and J.R. Dingler. 1977. Coastal processes and morphology of the Bering Sea coast of Alaska. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 18:159-225.

Salverson, S. and J. Dunn. 1976. Pacific cod (Family Gadidae). In: W. Pereyra, J. Reeves and R. Bakkala (ed.), Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA..

Sambrotto, R.N. and J.J. Goering. 1983. Interannual variability of phytoplankton and zooplankton production on the southeast Bering Sea shelf. In: W.S. Wooster (ed.), From year to year: Interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. Washington, Washington Sea Grant Program, Seattle. pp. 161-177.

Sanger, G.A. 1972. Preliminary standing stock and biomass estimates of seabirds in the subarctic Pacific region. In: Takenouti, A.Y. (ed.), Biological oceanography of the northern North Pacific Ocean. Idemitsa Shoten, Tokyo. pp. 589-611.

Sanger, G.A., V.F. Hironaka and A.K. Fukuyama. 1978. The feeding ecology and trophic relationships of key species of marine birds in the Kodiak Island area, May-September 1977. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 3:773-848.

Sasaki, T. 1983. Relative abundance and size structure of sablefish in the eastern Bering Sea, Aleutian region and Gulf of Alaska based on the results of Japan-U.S. joint longline surveys from 1979 to 1982. In: Proc. Int. Sablefish Symp., Univ. Alaska, Alaska Sea Grant Rep. 83-8. pp. 239-253.

Scattergood, L.W. 1949. Notes on the little piked whale (with bibliography). Murrelet 30:3-16.

Scheffer, V.B. 1950. The food of the Alaska fur seal. U.S. Fish Wildl. Serv. Wildl. Leafl. No. 329. 16 pp.

Scheffer, V.B. 1958. Seals, sea lions, and walruses: a review of the Pinnipedia. Stanford Univ. Press, CA. 179 pp.

Scheffer, V. 1959. Invertebrates and fishes collected in the Aleutians, 1936-38. In: O. Murie, Fauna of the Aleutian Islands and Alaska Peninsula. U.S. Fish and Wildl. Serv. Rep. No. 61. pp. 365-406.

Schell, D.M. and S.M. Saupe. 1986. Primary production, trophic energetics, and nutrient cycling in North Aleutian Shelf waters. Unpubl. rep. by Univ. Alaska, Inst. Mar. Sci to LGL Ecol. Res. Assoc., Inc., Bryan, TX.

Schneider, D. and G.L. Hunt. 1982. Carbon flux to seabirds in waters with different mixing regimes in the southeastern Bering Sea. Mar. Biol. 67:337-344.

Schneider, K.B. 1981. Distribution and abundance of sea otters in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 837-845.

Schumacher, J.D. 1982. Transport and fate of spilled oil. In: M.J. Hameedi (ed.), Proc. of a synthesis meeting: The St. George Basin environment and possible consequences of planned offshore oil and gas development. Anchorage, AK, 28-30 April 1981. U.S. Dep. Commer., NOAA/BLM, Anchorage.

Schumacher, J.D. and T.H. Kinder. 1983. Low-frequency current regimes over the Bering Sea shelf. J. Phys. Oceanogr. 13:607-623.

Schumacher, J.D., C.A. Pearson and J.E. Overland. 1982. On the exchange of water between the Gulf of Alaska and the Bering Sea through Unimak Pass. J. Geophys. Res. 87:5785-5795.

Schumacher, J.D. and R.K. Reed. 1980. Coastal flow in the northwest Gulf of Alaska: The Kenai Current. J. Geophys. Res. 85:6680-6688.

Schumacher, J.D. and R.K. Reed. 1985. On the Alaska coastal current in the western Gulf of Alaska. J. Geophys. Res. 90:

Schusterman, R.J. 1981. Steller sea lion - Eumetopias jubatus. In: S.H. Ridgeway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 1. Academic Press, New York. pp. 119-142.

Schwarz, L. 1985. Alaska Peninsula-Aleutian Islands area, herring sac-roe report. Alaska Dep. Fish and Game, Div. Comm. Fish. 18 pp.

Scranton, M.I. and P.G. Brewer. 1977. Occurrence of methane in the near surface waters of the western sub-tropical North Atlantic. Deep Sea Res. 24:127-138.

Searing, G.F. 1977. Some aspects of the ecology of cliff-nesting seabirds at Kongkok Bay, St. Lawrence Island, Alaska, during 1976. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 5:263-412.

Sears, H.S. and S.T. Zimmerman. 1977. Alaska intertidal survey atlas. U.S. Dep. Commer., NOAA, NMFS, Auke Bay, Alaska.

Serobaba, I. 1968. Spawning of the Alaska pollock, Theragra chalcogramma, in the northeastern Bering Sea. J. Ichthy. 8:789-798.

Shaboneev, I. 1965. Biology and fishing of herring in the eastern part of the Bering Sea. In: P. Moiseev (ed.), Soviet fisheries investigations in the northeastern Pacific. Vol. 4. pp. 130-146. (Israel Program for Scientific Translations, 1968.)

Sharma, G.D. 1974. Contemporary depositional environment of the eastern Bering Sea. Part 1. Contemporary sedimentary regimes of the eastern Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 517-540.

Sharma, G.D. 1979. The Alaskan shelf--hydrographic, sedimentary, and geochemical environment. Springer-Verlag, New York.

Sharma, G.D., F.F. Wright, J.J. Burns and D.C. Burbank. 1974. Sea-surface circulation, sediment transport, and marine mammal distribution, Alaska Continental Shelf. Nat. Aero. and Space Adm., Final Rep. ERTS Project 110-H. 73 pp.

Shaul, A. 1985. Salmon report to the Alaska Board of Fisheries. Alaska Peninsula-Aleutian Islands Management Area. Alaska Dept. Fish and Game, Div. Comm. Fish. 25 pp.

Shaul, A., J. McCullough and L. Melloy. 1984. 1984 salmon and herring annual report, Alaska Peninsula-Aleutian Islands areas. Alaska Dep. Fish and Game, Div. Comm. Fish.. 230 pp.

Shaw, D.G. and E.R. Smith. 1981. Hydrocarbons of animals of the Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle, WA. pp. 383-388.

Shubinikov, D. 1963. Data on the biology of sablefish of the Bering Sea. In: P. Moiseev (ed.), Soviet fisheries investigations in the northeast Pacific. Vol. 1. pp. 287-296. (Transl. Israel Prog. Sci. Transl., 1968.)

Shuntov, V.P. 1972. Sea birds and the biological structure of the ocean. Pac. Res. Inst. Fish. Mgmt. Oceanogr. (TINRO), Far-Eastern Publ., Vladivostok. 398 p. (Transl. from Russian, Agence Tunisienee de Public-relations for U.S.D.I., Bur. Sport Fish. Wildl. and Nat. Sci. Found. 1974. 566 pp.)

Simenstad, C.A., J.A. Estes and K.W. Kenyon. 1978. Aleuts, sea otters, and alternate stable state communities. Science 200:403-411.

Simenstad, C., J. Isakson, and R. Nakatani. 1977. Marine fish communities. In: M. Merritt and R. Fuller (eds.), The environment of Amchitka Island, Alaska. Div. Military Application, Energy Research and Development Admin., Tech. Info. Center. pp. 451-492.

Skalkin, V. 1964. Diet of rockfish in the Bering Sea. In: P. Moiseev (ed.), Soviet fisheries investigations in the northeast Pacific. Vol. 2. pp. 159-174. (Transl. Israel Prog. Sci. Transl, 1968.)

Skud, B. 1977. Drift, migration and intermingling of Pacific halibut stocks. Int. Pacific Halibut Comm., Sci. Rep. 63. 42 pp.

Sleptsov, M.M. 1955. Biologiya i promysel kitiv dal'nevostochnykh morei (Biology of whales and the whaling fishery in far eastern seas). Pisch. Prom., Moscow. In Russian. (Tale of contents and conclusions transl. by W.E. Ricker). Fish. Res. Board Can. Transl. Ser. No. 118, 6 pp.)

Smith, G. 1981. The biology of walleye pollock. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea Shelf: Oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington, Press, Seattle. pp. 527-551.

Smith, G.J.D. and D.E. Gaskin. 1974. The diet of harbor porpoises (Phocoena phocoena L.) in coastal waters of eastern Canada, with special reference to the Bay of Fundy. Can. J. Zool. 52:777-782.

Smith, R., A. Paulson and J. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 1:33-107.

Smith, S.L. and J. Vidal. 1986. Variations in the distribution, abundance, and development of copepods in the southeastern Bering Sea in 1980 and 1981. Continental Shelf Research 5(1/2):215-239.

Smith, T. 1980. Catches of male and female sperm whales by 2-degree square by Japanese pelagic whaling fleets in the North Pacific, 1966-77. Rep. Int. Whal. Comm. (Special Issue 2):263-275.

Smith, T., D.B. Siniff, R. Reichle and S. Stone. 1981. Coordinated behavior of killer whales, Orcinus orca, hunting a crabeater seal, Lobodon carcinophagus. Can. J. Zool. 59:1185-1189.

Sowls, A.L., S.A. Hatch and C.J. Lensink. 1978. Catalog of Alaskan seabird colonies. U.S. Fish and Wildl. Serv. Rep. FWS/OBS-78/78.

Spaulding, M.L., T. Isaji, E. Anderson, A.C. Turner, K. Jayko, and M. Reed. 1986. Ocean circulation and oil spill trajectory simulations for Alaskan waters: Spill trajectory simulations for Shumagin Oil and Gas Lease Sale No. 86. Rep. by Applied Science Associates, Inc., to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK. 123 pp.

Steiner, W.W., J.H. Hain, W.E. Winn and P.J. Perkins. 1979. Vocalizations and feeding behavior of the killer whale (Orcinus orca). J. Mammal. 60:823-827.

Stevens, B.G., B.A. Armstrong and R. Cusimano. 1982. Feeding habits of the Dungeness crab Cancer magister as determined by the Index of Relative Importance. Mar. Biol. 72:135-145.

Stevens, B.G. and R.A. MacIntosh. 1985. Report to industry on the 1985 eastern Bering Sea crab survey. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Processed Rep. 85-20.

Stewart, B.S. and S. Leatherwood. 1985. Minke whale Balaenoptera acutorostrata Lacepede 1804. In: S.H. Ridgeway and R.J. Harrison (eds.), Handbook of marine mammals. Vol. 3. Academic Press, New York.

Stewart, B.S., P.K. Yochem, S.A. Karl, S. Leatherwood and J.L. Laake. 1985. Aerial surveys of the former Akutan, Alaska, whaling grounds. In: S. Leatherwood (ed.), A study of past and current uses by endangered whales of waters in and near the St. George Basin, Alaska. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK.

St-Pierre, G. 1984. Spawning locations and season for Pacific halibut. Int. Pac. Halibut Comm., Sci. Rep. No. 70. 46 p.

Straty, R. 1974. Ecology and behavior of juvenile sockeye salmon Oncorhynchus nerka in Bristol Bay and the eastern Bering Sea. In: D.W. Hood and E. Kelley (eds.), Oceanography of the Bering Sea with emphasis on renewable resources. Inst. Mar. Sci., Univ. Alaska Inst. Mar. Sci. Occ. Publ. No. 2. Fairbanks. pp. 285-319.

Straty, R. 1981. Trans-shelf movements of Pacific salmon. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea Shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 575-595.

Strauch, J.G., Jr. 1984. Marine mammals. In: L.E. Jarvela (ed.), The Navarin Basin environment and possible consequences of planned offshore oil and gas development. U.S. Dep. Commer., NOAA, OMPA. Anchorage, AK.

Strauch, J.G. and G.L. Hunt, Jr. 1982. Marine birds. In: M.J. Hameedi (ed.), Proceedings of a synthesis meeting: The St. George Basin environment and possible consequences of planned offshore oil and gas development, Anchorage, Alaska, April 28-30, 1981. U.S. Dep. Commer., NOAA, OMPA. Anchorage, AK. pp. 83-110.

Sugiura, J. 1958. Oceanographic conditions in the Northwest North Pacific based upon the data obtained on board the Komahashi from 1934 to 1936. J. Oceanogr. Soc. Japan. 14:1-5.

Swartzman, G. and R. Haar. 1980. Exploring interactions between fur seal populations and fisheries in the Bering Sea. Final Rep. to U.S. Mar. Mammal Comm. Contract No. MM1800969-5. Natl. Tech. Info. Serv., Springfield, VA. 67 pp.

Swift, J.H. and K. Aagaard. 1976. Upwelling near Samalga Pass. Limnol. Oceanogr. 21:399-408.

Swinnerton, J.W. and R.A. Lamontague. 1974. Oceanic distribution of low-molecular-weight hydrocarbons. Envir. Sci. and Technol. 8:657-663.

Sykes, L.R. 1971. Aftershock zones of great earthquakes, seismicity gaps, and earthquake prediction for Alaska and the Aleutians. J. Geophys. Res. 76:8021-8041.

Sykes, L.R., J.B. Kisslinger, L. House, J.N. Davies and K.H. Jacob. 1980. Rupture zones of great earthquakes, Alaska-Aleutian arc, 1974-1980. Science 210:1343-1345.

Takagi, K., K. Aro, A. Hartt and M. Dell. 1981. Distribution and origin of pink salmon (Oncorhynchus gorbuscha) in offshore waters of the North Pacific Ocean. Int. North Pacific Fish. Comm., Bull. 40. 195 pp.

Takahashi, Y. and H. Yamaguchi. 1972. Stock of the Alaska pollock in the eastern Bering Sea. Bull. Jap. Soc. Sci. Fish. 38:389-399.

Takenouti, A.Y. and K. Ohtani. 1974. Currents and water masses in the Bering Sea: A review of Japanese work. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. Fairbanks, AK. pp. 39-57.

Tanner, Z. L. et al. 1880. Explorations of the fishing grounds of Alaska, Washington Territory, and Oregon during 1888 by the U.S. Fish Comm. Steamer Albatross. U.S. Fish. Comm. 8:1-92.

Tarasevich, M.N. 1968a. Food connections of sperm whales in the Northern Pacific. Zool. Zhur. 47:595-601. In Russian. (Transl. by Ken Coyle, Univ. Alaska, Fairbanks, 8 pp.)

Tarasevich, M.N. 1968b. Dependence of distribution of the sperm whale males upon the character of feeding Zool. Zhur. 47:1683-1688. In Russian. (Transl. by Ken Coyle, Univ. Alaska, Fairbanks, 1982, 8 pp.)

Tarverdieva, M.I. and K.A. Zgurovsky. 1985. On food composition of the deep-water crab species Lithodes acquispina Benedict and Chionoecetes tanneri Rathbon in the Bering and Okhotsk seas. Proc. Int. King Crab Symp., Jan. 1985, Anchorage, AK. pp. 319-329.

Tetra Tech. 1979. Working draft environmental impact statement for World War II debris removal and cleanup, Aleutian Islands and lower Alaska Peninsula, Alaska. Rep. to U.S. Army Corps of Engineers, Alaska District.

Thorsteinson, F. and T. Merrell. 1964. Salmon tagging experiments along the south shore of Unimak Island and the southwestern shore of the Alaska Peninsula. U.S. Fish and Wildl. Serv. Special Sci. Rep. Fish. No. 486. 15 pp.

Thorsteinson, F.V. and L.K. Thorsteinson. 1982. Finfish resources. In: M.J. Hameedi (ed.), Proc. of a synthesis meeting: The St. George Basin environment and possible consequences of planned offshore oil and gas development. Anchorage, AK. 28-30 April 1981. U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK.

Thorsteinson, F.V. and L.K. Thorsteinson. 1984. Fishery resources. In: L.K. Thorsteinson (ed.), Proc. of a synthesis meeting: The North Aleutian Shelf environment and possible consequences of offshore oil and gas development. Anchorage, AK., 9-11 March 1982. U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK.

Thorsteinson, L.K. (ed.). 1984. Proc. of a synthesis meeting: The North Aleutian Shelf environment and possible consequences of offshore oil and gas development. Anchorage, AK, 9-11 March 1982. U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK.

Tomilin, A.G. 1957. Cetacea. Vol. 9. Mammals of the USSR. (Transl. by Isreal Program Sci. Transl. 1967.) NTIS No. TT 65-50086. 717 pp.

Tonneson, J.N. and A.O. Johnson. 1982. The history of modern whaling. (Transl. from Norwegian by R.I. Christopherson). Univ. California Press, Berkeley. 298 pp.

Townsend, C.H. 1901. Dredging and other records of the United States Fish Commission Steamer Albatross, with bibliography relative to the work of the vessel. U.S. Comm. Fish and Fish. Report to the Comm. 1900, Part 26, pp. 387-560.

Townsend, C.H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. Zoologica (N.Y.) 10. 50 pp.

Trapp, J.F. 1975. The distribution and abundance of seabirds along the Aleutian Islands and Alaska Peninsula, Fall 1974. U.S. Fish and Wildl. Serv. Trip Rep. Aleutian Islands Nat'l. Wildl. Refuge, Adak, Alaska. 19 pp.

Trapp, J.L. 1979. Variation in summer diet of Glaucous-winged Gulls in the western Aleutian Islands: an ecological interpretation. Wilson Bull. 91:412-419.

Troy, D.M. and J.S. Baker. 1985. Population studies. In: S.R. Johnson (ed.), Population estimation, productivity, and food habits of nesting seabirds at Cape Peirce and the Pribilof Islands, Bering Sea, Alaska. Rep. by LGL Ecol. Res. Assoc., Inc., to U.S. Dep. Int., MMS, Anchorage, AK. pp. 34-190.

Truett, J.C. (ed.). 1984. Proc. of a synthesis meeting: The Barrow Arch environment and possible consequences of planned offshore oil and gas development. Girdwood, AK., 30 October-1 November 1983. U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK.

Trumble, R. 1973. Distribution, relative abundance and general biology of selected underutilized fishery resources of the eastern North Pacific Ocean. M.S. Thesis, Univ. Washington, Seattle. 178 pp.

Turner, L. 1886. Part 4. Fishes. In: Contributions to the natural history of Alaska. Arctic series of publications issued in connection with the Signal Service, U.S. Army. Wash. Govt. Printing Office. pp. 87-113.

U.S. Dep. Commerce. 1980. Final environmental impact statement on the interim convention on conservation of the North Pacific fur seal. NOAA, NMFS, Washington, D.C. 116 pp.

U.S. Dep. Commerce. 1984. Outer continental shelf environmental assessment program: Comprehensive bibliography. NOAA, OCSEAP, Anchorage, AK. 607 pp.

U.S. Dep. Commerce. 1986. Outer continental shelf environmental assessment program: Comprehensive bibliography. NOAA, OCSEAP, Anchorage, AK. 705 pp.

U.S. Fish and Wildlife Service. 1986. Seabird colony catalog: Archives. U.S. Fish and Wildl. Serv., Seabird Colony Catalog, Anchorage, AK.

U.S. Hydrographic Office. 1958. Oceanographic survey results, Bering Sea area, winter and spring 1955. Tech. Report No. 56. 95 pp.

Veltre, D. and M. Veltre. 1982. Resource utilization in Unalaska, Aleutian Islands, Alaska. Alaska Dept. Fish and Game, Div. Subsistence, Tech. Pap. No. 58. 131 pp.

Venkatesan, M.I., M. Sandstrom, S. Brenner, E. Ruth, J. Bonilla and I.R. Kaplan. 1981. Organic geochemistry of surficial sediments of the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and biological resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 389-409.

Vesin, J., W. Leggett and K. Able. 1981. Feeding ecology of capelin (Mallotus villosus) in the estuary and western Gulf of St. Lawrence and its multispecies implications. Can. J. Fish. Aquat. Sci. 38:257-267.

Votrogov, L.M. and M.V. Ivashin. 1980. Sightings of fin and humpback whales in the Bering and Chukchi seas. Rep. Int. Whaling Comm. 30:247-248.

Wada, S. 1980. Japanese whaling and whale sightings in the North Pacific 1978 season. Rep. Int. Whal. Comm. 30:415-424.

Wahl, T.R. 1978. Observations of Dall's porpoise in the northwestern Pacific Ocean and Bering Sea in June 1975. Murrelet 60:108-110.

Walker, R. and K. Schnepf. 1982. Scale pattern analysis to estimate the origin of herring in the Dutch Harbor fishery. Final Rep. from Univ. Washington, Seattle to Alaska Dep. Fish and Game. 14 pp.

Wall, J., and P. Macy. 1976. An annotated bibliography on non-salmonid pelagic fishes of the gulf of Alaska and eastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Processes Rep. 70 pp.

Walters, G., G. Smith, P. Raymore and W. Hirschberger. 1985. Studies of the distribution and abundance of juvenile groundfish in the northwestern Gulf of Alaska, 1980-1982: Part II, Biological characteristics in the extended region. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-77. 95 p.

Warner, I. and P. Shafford. 1981. Forage fish spawning surveys--southern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 10:1-64.

Wehle, D.H.S. 1980. Comparative biology of the tufted puffin (<u>Lunda cirrhata</u>), horned puffin (<u>Fratercula corniculata</u>), common puffin (<u>F. arctica</u>), and rhinoceros auklet (<u>Cercorhinca monocerata</u>). Ph.D. Thesis, Univ. Alaska, Fairbanks.

Wespestad, V. and L. Barton. 1981. Distribution, migration and status of Pacific herring. <u>In</u>: D.W. Hood and J. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 509-525.

Wespestad, V. and S. Fried. 1983. Review of the biology and abundance trends of Pacific herring. <u>In</u>: W. Wooster (ed.), From year to year: interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. Washington, Washington Sea Grant Rep., Seattle. pp. 17-29.

Whitledge, T.E., W.S. Reeburgh and J.J. Walsh. 1986. Seasonal inorganic nitrogen distributions and dynamics in the southeastern Bering Sea. Continental Shelf Research 5:109-132.

Wilderbauer, T., K. Wakabayashi, L. Ronholt and H. Yamaguchi. 1985. Survey report: Cooperative U.S.-Japan Aleutian-Islands groundfish trawl survey-1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-93.

Wilimovsky, N. 1964. Inshore fish fauna of the Aleutian archipelago. Science in Alaska, 1963. Proc. 14th Alaska Sci. Conf., Am. Assoc. Advance. Sci., Alaska Div. pp. 172-190.

Wilke, F. and K.W. Kenyon. 1957. Migration and food of the northern fur seal. Trans. N. Am. Wildl. Conf. 19:430-440.

Wilson, J.R. and A.H. Gorham. 1982a. Underutilized species, Vol. I: Squid. Univ. Alaska, Alaska Sea Grant Rep. 82-1. Fairbanks. 77 p.

Wilson, J.R. and A.H. Gorham. 1982b. Alaska underutilized species, Vol. II: Octopus. Univ. Alaska, Alaska Sea Grant Rep. 82-3. Fairbanks.

Winn, H.E. and N.E. Reichley. 1985. Humpback whale Megaptera novaengliae (Borowski, 1781). In: S.H. Ridgeway and R.J. Harrison (eds.), Handbook of Marine Mammals Vol. 3. Academic Press, London.

Wooster, W. (ed.). 1983. From year to year: interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Univ. Washington, Washington Sea Grant Rep. 83-3. Seattle. 208 pp.

Wright, C. 1981. Observations in the Alaskan Stream during 1980. U.S. Dep. Commer., NOAA Tech. Memo. ERL-PMEL-23. Seattle, WA.

Yesner, D.R. and J.S. Aigner. 1976. Comparative biomass estimates and prehistoric cultural ecology of the southwest Umnak Region, Aleutian Islands. Arctic Anthropology 12:91-112.

Yukhov, V.L., E.K. Vinogradova and L.P. Medvedev. 1975. Ob'ekty pitaniya kosatok (Orcinus orca L.) in the Antarctic and adjacent waters). Morskie Mlekopitayuschchie Chast' 2:183-185. In Russian. (Transl. by Transl. Bur., Multilingual Serv. Div., Dep. Sec. State, Ottawa, Ont., Canada, Fish. Res. Mar. Serv. Transl. Ser. No. 3822, 1976, 5 pp.).

Zenkovich, B.A. 1934. (Research data on cetacea of far eastern seas). Bull. Far East Acad. Sci., USSR, No. 10. In Russian. (Transl. by F. Essapian, Miami, Fla., 34 pp.)

Zimushko, V.V. and S.A. Lenskaya. 1970. Feeding of the gray whale (Eschrichtius robustus Erx.) at foraging grounds. Ekologia, Akad. Nauk SSSR, 1:26-35. (Transl. by Consultants Bur., iv. of Plenum Publ. Corp., 227 West 17th St., New York, NY 10011.)

PART II. ANNOTATED BIBLIOGRAPHY

PART II. ANNOTATED BIBLIOGRAPHY

1. INTRODUCTION

This bibliography is provided to accompany PART I. ECOSYSTEM ANALYSIS. The purpose of the bibliography is to reference and briefly describe published and unpublished research conducted wholly or partly in the study area designated for this project (see Fig. 2-1). As such, it excludes many of the references used in Part I.

Included in this bibliography are studies of biota, investigations of the physical and chemical components and processes that influence the biota, and research that analyzes or clarifies the vulnerabilities of the biota and their habitats to impact from oil and gas development activities. Many disciplines have been investigated to a limited extent in the area of study, but to a much greater extent in peripheral areas (e.g., the southeastern Bering Sea); reports of investigations that took place entirely outside the study area are not included in this bibliography. Research seeming to have no relevance to biota, its habitat, or its vulnerability to OCS development is not included.

The entries in this bibliography are alphabetized by authors' last names. To assist users in finding printed information by category, a subject index is provided following the annotations.

2. BIBLIOGRAPHY

1. Aagaard, K., L.K. Coachman, F. Favorite, J.A. Galt, and C.A. Paulson. 1974. Physical oceanography and air-sea interaction. In: D.W. Hood (convenor). PROBES: prospectus on processes and resources of the Bering Sea shelf, 1975-1985. Deliberations of a workshop, Salishan Lodge, Oregon, 24-30 November 1973. Univ. Alaska Inst. Mar. Science, Fairbanks.

The authors discuss various aspects of the meteorology and oceanography of the southeastern Bering Sea. Existing information about weather and climatology, upwelling, general circulation, shelf and shelf-edge dynamics, heat exchange, effects of ice, air-sea interactions, and inflow through the eastern Aleutian passes is very briefly summarized. Six physical oceanography-meteorology research goals for the PROBES program are listed.

2. ADFG (Alaska Dep. Fish & Game). 1983. Legislative report, 1982 Aleutian Islands salmon stock assessment study (1983 supplement). Div. Comm. Fish., Juneau. 17 pp.

See Holms (1982).

3. ADFG (Alaska Dep. Fish & Game). 1985. Alaska habitat management guide, Southwest Region, Vols. 1-4. Div. Habitat, Juneau.

This 4-volume report provides a handy review of information about salmon, herring, groundfish, crabs, clams and shrimp in southwestern Alaska, including the Aleutian Islands. Summaries of life histories, habitat requirements, distribution and abundance are presented for major species, and subsistence and commercial fisheries are reviewed. Maps illustrate areas of species abundance and human harvests.

4. ADFG (Alaska Dep. Fish & Game). 1985. Westward Region shellfish report to the Alaska board of Fisheries. Div. Comm. Fish., Kodiak.

This report discusses the shellfish resources in Alaska's Western Region, which includes Kodiak, Chignik-South Peninsula, eastern Aleutian (study area for this report), western Aleutian, and Bering Sea areas. For each area, the history, fishery, and stock status of commercially important species is discussed. In the eastern Aleutian area, these include red king crab, brown king crab, Tanner crab, Dungeness crab, hair crab, shrimp, and octopus. Tables and figures of harvest rates are presented.

5. Allen, J.S., R.C. Beardsley, J.O. Blanton, W.C. Boicourt, B. Butman, L.K. Coachman, A. Huyer, T.H. Kinder, T.C. Royer, J.D. Schumacher, R.L. Smith, W. Sturges, and C.D. Winant. 1983. Physical oceanography of continental shelves. Rev. Geophys. and Space Phys. 21(5):1149-1191.

This paper summarizes known information about several continental shelf areas, including the eastern Bering Sea. Authors Schumacher, Kinder and Coachman discuss several aspects of the physical oceanography of the eastern Bering region: hydrography, currents, climatology, ice, and physical-biological interactions. Entry of coastal waters from the Gulf of Alaska through Unimak Pass is described.

6. Armstrong, D.A., L.S. Incze, D.L. Wencker, and J.L. Armstrong. 1983. Distribution and abundance of decapod larvae in the southeastern Bering Sea with emphasis on commercial species. Rep. to U.S. Dep. Commer., NOAA, OCSEAP, by Univ. Washington School of Fisheries, Seattle. 388 pp.

This report describes results of sampling for decapod crustacean larvae in the water column in the southeastern Bering Sea. Sampling extended well into the eastern Aleutian area north of Unimak Pass. Distribution of larvae of red king crab, Tanner crabs, Korean hair crabs, shrimps, hermit crabs, and selected other species are described. General life history and fishery information on these species are also given.

7. Armstrong, D.A. 1986. Unpubl. data from rock dredge samples taken in Unimak Pass, July 1985, Miller Freeman cruise.

D. Armstrong, University of Washington, sampled with rock dredge at a few locations in Unimak Pass during summer 1985 from the R/V Miller Freeman. Data are not yet published, but catches included sponges, clams, brittle stars, sea cucumbers, hermit and Tanner crabs, and snails.

8. Arneson, P.D. 1977. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. U.S. Dep. Commer., NOAA, OCSEAP, Vol. II. Receptors - Birds: 1-33.

This is a progress report on work accomplished on a series of aerial and small boat surveys of coastal habitats and birds encountered in those habitats by season. The report contains maps of habitats mapped and raw data on birds observed in the areas covered. The Unimak Pass study area is contained in their study area number 9, Aleutian Shelf.

9. Arneson, P.D. 1978. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. U.S. Dep. Commer., NOAA, OCSEAP. Annu. Rep. 1:431-481.

Exposed inshore habitats were found to be important wintering habitat for sea ducks, emperor geese, rock sandpipers and large gulls in the eastern Aleutian Islands. The Samalga Island section supported the highest bird densities. Inclement weather precluded comprehensive surveys to further substantiate the importance of this region to wintering marine birds. Species composition and abundance of birds changed quickly during spring and fall migrations. The report concluded that one survey per season provides an inadequate database upon which to make concrete conclusions about bird densities and habitat usage; it would be helpful to standardize coastal survey techniques in future studies. Habitat availability as well as habitat preferences of birds should be recorded in all surveys.

10. Arneson, P.D. 1980. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP, from Alaska Dep. Fish & Game, Anchorage. 350 pp.

This document reports on an extensive series of aerial and boat surveys of coastal habitats for birds from Cape Newenham on the west to Cape Fairweather on the east, and south as far as Samalga Island. All of the Unimak Pass study area is included in the area surveyed by the author. Bird densities were calculated by season for coastal segments within all regions surveyed. Maps and tables present bird densities by species or species groups. This report represents a major effort in documenting bird abundance by region in all coastal areas of south-central Alaska, including the eastern Aleutian Islands.

11. Aron, W. 1960. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. Univ. Wash. Dep. Oceanogr., Tech. Rep. No. 63, Seattle. 216 pp.

See Aron (1962).

12. Aron, W. 1962. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Can. 19:271-314.

Aron describes the final results of three mid-water trawl surveys in 1958-59 in the North Pacific Ocean; however, virtually all stations are far outside our present study area. Catches at four sites north and south of Unimak Pass are listed in an earlier report (Aron 1960)--a total of 27 juvenile or adult fish (mostly lanternfish) and 31 larval fish were caught and dominant invertebrates were euphausiids, amphipods and shrimp.

16. Bakkala, R., V. Wespestad, and H. Zenger. 1983. Pacific cod. In: R. Bakkala and L. Low (eds.), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1982. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-42. pp. 29-50.

A trawl survey of the Aleutian Islands from Unimak Pass to Atka Island was conducted in February-March 1982 by the Northwest and Alaska Fisheries Center. The principal objective was to assess the abundance of Pacific cod. Biomass estimates indicated that most cod were on the Bering Sea side of the islands and that cod may migrate in winter from other areas to spawn in the eastern Aleutian Islands region. Catches of other species are apparently not available in report form.

17. Beikman, H.M. 1975. Preliminary geologic map, Alaska Peninsula and Aleutian islands. U.S. Geol. Surv. Map MF-674.

Two map sheets are provided. Sheet 1 shows the locations of geologic features of various ages and types. Sheet 2 provides detailed descriptions of the features mapped in Sheet 1 and shows sources of the data used in the mapping.

18. Best, E. 1977. Distribution and abundance of juvenile halibut in the southeastern Bering Sea. Int. Pacific Halibut Comm., Sci. Rep. 62. 23 pp.

In addition to a discussion of halibut distribution and abundance in the southeastern Bering Sea, Best summarizes the available information describing possible exchange of halibut stocks between the Bering Sea and Gulf of Alaska. Larval transport from the Gulf into the Bering Sea is thought to occur, but the evidence is circumstantial. Tagging data from the Unimak Pass area show that juveniles may move from the Bering Sea into the Gulf and vice versa.

19. Best, E. 1981. Halibut ecology. In: D.W. Hood and A.J. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA, Univ. Washington Press, Seattle. pp. 495-508.

The distribution of halibut within the Bering Sea is seasonal and dependent on climatic conditions. The fish migrate to deep water for spawning during winter and return to shallow areas for summer feeding. The timing and extent of the summer movement are controlled by oceanographic conditions. Spawning occurs between Unimak Island and the Pribilof Islands, and probably other areas in the Bering Sea, at depths of 250-550 m. Tagging studies show a movement of halibut from the Bering Sea into the Gulf of Alaska.

20. Black, R.F. 1974a. Geology and ancient Aleuts, Amchitka and Umnak Islands, Aleutians. Arctic Anthropology. 11:126-140.

The author discusses the different geologic histories of Amchitka and Umnak islands in the Quaternary, and evaluates the effects the histories had on the region's first inhabitants, the ancient Aleuts. Parts of the Aleutians were habitable throughout the late Quaternary; the climate was never as cold as it was in northern parts of the Bering Land Bridge. Umnak Island was probably first inhabited by people moving westward along the Alaska Peninsula after the area was deglaciated to some extent 8000-10,000 years ago.

21. Black, R.F. 1974b. Late-Quaternary sea-level changes, Umnak Island, Aleutians--their effects on ancient Aleuts and their causes. Quaternary Research 4:264-281.

Late-Quaternary sea-level changes in the eastern Aleutian Islands are used in the reconstruction of the migrations and environment of the ancient Aleuts. A radiocarbon-dated ash stratigraphy provides the chronology into which geomorphic events are fitted. These provide evidence for the sea-level changes. Deployment of beach material and coastal configuration intimate that sea level was about 2-3 m above the present level about 8250 radiocarbon yr BP. Beach deposits suggest that sea level remained high until about 3000 radiocarbon years ago when it gradually dropped to its present position. It is concluded that the ancient Aleuts that settled Anangula about 8400 years ago used boats; all major passes in the eastern Aleutians were flooded, and did not have winter ice. (From author's abstract.)

22. Black, R.F. 1975. Late-Quaternary geomorphic processes--effects on the ancient Aleuts of Umnak Island in the Aleutians. Arctic 18:159-169.

Glaciation, volcanic activity, marine processes and wind action affected in various ways the lives of the ancient Aleuts of Umnak Island, who first settled at Anangula about 8400 BP following deglaciation some 3000 years earlier. Expanding alpine glaciers reached the sea in places about 3000 BP without the nearby people being much affected. A catastrophic eruption of Okmok Volcano about 8250 BP is suggested as the cause of the abandonment of the oldest known site of Anangula, and subsequent migration westward into the central Aleutians. Cutting of strandflats between 8250 and 3000 BP led to the development of a very large, accessible, year-round food resource, and an apparent proliferation of settlements. In marked contrast to other parts of Beringia, Umnak Island became the site most favorable for human settlement. (Author's abstract.)

23. Black, R.F. 1976. Geology of Umnak Island, eastern Aleutian Islands, as related to the Aleuts. Arctic and Alpine Research 8:7-35.

Umnak Island, eastern Aleutian Islands, is capped by active volcanoes, was extensively glaciated, and is being eroded rapidly by the sea. During the Holocene, Umnak and other Aleutian Islands had the most equable climate, the best year-round food supply, and the least displacements of coastlines from sea-level fluctuations of all places in the Bering Land Bridge, the migration route of ancient people to the Western Hemisphere. The Aleuts could have entered the eastern Aleutians after about 11,000 to 12,000 years ago when massive ice caps waned. The earliest known occupation at Anangula is 8400 years old. Occupation in southwest Umnak Island was probably continuous to the present day. The Aleuts have always been influenced markedly by geologic processes, especially volcanic eruptions, coastal erosion and deposition, and wind-induced upwelling that enhances the marine biomass. The most important geologic event probably was the cutting of strandflats during the Hypsithermal, about 8250 to 3000 years ago. This led to an enormopus increase in renewable food resources easily gathered year-round and the apparent proliferation of Aleuts in post-Hypsithermal time. A Neoglacial advance to the sea of alpine glaciers does not seem to have affected them. (From Author's abstract.)

24. Blackburn, J., P. Rigby, and D. Owen. 1980. An observer program for the domestic groundfish fisheries in the Gulf of Alaska and Bering Sea/Aleutian Islands. North Pacific Fish. Manage. Council, Anchorage, AK. Council Document No. 16. 50 pp.

A winter trawl fishery along the 100-fathom contour north of Akutan and Unimak Pass was monitored January to April 1980. The catch was 81% Pacific cod (the targeted species) and 10% pollock, with the remainder consisting of 24 species of fish and invertebrates. Catches per unit effort (kg/h) were: 2216 Pacific cod, 274 pollock, 248 for the remaining fish species, and 6.4 for invertebrates.

25. Blau, S.F. 1985. Overview and comparison of the major red king crab (_Paralithodes camtschatica_) surveys and fisheries in western Alaska, 1969-1984. Proc. Int. King Crab Symp., Jan. 1985, Anchorage, AK. pp. 23-48.

The Alaska Department of Fish and Game (ADFG) and National Marine Fisheries Service (NMFS) have studied the population structure and dynamics of the red king crab (_Paralithodes camtschatica_) and its relationship to commercial fishing. Surveys conducted in the Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet king crab management areas are the focus of this paper. Trawl surveys were conducted by NMFS in Bristol Bay and their results since 1969 are examined. The remaining four areas were surveyed by ADFG using crab pots starting in Kodiak in 1972. The survey catch of male and female red king crab including their length frequencies are given for each area. The total number of legal males tagged throughout each area's survey history is summarized. The commercial king crab fishing effort, catch, exploitation rate and population estimates are given for each area by survey year. The Unimak Pass area and eastern Aleutians are included in the Dutch harbor survey area. (From author's abstract.)

26. Braham, H.W. 1984. Distribution and migration of gray whales in Alaska. In: M.L. Jones, S. Leatherwood, and S.L. Swartz (eds.), The gray whale (*Eschrichtius robustus* Lilljebord, 1861). Academic Press, New York. pp. 249-266.

This paper provides an extensive review of published and unpublished reports; sightings of whales during scientific cruises, land-based studies, and other research; and anecdotal accounts of gray whale presence throughout Alaskan waters. Information is summarized by sections of the Alaskan coastline, including the Unimak Pass area. Most whales appear to pass through Unimak Pass on spring migration into the Bering Sea and head northeastward along the Alaska Peninsula. No gray whales were reported among the eastern Aleutian Islands west of Unimak Pass. Following absence in mid-summer, whales were again seen in the Unimak Pass area from September to December.

27. Braham, H.W., and M.E. Dalheim. 1982. Killer whales in Alaska documented in the platforms of opportunity program. Rep. Int. Whal. Comm. 32:643-646.

This paper reports on the distribution of sightings of killer whales in Alaskan waters, irrespective of survey effort, obtained from 1958 to 1980. There is some indication that this species prefers nearshore waters to deeper oceanic waters. It also appears to be a year-round resident in ice-free areas. Sightings are shown in the Unimak Pass study area, particularly in the pass itself and north of Unalaska Island and the Krenitzin Islands.

28. Braham, H.W., R.D. Everitt, B.D. Krogman, D.J. Rugh, and D.E. Withrow. 1977. Marine mammals of the Bering Sea: preliminary analysis of distribution and abundance, 1975-76. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fisheries Center, Marine Mammal Div., Seattle, WA. 90 pp.

The authors report on preliminary findings of a series of aerial surveys and shipboard surveys of marine mammals of the Bering Sea. Most of the survey effort was concentrated in areas north of the Unimak Pass study area, but specific surveys to document sea lion and harbor seal haulout areas in the eastern Aleutian Islands were also made. Important haulout and rookery sites within the study area are mapped and discussions by species are also presented. The authors emphasize that data are preliminary and to be followed by continued survey effort.

29. Braham, H.W., R.D. Everitt, and D.J. Rugh. 1980. Northern sea lion population decline in the eastern Aleutian Islands. J. Wildl. Manage. 44:25-33.

Aerial surveys were flown in the Unimak Pass study area during June, August, and October from 1975 to 1977 to identify important sea lion rookery and haulout sites and assess population levels. Extensive tables identify areas of sea lion use in the study area and indicate populations using these sites. Comparisons are then made with historical (1950's and 1960's) data. A 50% decrease in the sea lion population in this area was estimated. Cause of the decline is unknown but may be due to population shifts westward in the Aleutian Islands, pathogens, or resource competition with commercial fisheries.

30. Braham, H.W., C.H. Fiscus and D.J. Rugh. 1977. Marine mammals of the Bering and southern Chukchi seas. U.S. Dep. Commer., NOAA, OCSEAP, Annu. Rep. 1:1-99.

This report summarizes existing knowledge on distribution of marine mammals in the eastern Bering and southern Chukchi seas. Figures present results of recent aerial surveys for marine mammals and some specific surveys for harbor seals and sea lions in the eastern Aleutian Islands are presented. Most data is preliminary and discussions are tentative. Several surveys specific to the Unimak Pass study area are reported upon.

31. Braham, H.W., G.W. Oliver, C. Fowler, K. Frost, F. Fay, C. Cowles, D. Costa, K. Schneider, and D. Calkins. 1982. Marine mammals. In: M.J. Hameedi (eds.), Proc. of a synthesis meeting: the St. George environment and possible consequences of planned offshore oil and gas development. Anchorage, Alaska, 28-30 April 1981. U.S. Dep. Commer., NOAA, OMPA. pp. 55-81.

This report provides a brief review of information on the occurrence of marine mammals in the proposed St. George basin petroleum lease area. Information is gathered from many published and unpublished papers and reports and from unpulished data provided by the authors. In addition to reviewing the status and distribution of all marine mammals present in the study area, the authors discuss trophic relationships, sensitivity and vulnerability to petroleum development, and information needs. Most of the St. George basin lies outside of the Unimak Pass study area, but discussions and range maps often include information applicable to populations of marine mammals using the Unimak Pass area.

32. Brannian, L. 1984. Recovery distribution of chum salmon tagged in the North Pacific offshore of the Alaska Peninsula and eastern Aleutian Island chain. Alaska Dep. Fish & Game, Info. Leaflet 237. 30 pp.

Chum salmon were tagged in the vicinity of the Alaska Peninsula and eastern Aleutian Islands (mainly near Umnak and Unalaska islands) to determine distribution and movement patterns. Recoveries of these fish were made throughout western Alaska and Asia. Results indicate differences in the timing of stocks migrating by the eastern Aleutian Islands: (1) May and early June (the summer run of Yukon River chums), (2) June (Norton Sound and Kuskokwim Bay chums), (3) mid to late June (Bristol Bay and the fall run of Yukon River chums), and (4) mid-June to early July (Kotzebue chums).

33. Brueggeman, J.J., T.C. Newby, and R.A. Grotefendt. 1985. Seasonal abundance, distribution and population characteristics of blue whales reported in the 1917 to 1939 catch records of two Alaska whaling stations. Rep. Int. Whal. Comm. 35:405-411.

Previously unavailable records of the catch of blue whales at Akutan and Port Hobron whaling stations in Alaska were analyzed to assess the abundance, distribution, and population characteristics of blue whales summering in Alaska. Records indicate that blue whales summered in nearshore waters near both whaling stations but were more abundant near the Akutan station, within the Unimak Pass study area. Blue whales were hunted on the Pacific Ocean side of the eastern Aleutian Islands where they were apparently more abundant. Although the local population was decreased by the whaling, size and productivity information indicate they were reproducing throughout the period of exploitation. Maps of whale catches and other data from the Akutan station are applicable to the Unimak Pass study area.

34. Brueggeman, J.J., T. Newby, and R.A. Grotefendt. 1986. Catch records of twenty North Pacific right whales from two Alaska whaling stations, 1917-1939. Arctic 39:43-46.

Previously unavailable records of the catch of right whales at Akutan and Port Hobron whaling stations in Alaska were analyzed to add to the knowledge of the pelagic distribution of right whales in the North Pacific Ocean. Nine of the 20 whales taken were within the Unimak Pass study area when captured and most were within 56 km of shore. Two were caught within Unimak Pass itself. Although sample sizes were limited, results suggest that the North Pacific right whale population was inhabiting its historic summering grounds after the period of heavy exploitation in the 1800's, reproducing as late as 1926, and supporting a subadult cohort at least until the species was protected in 1935.

35. Burk, C.A. 1966. The Aleutian Arc and Alaska continental margin. Continental margins and island arcs. Geol. Surv. of Canada. Pap 66-15:206-215.

The author gives an overview of the geology of the Alaska Peninsula and the Aleutian Islands. He provides evidence to show that the Shumagin-Kodiak shelf and the southeastern Bering Shelf had similar geologic histories, and that the Aleutian Arc was superimposed on these bases in the early Tertiary, extending itself across both oceanic and continental crust.

36. Burrell, D.C. 1977. Natural distribution of trace heavy metals and environmental background in Alaskan shelf and estuarine areas. U.S. Dep. Commer., NOAA, OCSEAP. Annu. Rep. 13:290-506.

This project covered lower Cook Inlet, Norton Sound, the southern part of the Chukchi Sea, the Gulf of Alaska, and the Bering and Beaufort seas. For the soluble contents analysed, Cd, Pb, Cu, Ni, Hg, and V concentrations in filtered seawater from all shelf regions of Alaska were generally lower than commonly accepted oceanic means. Distributions were quite uniform. Heavy metal contents were a function of the sediment grain size and the lithology. The concentrations of particulate heavy metals in the water were related to the particulate sediment load with enhanced concentrations adjacent to the sediment interface and in coastal waters. The Alaskan shelf regions could well serve as a type example of pristine coastal environments. (From author's abstract.)

37. Burrell, D.C., K. Tommos, A.S. Naidu, and C.M. Hoskin. 1981. Some geochemical characteristics of Bering Sea sediments. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 305-319.

Biogeochemical data are presented for surficial Bering Sea sediments; most are for separate single collections on the southeastern shelf and Norton Sound. In general, the distribution of size fractions conform to the present physical environment as this is currently understood; relict and palimpsest sediment is of minor distribution. Southeastern shelf infauna demonstrates a reciprocal relationship: individual organisms are at a maximum in fine sand-sized sediment, but wet-weight biomass increases in sediment finer and coarser than this. Heavy metal contents correlate with fineness of mean grain size; hence contents are, in general, relatively reduced over these shelf areas. Increases in near-bottom particulate contents may be attributed to sediment resuspension. One sampling site, immediately North of Unimak Pass, is in the eastern Aleutian study area.

38. Byers, F.M., Jr. 1959. Geology of Umnak and Bogoslof islands, Aleutian Islands, Alaska. U.S. Geol. Surv. Bull. 1028-L:267-369.

The author analyses the geology of Umnak and Bogoslof islands in the eastern Aleutians. Umnak Island is separated into northeastern and southwestern parts by a central constriction; the rocks are late Tertiary and Quaternary volcanics resting on early to middle Tertiary plutonic and metamorphic rocks. Bogoslof, the youngest island in the Aleutians, is composed almost entirely of historic lavas.

39. Byrd, G.V., G.J. Divoky, and E.P. Bailey. 1980. Changes in marine bird and mammal populations on an active volcano in Alaska. Murrelet 61:50-62.

This paper reports on the results of a four-day visit to Bogoslof and Fire islands from 28 June to 1 July 1973. Because of the highly dynamic alterations in the shapes of these two islands over the last two centuries, colonization by birds, mammals, and plants has been of interest. The authors counted 900 bull, 2400 cow and 2328 young northern sea lions on the islands. In addition, 15 species of birds were found breeding there, including 12 species of seabirds, comprising over 90,000 individuals. Both of the islands lie within the Unimak Pass study area.

40. Byrd, G.V., and D.D. Gibson. 1980. Distribution and population status of whiskered auklet in the Aleutian Islands, Alaska. Western Birds 11:135-140.

This short paper reviews the geographic distribution and population status of the Whiskered Auklet in the Aleutian Islands up to 1974. Highest numbers of this species were seen in the Fox Islands during the breeding season. Feeding concentrations of birds were most frequently associated with tide rips in passes between islands. The minimum population estimated for the Aleutian Islands was 25,000 birds.

41. Cimberg, R.L., D.P. Costa, and P.A. Fishman. 1984. Ecological characterization of shallow subtidal habitats in the North Aleutian Shelf. U.S. Dep. Commer., NOAA, OCSEAP, Final Rep. 44(1986):437-646.

This report describes results of sampling to determine distributions of infauna, epifauna, sea otters, and the trophic relations between the benthic communities and sea otters. The area sampled extended along the north side of the Alaska Peninsula (0-50 m depths) from Cape Seniavin to Unimak Pass, encroaching on the extreme eastern end of the Unimak Pass study area. Infaunal and epifaunal distributions correlated strongly with substrate type (grain size composition) and with depth. Sea otter populations varied seasonally in abundance; otters probably fed mainly on crabs, bivalves, and fish. Discussions are presented on the potential effect of oil on the biota.

42. Cline, J.D. 1981. Distribution of dissolved LMW hydrocarbons in Bristol Bay, Alaska: implications for future oil and gas development. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 425-444.

In September and October 1975, and again in July 1976, the distribution of dissolved, low molecular weight (LMW) hydrocarbons was determined in Bristol Bay, Alaska. The concentrations were relatively low compared to other Alaskan shelf areas and showed a significant seasonal signature. Local production of methane was accelerated in summer as it was for the alkenes. The concentrations of ethane and ethene were in linear relation in summer, suggesting a common source or perhaps a common organic precursor. The distribution of methane was strongly coupled to circulation and, in particular, to the location of hydrographic fronts. In contrast, the alkenes appeared to be regulated more by biological activity than by circulation. In composition, LMW hydrocarbons arising from a thermogenic source can be readily distinguished from their biological equivalents on the basis of the relative concentrations of ethane and ethene. Elementary modeling of a line hydrocarbon source suggested that hydrocarbon trajectories could be traced for several hundred km, assuming a source concentration 100 times above ambient levels. (From author's abstract.)

43. Coachman, L.K. 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. Continental Shelf Research 5(1/2):23-108.

The author evaluates available data to discuss in some detail water movements in the southeastern Bering Sea. Effects of tidal currents, low-frequency flows, winds, vertical heat exchange, ice, lateral water mass interaction, and boundary fresh-water addition are discussed. Unimak Pass is at the extreme southern edge of the area considered.

44. Coachman, L.K., and R.L. Charnell. 1977. Fine structure in outer Bristol Bay, Alaska. Deep Sea Res. 24:869-889.

A salinity-temperature-depth (STD) cruise in Bristol Bay in the Bering Sea during March, 1976, showed the existence of a subsurface layer with large density inversions. This fine-structure layer, which covered a horizontal distance of some 100 km, showed a maximum negative density gradient of 55×10^{-6} kgm^{-4}. Stations showing these inversions were in the zone of interaction between Bering Sea water and the shelf water of Bristol Bay, which had been displaced about 100 km south of its usual location by strong northerly winds. The layer persisted for nearly one week. Hypotheses are advanced to account for its formation and persistence. (Authors' abstract.)

45. Cooney, R.T. 1978. Environmental assessment of the southeastern Bering Sea: zooplankton and micronekton. U.S. Dep. Commer., NOAA, OCSEAP, Final Rep. Biological Studies Vol. 1:238-337.

This report describes the distributions, abundances, and trophic characteristics of zooplankton communities in the southeastern Bering Sea. No specific descriptions of the eastern Aleutian fauna are presented, but the author notes that the eastern Aleutian area helps accommodate the transport of North Pacific zooplankton into the Bering Sea.

46. Cooney, R.T. 1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 947-974.

Zooplankton and micronekton distribution, abundance, and production are reviewed for the Bering Sea. Regional differences in community composition are related to water mass characteristics and large-scale hydrographic patterns. A listing of both holoplankton and micronekton includes 341 species. Though generally focused outside the eastern Aleutian study area, this study has strong implications for the zooplankton community characteristics in the eastern Aleutians.

47. Cupp, E. 1937. Seasonal distribution and occurrence of marine diatoms and dinoflagellates at Scotch Cap, Alaska. Scripps Institute of Oceanogr. Tech. Ser. 4:71-100.

A series of daily surface collections of marine diatoms and dinoflagellates was taken at Scotch Cap Light on Unimak Island, Alaska (southeast side of Unimak Pass), from 1 August 1926 to 30 June 1933. In general, the average yearly cycle of diatom abundance at Scotch Cap Light closely resembled that reported for the north European coast. The spring maximum peaked in April and May, fthe smaller autumn maximum in September. Dinoflagellate production was negligible.

48. Davies, J.N. 1977. A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Island-eastern Aleutian Islands region of the Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Quart. Rep. July-September. 3:465-497.

The author analyzes seismotectonic hazards in the eastern Aleutian Islands and Pribilof Islands by means of collecting and analyzing seismic data from permanent recording stations. The Shumagin seismic gap near the eastern Aleutians is identified as an

area likely to experience great earthquakes and associated events within a few decades.

49. Davies, J.N., and K.H. Jacob. 1979. A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Islands-eastern Aleutian Islands region of the Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 9:2-93.

The authors assess the volcanic and earthquake hazards that exist in the eastern Aleutian Islands, Pribilof Islands, and the western Gulf of Alaska. The work focuses mainly on collection and analysis of new seismic data. The Aleutian Arc segment near the Shumagin Islands and the tip of the Alaska Peninsula was found to be the likely site of one or more great or large earthquakes within the next few decades. Such events provide high potential hazards to oil and gas exploration and/or development in the form of tsunamis and submarine mudflows.

50. Davies, J.N., L.R. Sykes, L. House, and K.H. Jacob. 1981. Shumagin seismic gap, Alaska Peninsula: history of great earthquakes, tectonic setting, and evidence for a high seismic potential. J. Geophys. Res. 86:3821-3855.

At least 80 years have elapsed since the Shumagin seismic area near Unimak Pass last ruptured in a great earthquake. The authors believe that a high probability exists for a great earthquake to occur in this seismic "gap" within one or two decades. They speculate that such an earthquake or earthquakes could generate large tsunamis and associated hazards to shore-based facilities.

51. Dodimead, A.J., F. Favorite, and T. Hirano. 1963. Review of the oceanography of the subarctic Pacific Region. Int. North Pacific Fish. Comm. Bull. No. 13. 195 pp.

The oceanography of the subarctic Pacific Region is reviewed with emphasis on the extensive new work accomplished since 1955 by the research organizations of the members of the International North Pacific Fisheries Commission - Canada, Japan, and the United States. Portions of the Bering Sea are included and a special appendix on the oceanography of Bristol Bay is attached.

52. Donaldson, W.E., and D.M. Hicks. 1980. Explorations for the Tanner crab _Chionoecetes bairdii_ off the coasts of Kodiak Island, the Alaska Peninsula, and Aleutian Islands, 1978 and 1979. Alaska Dep. Fish & Game Tech. Data Rep. No. 50. Juneau, Alaska.

This report extends work conducted since 1973 to (1) find a method to index Tanner crab (_Chionoecetes bairdii_) populations by age classes where possible, and (2) determine migration patterns and distribution of the various Tanner crab stocks. The surveys (crab pots) included the eastern Aleutian study area (Dutch Harbor survey area), for which catch locations, crab numbers, and crab size ranges were reported for 1979. Mostly adult males were caught.

53. Drewes, H., G.D. Fraser, G.C. Snyder, and H.F. Barnett, Jr. 1961. Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska. U.S. Geol. Surv. Bull. 1028-5:583-676.

The authors discuss the distributions and origins of the geologic features of Unalaska Islands, extending this knowledge by inference onto the surrounding shallow shelf. The island is largely volcanic; much of the island is veneered by a thin mantle of till, volcanic ash, humus, and soil. Moraines are restricted to the vicinity of present glaciers. The internal structure of the island is poorly understood because few stratigraphic horizons were mapped.

54. Dunlop, H., F. Bell, R. Myhre, W. Hardman, and G. Southward. 1964. Investigation, utilization and regulation of the halibut in southeastern Bering Sea. Int. Pacific Halibut Comm. Rep. 35. 72 pp.

Concentrations of commercial-sized halibut are restricted to a narrow band on the edge of the continental shelf between Unimak Pass and the Pribilof Islands, and to a lesser extent along the Aleutian Islands. Their distribution is related to water depth and temperature, and varies seasonally. Tagging data demonstrate the emigration of halibut from the Bering Sea into the Gulf of Alaska and as far south as Oregon. Such emigration indicates that halibut in the eastern Bering Sea are not biologically separable from those in the eastern Pacific. Also, ocean currents in the region and the life cycle of the halibut suggest that some of the young in the Bering Sea are probably produced from spawning areas south of the Alaska Peninsula.

55. Everitt, R.D., and H.W. Braham. 1978. Harbor seal (Phoca vitulina richardii) distribution and abundance in the Bering Sea: Alaska Peninsula and Fox Islands. Proc. Alaska Sci. Conf. 29:389-398.

This paper resulted from aerial surveys for sea lions and harbor seals flown during summer months of 1975-77. (Only harbor seals were reported in this paper). Highest single count for the Fox Islands was approximately 4000 seals seen in August of 1976. Virtually all of the coastlines of these islands contained some seals. All areas within the Unimak Pass study area were surveyed during this study.

56. Everitt, R.D., and H.W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Sci. 54:281-288.

Aerial surveys were flown during the harbor seal breeding season (late June to August) in 1975, 1976, and 1977 from the eastern Aleutian Islands (Samalga Island eastward) to northern Bristol Bay.

Numbers of animals observed and major haul-out areas within the Unimak Pass study area are reported. The maximum count for the eastern Aleutian Islands for any one survey was 3948 in August 1976. More harbor seals were observed on the north side of the Alaska Peninsula (from Port Moller northeastward) than in the eastern Aleutian Islands.

57. Fadeev, N. 1963. The fishery and biological characteristics of yellowfin soles in the eastern part of the Bering Sea. In: P. Moiseev (ed.), Soviet Fisheries Investigations in the Northeast Pacific. Transl. Israel Prog. Sci. Transl. 1968. pp. 332-396.

The eastern part of the Bering Sea is inhabited by a single population of yellowfin sole; this species is more abundant than other flatfish species. Biological characteristics and migrations are described. Of particular interest are Fadeev's comments regarding this sole's wintering concentrations, the largest of which are located on the outer shelf or the slope in Unimak Pass. The distribution and movements of yellowfin sole showed "drastic changes" after 1962, which were probably caused by a considerable increase in commercial fishing pressure at that time.

58. Favorite, F. 1967. The Alaskan stream. Int. North Pacific Fish. Comm. Bull. 21:1-20.

The general oceanographic features and continuity of the Alaskan Stream are discussed using data obtained during May through August 1959. The Alaskan Stream is defined as the extension of the Alaska Current which flows westward along the south side of the Aleutian Islands. It is continuous as far westward as 170°E where it divides, sending one branch northward into the Bering Sea and one southwestward to rejoin the eastward flowing Subarctic Current. Transport in eastern Aleutian passes is noted. Observed westward velocities near Atka and Adak islands were in excess of 100 cm/sec, but maximum geostrophic velocities (referred to 1000-m level) of only 30 cm/sec were obtained from station data. Volume transport, computed from geostrophic currents, was approximately $6x10^6$ m^3/sec. Evidence is presented that the Alaskan Stream is driven primarily by the action of wind stress. (Adapted from author's abstract.)

59. Favorite, F. 1974. Flow into the Bering Sea through Aleutian Island passes. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea. Univ. of Alaska Inst. Mar. Sci., Occ. Pub. No. 2, Fairbanks. pp. 3-37.

Present knowledge concerning flow through Aleutian Island passes has been accumulated from the records of historical oceanographic cruises and expeditions, and through the results of oceanographic research conducted in this area by the Northwest Fisheries Center of the National Marine Fisheries Service since 1955. Flow through the various openings in the Aleutian-Commander Island arc is shown to be quite variable in direction and magnitude. Westward volume transports in the Alaskan Stream south of the Aleutian Islands in summer vary more than 50 percent, but there is little evidence of the annual winter intensification suggested by wind-stress transports and reflected in sea level data in the Gulf of Alaska. Analyses of volume transport data indicate a mean northward flow of 14 Sv through openings in the Aleutian-Commander Island arc east of the Commander Islands. This result falls between two Soviet estimates of 8 and 19.5 Sv, and the value is quite close to the estimate of 16 Sv obtained from wind-stress data. It is suggested that moored buoy arrays be established to obtain long-term measurements of actual flow and that a series of monitoring stations be designated and occupied on a cooperative basis. (Author's abstract.)

60. Favorite, F., T. Laevastu, and R.R. Straty. 1977. Oceanography of the northeastern Pacific Ocean and eastern Bering Sea, and relations to various living marine resources. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fisheries Center Processed Rep. 280 pp.

This report relates faunal population distributions to physical parameters such as temperature and salinity. The authors describe the timing and migration routes of Bristol Bay juvenile and adult sockeye salmon and relate these patterns to salinity and temperature distributions.

61. Feder, H.M., J. Hilsinger, M. Hoberg, S. Jewett, and J. Rose. 1978. Survey of the epifaunal invertebrates of the southeastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 4:1-126.

This report provides a distributional inventory of dominant epibenthic species on the southeastern Bering Sea shelf; sampling barely entered the Unimak Pass study area at its extreme northeastern part. Preliminary observations of trophic relationships were made. Distribution patterns of epifauna were described in terms of individuals and biomasses of dominant species. Too few samples were taken from the Unimak Pass area to provide conclusive detail about the epifauna of the area.

62. Feder, H.M., and S.C. Jewett. 1980. A survey of the epifaunal invertebrates of the southeastern Bering Sea with notes on the feeding biology of selected species. Univ. Alaska Inst. Mar. Sci. Rep. R78-5. 105 pp.

This report provides an inventory and distributional analysis of dominant epibenthic species in the southeastern Bering sea, plus some observations on trophic interactions with other species. The survey area barely touches on the eastern Aleutian study area in the northeastern corner near Unimak Pass. The paper is very similar to Feder et al. 1978.

63. Feely, R.A., and J.D. Cline. 1977. The distribution, composition, and transport of suspended particulate matter in the northeastern Gulf of Alaska, southeastern Bering Shelf, and lower Cook Inlet. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 13:89-179.

The distribution and chemical nature of suspended matter on the southeastern Bering Sea shelf and in the Gulf of Alaska are discussed. Along the Alaska Peninsula (and other coastal areas), suspended matter is mostly terrigenous and concentrations decrease rapidly away from the coast. Suspended matter tends to be greater near shallow bottoms, probably because of resuspension.

64. Feely, R.A., G.J. Massoth, A.J. Paulson, and M.F. Lamb. 1980. Distribution and elemental composition of suspended matter in Alaskan coastal waters. U.S. Dep. Commer., NOAA, OCSEAP. Final Rep. 41(1986):1-208.

This report is basically the same as Feely et al. 1981.

65. Feely, R.A., G.J. Massoth, A.J. Paulson, M.F. Lamb, and E.A. Martin. 1981. Distribution and elemental composition of suspended matter in Alaskan coastal waters. U.S. Dep. Commer., NOAA Tech. Memo ERL-PMEL-27, 119 pp.

This report describes the distribution and chemical composition of suspended material on the continental shelves of Alaska. The purpose was to determine the chemical nature and transport pathways of particulate matter which would act as effective scavengers of petroleum compounds in the shelf waters. Areas addressed include the northeast Gulf of Alaska, lower Cook Inlet, southeastern Bering Sea shelf, and Norton Sound. In the southeastern Bering Sea, surface water particulate matter was found to be dominated by input from northern rivers, notably the Kuskokwim, Togiak, Igushik, Kvichak, and Nushagak rivers. The material originating from these rivers is over 76% inorganic. High surface values (> 6 mg/l) were found near Unimak Pass and along the NAS coast from Port Moller eastward. In the high concentration areas the organic matter is thought to be primarily of marine origin because of its C/N ratio.

66. Fiscus, C.H., and G.A. Baines. 1966. Food and feeding behavior of Steller and California sea lions. J. Mammal. 47:195-200.

This paper describes the contents of 22 Steller and 6 California sea lion stomachs collected from various parts of their range. Seven of the Steller sea lions were collected in Unimak Pass in the early 1960's. Most of these animals had fed on capelin, along with some sandlance, cods, and flounders. Both species appear to prefer smaller forage fishes over larger, commercially important species, such as salmon. Feeding behavior of sea lion groups in Unimak Pass was also observed in 1962.

67. Fiscus, C.H., D.W. Rice, and A.M. Johnson. 1969. New records of Mesoplodon stejnegeri and Ziphius cavirostris from Alaska. J. Mammal. 50:127.

This short note describes the locations and gives evidence to support records of these two cetaceans in Alaska. All records involve stranded or floating dead animals. Beached specimens of Ziphius cavirostris have been found twice within the Unimak Pass study area, one on Samalga Island and another on Akun Island.

68. Forsell, D.J. 1983a. Observations of seabirds at Aiktak Island - August 1982. Unpubl. Rep., U.S. Fish and Wildl. Serv., Anchorage, AK. 2 pp.

A very short report describing seabird nesting plots revisited in 1982 following establishment in 1981. Marked storm-petrel and puffin burrows were checked for occupancy and contents, and notes on other marine birds seen on the island were included. Aiktak Island is a small island located on the southeast side of Unimak Pass.

69. Forsell, D.J. 1983b. Progress report on field studies in the Aleutian Islands, Semidi Islands, and Bering Sea, 1983. Unpubl. Rep., U.S. Fish and Wildl. Serv., Anchorage, AK. 6 pp.

Observations were taken aboard ship and on land in the St. Matthew Island area, in the Near Islands, on Aiktak Island, and in the Semidi Islands. Only observations taken on Aiktak Island fall within the Unimak Pass study area. This island was searched for Aleutian Canada Geese, and permanent seabird plots established in 1981 were rechecked. Results of these studies were presented.

70. Frost, K.J., L.F. Lowry, and J.J. Burns. 1983. Distribution of marine mammals in the coastal zone of the Bering Sea during summer and autumn. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20:365-562.

This report compiles all available sightings of marine mammals in the coastal zone of the eastern Bering Sea during summer and autumn, and evaluates the importance of coastal areas to the various species. Available data indicate substantial fluctuations in numbers of animals at particular locations but are not adequate to measure fluctuations or to explain their causes. The western edge of Unimak Island, but not other islands in the eastern Aleutians, was included in the area analyzed.

71. Fujioka, J., and M. Sigler. 1984. Time-location traces of sablefish tag recoveries released by the U.S. National Marine Fisheries Service and the Fisheries Agency of Japan, 1972-83. U.S. Dep. Commer., NOAA, NMFS, Auke Bay, AK. Document 2828.

Sablefish tagging programs in the vicinity of the eastern Aleutian Islands demonstrated fish movements through the island passes, mostly in a northward direction.

72. Fukuhara, F.M. 1985. Northwest and Alaska Fisheries Center processed report 85-11: Biology and fishery of southeastern Bering Sea red king crab (Paralithodes camtschatica Tilesius). U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36, Part 2(1986):801-982.

This report discusses the general distribution, life history, and fishery of the red king crab in the southeastern Bering Sea, based largely on the existing literature. Distributional data presented include some from the extreme northeastern parts of the Unimak Pass study areas.

73. FWS (Fish and Wildlife Service). 1974. Preliminary report of biological data on proposed harbor sites at Unalaska, Alaska. Rep. by U.S. Fish and Wildl. Serv., Anchorage, AK. 35 pp.

This brief survey along the southeast shore of Unalaska Bay documents the fish, wildlife and invertebrates observed on several intertidal transects at sites being considered for construction of a small boat harbor. Fishes observed by divers were greenlings, red Irish lord, rock sole, sculpin and pricklebacks. Invertebrate species are listed.

74. Gill, R., Jr., C. Handel, and M. Petersen. 1979. Migration of birds in Alaska marine habitats. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. Biol. 5:245-288.

This report synthesizes information on the migration routes and timing of selected species (or species groups) of marine-oriented birds in Alaska. Species discussed include shearwaters, cormorants, brant, Emperor goose, Steller's eider, King eider, Common eider, scoters, shorebirds, kittiwakes, murres, and Tufted Puffin. Frequent mention is made of migration routes through Unimak Pass for several species, but the report is not specific to the Unimak Pass study area. Most of the information is concisely presented and is available in greater detail from the original reports.

75. Gould, P.J. 1982. Distribution and abundance of seabirds over marine waters of the eastern Aleutian Islands. Unpubl. Rep., U.S. Fish and Wildl. Serv., Anchorage, AK. 10 pp.

This is a review paper providing information on the most important species of seabirds inhabiting the eastern Aleutian Islands (primarily the Fox Islands). Summaries are given on population size and important use areas of endangered species, endemic species, and the most common species of marine birds. Some unpublished sightings are included which may not be available in other sources. Endangered marine birds sighted in the area are the Aleutian Canada Goose and Short-tailed Alabatross. Although no species are truly endemic to this area alone, important proportions of the total world populations of Whiskered Auklets and Red-legged Kittiwakes occur in this area. The most common marine birds identified in the area are Northern Fulmar, shearwaters, storm-petrels, Glaucous-winged Gull, kittiwakes, murres, and Tufted Puffin.

76. Gould, P.J., D.J. Forsell, and C.J. Lensink. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. U.S. Fish and Wildl. Serv., FWS/OBS-82/48. Anchorage, AK. 294 pp.

Short discussions of the occurrence and distribution of seabirds in pelagic waters, by species, are followed by maps of shipboard and aerial survey transects illustrating the densities of each species encountered. Indices of abundance are calculated by habitat for most species, but population estimates were not attempted. Survey areas include the Unimak Pass study area; the report provides important background data for Unimak Pass concerns.

77. Grant, W., and F. Utter. 1980. Biochemical genetic variation in walleye pollock, Theragra chalcogramma: population structure in the southeastern Bering Sea and the Gulf of Alaska. Can. J. Fish. Aquat. Sci. 37:1093-1100.

Genetic studies suggest there are no distinct stocks of pollock within the southeastern Bering Sea nor within the Gulf of Alaska, but that there are minor genetic differences between fish from these two regions. These results suggest that genetic exchange (i.e., dispersal) through the Aleutian Island passes is limited.

78. Grant, W., R. Bakkala, F. Utter, D. Teel, and T. Kobayashi. 1983. Biochemical genetic population structure of yellowfin sole, Limanda aspera, of the north Pacific Ocean and Bering Sea. Fish. Bull. 81:667-677.

Genetic comparisons were made between yellowfin sole collected in the Gulf of Alaska, Bering Sea and near Japan. Electrophoretic analyses indicate some genetic differences between Bering Sea and Gulf of Alaska fish, probably due to genetic isolation and divergence caused by reduced exchange during Pleistocene glaciation. These

results suggest that there still is limited genetic exchange (i.e., dispersal) between these two waterbodies via the Aleutian Island passes.

79. Grant, W., and F. Utter. 1984. Biochemical population genetics of Pacific herring (Clupea pallasi). Can. J. Fish. Aquat. Sci. 41:856-864.

This study examined genetic markers in herring populations in the Bering Sea and North Pacific Ocean. Electrophoresis analyses indicate two principal genetic races, the Asian-Bering Sea herring and the eastern North Pacific herring. These results suggest that a limited genetic exchange (i.e., dispersal) occurs between herring stocks through the Aleutian Island passes.

80. Griffin, K.L., M.S. Eaton, and R. Otto. 1983. An observer program to gather in-season and post-season on-the-ground red king crab catch data in the southeastern Bering Sea. North Pacific Fish. Manage. Council Doc. No. 22. 39 pp.

This report describes the results of a program to gather and analyze in-season and post-season crab catch data in the southeastern Bering Sea (some catch data were from the northeast part of the Unimak Pass study area) in a cooperative effort of the Alaska Department of Fish and Game (ADFG) and the National Marine Fisheries Service (NMFS).

It was concluded from the data collected that the number of fertilized female king crab observed in the 1982 NMFS June survey declined in September during the king crab fishery and finally that these oldshell barren females were no longer available in the April Tanner crab fishery and presumed dead. It was also discovered that if handling mortality of sublegal and non-targeted crab species is responsible for the absence of pre-recruitment in the king crab fishery, then the Tanner crab fishery which catches one king crab for every one legal Tanner may be the cause for the mortality. (Adapted from authors' abstract.)

81. Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle.

The continental shelf of the Bering Sea south of St. Matthew Island was surveyed by taking at least five van Veen grabs at each of 96 stations and sieving organisms with a 1-mm mesh screen. Multivariate statistical methods were used to define communities organized in roughly contiguous bands paralleling local bathymetry. Community boundaries coincide with frontal zones identified in the area, suggesting a community response to water-mass characteristics or differing between-front depositional environments. Large between-station variations within the same sedimentary and temperature regimes were noted, but cannot be interpreted with the existing data. Standing stocks appeared uniformly low away from most areas with a coastal influx of detritus. Two more stations from the northeast part of the Unimak Pass study area are included in the analyses. (Adapted from author's abstract.)

82. Hameedi, M.J. (ed.). 1982. Proceedings of a synthesis meeting: the St. George Basin environment and possible consequences of planned offshore oil and gas development. NOAA, BLM, Juneau, AK. 162 pp.

This report provides a discussion of the ecological processes and key species potentially effected by oil and gas exploration in the St. George Basin in the eastern Bering Sea. Major chapters include the Transport and Fate of Spilled Oil, Environmental Hazards to Petroleum Industry Development, and discussions of marine mammals, seabirds, fish and shellfish. Input from experts in each area was synthesized and data important to the understanding of local ecological processes was summarized. The Unimak Pass study area overlaps with the area described in this report.

83. Hartt, A. 1962. Movement of salmon in the North Pacific Ocean and Bering Sea as determined by tagging 1956-58. Int. North Pacific Fish. Comm. Bull. 6. 157 pp.

Salmon were tagged on the high seas in the North Pacific Ocean and Bering Sea in summer, 1956-58. A strong westward movement along the south side of the Aleutians was shown for all species destined for widespread areas (Japan, USSR, Kotzebue, Yukon River, Bristol Bay). Various Aleutian passes were important avenues for maturing salmon destined for Bering Sea tributaries, but usage of these passes varied between years. For example, the principal route of chum salmon was just west of Umnak Island in 1956 and west of Adak Island in 1957. Most mature sockeye, chum and pink salmon migrated through Aleutian waters between late May and late June; thereafter, immature sockeye and chums began to appear in catches and continued to be available at least through late August.

84. Harrison, C.S., and S.A. Hatch. 1975. Field observations on Unimak Island, Alaska, 11 to 25 August 1975. Unpubl. Field Rep. No. 75-017, U.S. Fish and Wildl. Serv., Anchorage, AK. 20 pp.

This narrative document describes bird and mammal use of the southwest end of Unimak Island and marine waters nearby in August 1975. The authors discuss the possibilities of conducting radar observations of migration in the area, and present observations of migration of seabirds and northern sea lions through the pass. Roosting and nesting of some marine birds, and beached bird surveys, were also discussed. Tables and figures illustrate the visual migration watches. All observations were taken within the Unimak Pass study area.

85. Hattori, A., and J.J. Goering. 1981. Nutrient distributions and dynamics in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 975-992.

Distribution of nutrients over the eastern Bering Sea's four water masses can be distinguished as: the deep Bering Sea water, the outer-shelf water, the mid-shelf water, and the coastal water. This zonation of nutrient distributions is closely related to the presence of three oceanic fronts defined by means of temperature-salinity data, and is consistent with existing descriptions of the physical oceanographic regime.

The surface and subsurface waters of the Bering Sea shelf and slope are, in general, richer in phosphate than in nitrate and silicic acid. However, in the bottom layer of the mid-shelf domain, nitrate is significantly less abundant than would be expected from N/P uptake by phytoplankton (about 15:1), and ammonium concentrations are very high. Apparently the regeneration of phosphate and ammonium is occurring at substantial rates in this water mass, but oxidation of ammonium to nitrate appears to be minimal. $NO_{-3}/PO_{-3/4}$ values in the bottom water of the mid-shelf domain in summer and winter are not substantially different. The ratios do, however, appear to increase slightly during the winter. The middle oceanic front which separates the mid-shelf domain from the outer-shelf domain is probably present the year round.

86. Hattori, A., J. Goering, and D.B. Boisseau. 1978. Ammonium oxidation and its significance in the summer cycling of nitrogen in oxygen depleted Skan Bay, Unalaska Island, Alaska. Mar. Sci. Commun. 4(2):139-151.

The authors found that the oxidation of ammonium to nitrite and nitrate proceeded at substantial rates in the water column of Skan Bay, Unalaska Island, below 35 m during August, 1972. Reduction of nitrate to nitrite and ammonium also occurred at a less intensive rate in the near-bottom water. The rates of ammonium oxidation estimated from 18-day water column concentration changes were consistent with those observed in 4-day bottle incubation experiments and in tracer experiments using ^{15}N-ammonium. The rates of oxidation below 35 m [100-150 mg N/(m^2 x day)] were similar to the production of organic nitrogen by phytoplankton within the euphotic zone. (From authors' abstract.)

87. Haynes, E.B. 1974. Distribution and relative abundance of larvae of king crab, *Paralithodes camtschatica*, in the southeastern Bering Sea. Fish. Bull. 73(3):804-812.

Workers sampling in spring and summer 1969-1970 found larvae of red king crab to be most abundant nearshore in the southeastern Bering Sea, and least abundant offshore and toward the shelf break to the west. The center of abundance moved northeastward with the

season; the change in distribution was apparently related to water current patterns.

88. Healy, M., J.J. Kelley, P.K. Park, and W.S. Reeburgh. 1974. Chemical oceanography. In: D.W. Hood (convenor). PROBES: a prospectus on processes and resources of the Bering Sea shelf, 1975-1985. Deliberations of a workshop, Salishan Lodge, Oregon, 24-30 November 1973. Univ. Alaska Inst. Mar. Sci., Fairbanks.

The paper briefly discusses the sources and in-situ processes of water and nutrients in the southeastern Bering Sea and recommends new research to enhance understanding of the chemical oceanography of the area. Vertical transport of deep water in the vicinity of the Aleutian Islands (Samalga Pass) is noted as one mechanism of transport.

89. Hein, J.R., D.W. Schell, and J. Miller. 1978. Episodes of Aleutian Ridge explosive volcanism. Science 199:137-141.

These authors investigated the Cenozoic volcanic history of the Aleutian Ridge and the Kamchatka Peninsula by analyzing core samples from the Deep Sea Drilling Project. In particular, they include analyses of bentonite beds. They show that volcanism has been cyclic; the middle and late Miocene and the Quaternary were times of greatest activity in the North Pacific and elsewhere around the Pacific Basin. Their analyses cast doubt on the theory that volcanism was the primary cause of global cooling in the Pleistocene.

90. Hessing, P. 1983. Gray whale (Eschrichtius robustus) migration into the Bering Sea observed from Cape Sarichef, Unimak Island, Alaska, spring 1981. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 19:47-74.

The author reports on the results of a migration watch for gray whales along the eastern shore of Unimak Pass in spring 1981. A total of 533.6 hours were censused over 87 days, and 3851 gray whales were recorded moving northward. Interpolating for uncounted periods, the cumulative count for northbound gray whales was 14,346 by the end of the census. The bulk of all whales passing by remained within 500 m of shore. Calves were first seen on 9 May, and became more common later in the season. Aerial surveys were also flown to document use away from shore. All effort was conducted within the Unimak Pass study area.

91. Holmes, P. 1982. 1982 Aleutian Islands salmon stock assessment study. Special report to the Alaskan Board of Fisheries. Alaska Dep. Fish & Game, Anchorage. 83 pp.

The purpose of this study was to assess salmon stocks at major islands along the Aleutian chain. Pink salmon are the predominant salmon species in the Aleutians, with even-year runs being much

higher than odd-year runs. The magnitude and timing of the runs can fluctuate considerably from year to year and stream to stream. The majority of the Aleutian Islands do not have enough salmon during a peak abundance to support a commercial harvest and there is little potential for a major fishery west of Unalaska Island. Escapement counts in 1982 in our area of current interest were: 1,600,000 salmon (97% pink) at Unalaska Island, 300,000 (99% pink) at Umnak Island, and 10,500 (partial count, 100% pink) at Akutan Island. Pink runs at Unalaska in 1983 were a "disaster" with only 1000 pinks harvested and an escapement of only 50,000. In addition, the run in Unalaska Bay began nine days later than the average date of return for this area.

92. Holmes, R.W. 1958. Surface chlorophyll-a, surface primary production, and zooplankton volumes in the eastern Pacific Ocean. Rapp. Proces. Verb. Reunions. Cons. Perm. Int. Explor. Mar. 144:109-116.

Limited data presented on productivity in Unimak Pass indicates that Unimak Pass may have one of the highest levels of productivity in the North Pacific.

93. Hood, D.W. 1981. Preliminary observations of the carbon budget of the eastern Bering Sea shelf. <u>In</u>: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 347-358.

Preliminary studies of the CO_2 system of the PROBES area of the Bering Sea shelf in May of 1976 and May and June of 1978 show partial pressures of CO_2 in the surface water as much as 250 A (ppm) less than overlying air, which averaged about 329 A (ppm). These low pressures are evidently produced by photosynthesis, but their persistence long after nutrients are depleted and photosynthesis is low indicates a large sink for CO_2 under earlier bloom conditions accompanied by limited respiration in the water-column which would recycle the fixed organic carbon back to the inorganic carbon pool.

Total CO_2 measurements made during the phytoplankton bloom period (May-June 1978) gave values significantly lower (1.5-1.8 mM) than those found under non-bloom conditions (2.00 mM). The CO_2 represented by the difference in total carbon dioxide between bloom and non-bloom conditions is apparently being held in the system as fixed carbon, either in the form of detritus available for consumption, or as the portion of primary production which is stored in the body tissues of flora and fauna. (From author's abstract.)

94. Hood, D.W. Unpubl. Data. Cruise 261-5 of RV <u>Acona</u> to Unimak Pass and North Alaskan Peninsula. Univ. Alaska Inst. Mar. Sci., Fairbanks.

Salinity, temperature, and carbon dioxide data were obtained in the Unimak Pass area in June 1978. Though storms limited station

occupation, 10 stations were occupied in a transect from west of Unimak Pass to Amak Island north of Izembek Lagoon. At all stations pCO_2 of the surface water was found to be near or less than air values, indicating no evidence of upwelling in the region on this occasion.

95. Hubbard, J. 1964. A comparative survey of the intertidal fishes of Kodiak and Umnak islands, Alaska. M.S. Thesis, Univ. Wisconsin, Madison. 139 pp.

Intertidal fishes in the study area, primarily in Nikolski Bay (Umnak Island) and Ananiuliak Island, were sampled by nets and rotenone in 1962. Thirty-three species were collected and annotated species accounts were prepared. There was a high degree of similarity between species caught in the eastern Aleutians and those caught in similar habitats at Kodiak Island.

96. Hunt, G.L., Jr., P.J. Gould, D.J. Forsell, and H. Peterson, Jr. 1981. Pelagic distribution of marine birds in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: pceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Wash. Press, Seattle. pp. 689-718.

The authors present a summary of data on pelagic distribution of seabirds in the eastern Bering Sea. Data sources include shipboard and aerial surveys of seabirds taken during OCSEAP studies from 1975-78. Range maps include the Unimak Pass and Krenitzin Islands areas, and discussions by species occasionally refer to distributions in these areas. Information is provided by season (spring, summer and fall), and the authors frequently relate marine bird distributions to known oceanographic frontal systems and other features of the marine environment.

97. Hunt, G.L., Jr., J. Kaiwi, and D. Schneider. 1981. Pelagic distribution of marine birds and analysis of encounter probability for the southeastern Bering Sea. Unpubl. Rep., Univ. Calif., Irvine. 151 pp.

Included in the report is a review of the pelagic distribution of seabirds in the Bering Sea based on several years of shipboard surveys, and the effects of oil on marine birds. Locations of large densities of marine birds and risk assessments for the area are attempted. Discussions of statistical considerations and other limitations of the analysis provide helpful insights into assessment problems. Regions on the Bering Sea side of the Unimak Pass study area are included in the discussions and on figures.

98. Hood, D.W., and J.J. Kelley. 1975. Upwelling phenomena in the eastern Aleutian passes with a suggested method for measuring material transport. In: D.W. Hood and Y. Takanouti (eds.), Bering Sea oceanography: an update. Univ. Alaska Inst. Mar. Sci. Rep. No. 75-2, Fairbanks. pp. 245-277.

The eastern Aleutian Island passes exhibit a type of upwelling, at least during the summer months, which is current induced. Near surface water in the vicinity of Amukta and Samalga passes have carbon dioxide partial pressures in excess of 500 ppm-atm, NO_3-N concentrations in excess of 27 g-at l^{-1}, with PO_4-P and SiO_2-Si at 3.0 and 73 g-at l^{-1}, respectively. Associated with the upwelled areas at the surface were low temperature, low oxygen concentration and high salinity anomalies. Subsurface sampling revealed a complicated distribution of chemical parameters suggestive of effects of turbulence and mixing. High surface water concentrations of nutrients and salinity associated with low oxygen concentrations and temperature occurred in the vicinity of the peak and over the limbs of the valley. The CO_2 vertical profile indicates that values as high as those observed can come only from a depth of about 200 m.

99. IPHC (Int. Pacific Halibut Comm.). 1980-85. Halibut trawl surveys at Unimak Island. File Data. Int. Pacific Halibut Comm., Seattle, WA.

IPHC annually surveys selected nursery areas in the eastern Bering Sea and Gulf of Alaska to estimate the relative abundance of juvenile halibut. Of interest to the present project are the surveys conducted in the Unimak Bight area south of Unimak Island. In this area 25-50 trawl samples were collected annually and the following data were recorded: number and weight (all fish and invertebrates caught), and length (halibut and occasionally king crab). Gear and method descriptions are provided by Best and Hardman (1982). Copies of trawl data were provided by S. Hoag, IPHC.

100. Jewett, S.G., and H.M. Feder. 1981. Epifaunal invertebrates of the continental shelf of the eastern Bering and Chukchi seas. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1131-1155.

Epifaunal invertebrates were surveyed over much of the eastern Bering and Chukchi seas continental shelves. Sampling barely entered the Unimak Pass study area at the northeastern corner. Information on the distribution, abundance, and biomass of the dominant species is discussed by area and depth strata. Four commercially important crabs (Paralithodes camtschatica, P. platypus, Chionoecetes opilio, and C. bairdi) and four seastar species (Asterias amurensis, Evasterias echinosoma, Leptasterias polaris acervata, and Lethasterias nanimensis) account for nearly 70 percent of the epifaunal biomass of the entire eastern shelf region. Commercially important crabs dominate the southeastern portion of the shelf; echinoderms, in particular seastars, abound in the northeastern

Bering Sea and southeastern Chukchi Sea. (Adapted from authors' abstract.)

101. Jones, E.J.W., J. Ewing, and M. Truchan. 1971. Aleutian plain sediments and lithospheric plate motions. J. Geophys. Res. 76:8121-8127.

Airgun reflection profiles indicate that the relict Aleutian abyssal plain of the North Pacific consists of two tongues of well-stratified sediments deposited from turbidity currents which entered the region from a northerly direction. The distribution of the turbidities appears to have been largely governed by a topographic grain imparted to the basement surface by Late Cretaceous-Paleocene plate motions associated with the generation of the Great Magnetic Bight. The last channelized routes of turbidity current flows to the southern portion of the area were severed during the Late Miocene, and since then only pelagic sediments have accumulated. The pattern of sedimentation and the time at which the Aleutian plain became isolated from its source of terrigenous sediments are consistent with models recently proposed for plate motions in the northeastern Pacific since the close of the Mesozoic. (From authors' abstract.)

102. Kelleher, J.A. 1970. Space-time seismicity of the Alaska-Aleutian seismic zone. J. Geophys. Res. 75:5745-5756.

This study examines space-time patterns in the distribution of major earthquakes of the Alaska-Aleutian seismic zone. The evidence suggests that major earthquakes of this zone tend to progress in time from east to west. Extrapolation of past trends indicates that a major Alaska-Aleutian earthquake may occur near 56°N, 158°W between about 1974 and 1980. Three kinds of evidence indicate that earthquakes of about magnitude 7.7 and larger should be used to identify space-time earthquake patterns in the Alaska-Aleutian seismic zones: (1) Space-time graphs of earthquakes of about magnitude 7.7 and larger show strong linear trends. (2) Aftershock zones of successive large earthquakes ($M \geq 7.7$) are approximately adjacent. (3) The direction of fracture propagation is generally away from the focal zone of the previous adjacent large earthquake, which suggests that the concentration of stress before the event was greatest near the region of the adjacent earlier earthquake. Since this pattern is reasonably consistent, the linear trends of large earthquakes in this seismic zone are probably caused by some physical phenomena rather than some unusual chance distribution. The space-time distribution of the U.S. Coast and Geodetic Survey (CGS) seismicity gaps in the region predicts the next major Alaska-Aleutian earthquake. The Commander Islands and the northern Kuriles both appear to be likely locations for large earthquakes.

103. Kelley, J.J., and D.W. Hood. 1971. Carbon dioxide in the Pacific Ocean and Bering Sea: upwelling and mixing. J. Geophys. Res. 76(3): 745-752.

Measurements were made of the equilibrium concentration of carbon dioxide with respect to air in the surface waters of the North Pacific Ocean and Bering Sea on a summer 1968 cruise aboard the R. V. Oceanographer. These were compared with earlier data collected in the southeastern Pacific Ocean off Peru and Chile. Experimental procedure used infrared analysis of equilibrated air and sea water for CO2. Supersaturation of CO2 in the sea with respect to air was noted within northeastern Pacific coastal regions associated with dilution by river inflow and upwelling. Similarly, data obtained off the South American coast showed high surface-water concentrations of CO2 in areas of upwelling. Undersaturation was observed in the northeast Pacific Ocean near Unimak Pass and east of St. Matthew Island in the Bering Sea. Near-equilibrium conditions were observed between 48 and 49 degrees N latitude and from 161 to 150 degrees W longitude.

104. Kelley, J.J., and D.W. Hood. 1974. Upwelling in the Bering Sea near the Aleutian Islands. Tethys 6(1-2): 149-156.

Continuous measurement of equilibrium partial pressures of carbon dioxide on the surface seawater was used to evaluate the spatial extent of upwelling near the eastern Aleutian Islands. Near-surface water in the vicinity of Amukta and Samalga Passes had carbon dioxide partial pressures of 500 ppm, nutrient concentrations of over 15 μg-atoms NO3-N/liter, 2.5 μg-atoms PO3-P/liter and 70 μg-atoms SiO2-Si/liter. Associated with the upwelled areas were low surface-water temperature, low oxygen concentration and high salinity anomalies. Subsurface sampling revealed a complicated distribution of chemical parameters suggestive of turbulence and mixing effects. These anomalies were most intense in the vicinity of subsurface valleys and ridges.

105. Kelley, J.J., L. Longerich, and D.W. Hood. 1971. Effect of upwelling, mixing and primary productivity on CO2 concentrations in surface waters of the Bering Sea. J. Geophys. Res. 76: 8687-8693.

Late spring and early fall measurements were made of carbon dioxide concentration in Bering Sea surface waters north of Amukta and Samalga passes in the eastern Aleutian Islands. High values of CO2, NO3-N, and salinity were accompanied by low oxygen and temperature values. All the isopleths of these parameters give evidence of vertically mixed water. Seasonal variation of CO2 in surface waters was observed particularly in areas of low vertical mixing and high productivity.

106. Kenyon, K.W. 1975. The sea otter in the eastern Pacific Ocean. U.S. Bur. Sport Fish. Wildl., N. Am. Fauna No. 68. 352 pp.

This monograph reports on results of 12 years of study of sea otters by the author, who worked primarily in the Aleutian Islands. Chapters on physical characteristics, habitat requirements, behavior, food habits, distribution populations, reproduction, limiting factors, and observations on captive animals are included. Much of the information presented on Aleutian Islands sea otters will be applicable to populations now present in the Unimak Pass study area. A few surveys of the Fox Islands were done to assess populations, but little other field work was reported on for this area.

107. Kenyon, K.W., and D.W. Rice. 1961. Abundance and distribution of the Steller sea lion. J. Mammal 42:223-234.

Observations were tabulated on sea lion rookery and haulout sites in the Aleutian Islands and Alaska Peninsula during sea otter surveys in 1959 and 1960. The authors found 98 rookery or haulout sites with an estimated population of about 100,000 animals for this area. Tables and maps present the locations of all known use areas, and discussions describe haulout habitat and seasonal use of these sites. The Unimak Pass study area is encompassed in the area surveyed, and haulout locations and populations using the area are described.

108. Kim, S., and A. Kendall. 1983. The numbers and distribution of walleye pollock eggs and larvae in the southeastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS Northwest and Alaska Fish. Center Processed Rep. 83-22. 35 p.

This report uses past survey data to examine the spatial and temporal distribution of pollock spawning as inferred from the distribution of their planktonic eggs. Spawning occurs over a large area of the southeastern Bering Sea, mainly between the Pribilof Islands and Unimak Pass, and between the 100-200 m depth contours, but data are insufficient to resolve the pattern of spawning and larval distribution adequately. Spawning peaks about 14-18 April.

109. Kinder, T. H. 1981. A perspective of physical oceanography in the Bering Sea, 1979. In: D.W. Hood and J. A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 5-13.

Until recently, physical oceanographic research in the Bering Sea concentrated on broad spatial and long temporal scales, and much of the field work occurred off the shelf in water overlying the deep basins. Research concentrated on basin-wide phenomena of long duration, and this work determined the views of oceanic climate or physical geography of the Bering Sea.

Since about 1975, the focus of research has shifted toward shorter spatial and temporal scales, and also from the deep basins onto the shelf. Deviations from the large-scale mean state, such as interannual variability, fronts, eddies, tides, and vertical finestructure, are important biologically as well as physically, and this trend in research will probably continue through the next decade.

110. Kinder, T. H., and J. D. Schumacher. 1981a. Hydrographic structure over the continental shelf of the southeastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The Eastern Bering Sea shelf: ceanography and Resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 31-52.

The authors synthesize recent work conducted over the eastern Bering Sea shelf. Shelf waters have slow mean flow (smaller than or equal to 2 cm/sec). Hydrographic structure is little influenced by this flow, but rather is formed primarily by boundary processes: tidal and wind stirring; buoyancy input from insolation, surface cooling, melting, freezing, and river runoff; and lateral exchange with the bordering oceanic water mass. Three distinct hydrographic domains can be defined using vertical structure to supplement temperature and salinity criteria. Inshore of the 50-m isobath, the coastal domain is vertically homogeneous and separated from the adjacent middle domain by a narrow (about 10-km) front. Between the 50-m and 100-m isobaths, the middle domain tends toward a strongly stratified two-layered structure, and is separated from the adjacent outer domain by a weak front. Between the 100-m isobath and the shelf break (about 170 m depth), the outer domain has surface and bottom mixed layers above and below a stratified interior.

111. Kinder, T. H., and J. D. Schumacher. 1981b. Circulation over the continental shelf of the southeastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The Eastern Bering Sea shelf: oceanography and Resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 53-75.

Using extensive direct current measurements made during the period 1975-78, the authors describe flow over the southeastern Bering Sea shelf. They define three distinct regimes. The coastal regime, inshore of the 50-m isobath, had a slow (1-5 cm/sec) counterclockwise mean current and occasional wind-driven pulses of a few days' duration. The middle regime, bounded by the 50- and 100-m isobaths, had insignificant (less than 1 cm/sec) mean flow but relatively stronger wind-driven pulses. The outer regime, between the 100-m isobath and shelf break (about 170 m), had a 1-5 cm/sec westward mean and low-frequency events unrelated to local winds. Over the entire shelf most of the horizontal kinetic energy was tidal, varying from 60 percent in the outer regime to 90 percent in the coastal regime. About 80 percent of the tidal energy was semidiurnal.

112. Kitano, K. 1970. A note on the salinity structure of the eastern Bering Sea. Bull. Tohoku Regional Fish. Res. Lab. 30: 79-85.

A detailed thermal structure in the eastern Bering Sea is described, based on data obtained by the training ship Oshoro Maru during the summers of 1964, 1965, and 1966. The description is based on the movement of extremely cold water over the continental shelf in the eastern Bering Sea and on the intrusions of warm water mainly across the Amukta and Amchitka passes. Some of the tendency of decrease and increase of temperature is also presented in a vertical section. The typical feature of vertical temperature distribution is mostly represented by five stratified thermal layers.

113. Koike, I., K. Furuya, H. Otobe, T. Nakai, T. Memoto, and A. Hattori. 1982. Horizontal distributions of surface chlorophyll a and nitrogenous nutrients near Bering Strait and Unimak Pass. Deep Sea Res. 29: 149-152.

Surface temperature, salinity, nitrate, ammonium, and chlorophyll-a were continuously monitored along a north-south transect across the Bering Strait and Unimak Pass regions of the Bering Sea in July 1978. A cold water mass, rich in nitrate and chlorophyll-a, north of the Bering Strait, was examined over a distance of 40 km; it was probably associated with local upwelling. Near Unimak Pass, chlorophyll-a was inversely correlated with nitrate, suggesting rapid growth of phytoplankton in nutrient-rich Alaskan Stream water during its travel into the Bering Sea. Phytoplankton species composition was consistent with this inference.

114. Laevastu, T., and R. Marasco. 1982. Fluctuations of fish stocks and the consequences of the fluctuations to fishery and its management. U.S. Dep. Commer., NOAA Tech. Mem. NMFS F/NWC-27. 53 p.

The authors analyze annual fluctuations in fish stock abundance in the Bering Sea and Gulf of Alaska with the aid of an ecosystem simulation model. They conclude that the total finfish biomass fluctuates little from year to year, but that biomass of individual species, may fluctuate greatly. Temperature anomalies seemed to have large effects on the fluctuations; effects were smallest in flatfishes and largest in pelagic species. Changes in fishing pressure and predation caused smaller changes. The Unimak Pass area is included in the region analyzed.

115. Laevastu, T., and R. Marasco. 1984. Some analyses of consequences of fisheries expansion in the Gulf of Alaska and eastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 84-14. 30 pp.

Ecosystem models (PROBUB) developed at the Northwest and Alaska Fisheries Center examine changes in abundances of key fish species in the southeastern Bering Sea, including the present study area. Some interesting conclusions of this modeling effort are:

(1) The natural fluctuations of cod and pollock biomasses are opposite in time. Increased fishing pressure suppresses the magnitudes of natural fluctuations.

(2) Increased harvests of cod, pollock and yellowfin sole reduce predation pressure on crabs and rockfishes, so the latter populations will increase.

(3) Cyclic temperature anomalies, lasting a few years, can cause large changes in fish biomasses. A cold temperature anomaly produces a larger final biomass than a warm anomaly due to lowered predation pressure and thus higher survival of larvae and juveniles.

116. Leatherwood, S. (ed.). 1985. A study of past and current uses by endangered whales of waters in and near the St. George Basin, Alaska. U.S. Dep. Commer., NOAA, OCSEAP Final Rep., HMRI Tech. Rep. 85-186. 95 pp.

This report discusses the history of shore whaling at Akutan and Port Hobron whaling stations from 1912 to 1939. Data on the distribution of whale catches are presented by month of year, and trends in catch data are analyzed to determine population status during and after whaling activities. Aerial surveys of the former whaling grounds were conducted to determine the present population status of endangered whales, but too few whales of any species were seen to formulate reliable estimates. Most of the whaling grounds of the Akutan station are within the Unimak Pass study area.

117. Leatherwood, S., A.E. Bowles, and R.R. Reeves. 1983. Endangered whales of the eastern Bering Sea and Shelikof Strait, Alaska: results of aerial surveys, April 1982 through April 1983, with notes on other marine mammals seen. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. H/SWRI Tech. Rep. 83-159. 320 pp.

Results of a series of aerial surveys are presented. Summaries of sightings by species are illustrated and discussed in relation to historical data and various oceanographic and geographic parameters. All marine mammals observed during the surveys are discussed, and data presented. Some degree blocks surveyed during the study fall within the Unimak Pass study area, but most of the work was done to the north of this area. Much of the data presented provides important background information for Unimak Pass concerns.

118. Liu, S.K., and J.J. Leendertse. 1979. A three-dimensional model for estuaries and coastal seas: VI Bristol Bay simulations. The Rand Corp., Rep. to U.S. Dep. Commer., NOAA, OCSEAP. 117 pp.

This report presents a simulation of tide and wind effects on water motion and transport in the southeastern Bering Sea. Discussions of physical processes in Bristol Bay, model setup and boundary specifications, model adjustments and simulations, and model verification and predictions are presented. Unimak Pass is located at the extreme southern edge of the area modeled.

119. Lloyd, D.S., C.P. McRoy, and R.H. Day. 1981. Discovery of northern fur seals (Callorhinus ursinus) breeding on Bogoslof Island, southeastern Bering Sea. Arctic 34:318-320.

This reference reports the discovery of a small number (only two breeding females) of northern fur seals breeding on Bogoslof Island in summer 1980. Bogoslof Island is within the Unimak Pass study area and represents the only substantiated breeding location for this species in the study area. The authors speculate that this may represent an attempt at colonization of a new rookery site for northern fur seals and provide evidence from similarities in oceanography of the surrounding area to that of other fur seal rookeries.

120. Loder, T. C. 1971. Distribution of dissolved and particulate organic carbon in Alaskan polar, sub-polar and estuarine waters. Ph.D. Thesis, Univ. AK, Fairbanks. 236 pp.

Data on dissolved organic carbon (DOC) and particulate organic carbon (POC) in the Unimak Pass area were collected on R/V Acona cruise 027: July 27 to August 9, 1966. Five stations were reoccupied several times during the cruise. Sixteen stations in all were visited. DOC values ranged from 0.60 to 1.90 mg C/l with an average of 1.20 mg C/l for depths less than 100m. POC values varied only 1.2 percent from a mean value of 741 ug C/l in the top 16 m of the water column. Transmissivity of surface waters was measured at seven stations. The calculated absorbance correlated well with the POC content of the water.

121. Longerich, L.L., J.J. Kelley, and D.W. Hood. 1971. Carbon dioxide in the surface waters near the coast of southern Alaska and eastern Aleutian Islands. In: D.W. Hood et al. (eds.), Oceanography of the Bering Sea, Phase 1. Univ. AK Inst. Mar. Sci. Rep. No. R-71-9. pp. 3-58.

Data are presented on pCO2 values found near the Alaska Peninsula and eastern Aleutian passes. In June pCO2 was deficient with respect to air in excess of 100 ppm at all locations except near Samalga and Amukta passes, where it was greater than air by over 100 ppm because of upwelling. In September, upwelling was still found at Samalga Pass and small positive values were found in Unimak Pass (plus 10 to 100 ppm). Amukta Pass was not revisited. All other stations showed near-equilibrium or negative (-10 to -100) pCO (w) values.

122. Loughlin, T.R., D.J. Rugh, and C.H. Fiscus. 1984. Northern sea lion distribution and abundance: 1956-80. J. Wildl. Manage. 48:729-740.

This paper provides a very thorough summary of northern sea lion distribution and abundance throughout the range of the species (which includes the eastern Aleutian Islands), comparing data from the late 1950's to data from the late 1970's. Although overall population levels appear to have remained similar between periods, there were some increases and decreases in local areas. One area where a decrease occurred was in the eastern Aleutian Islands. Causes for the population decline here are not definitely known, but are speculated to have been caused by seasonal movement of sea lions out of the area at the time of surveys, impacts on prey abundance by commercial fishing activities, pathogens, or commercial pup harvests on Akutan and Ugamak islands from 1970-72.

123. Low, L. 1976. Status of major demersal fishery resources of the northeastern Pacific: Bering Sea and Aleutian Islands. U.S. Dep. Commer., NOAA, NMFS. Northwest and Alaska Fish. Center Processed Rep. 116 pp.

This report reviews the commercial fisheries on major demersal fishes and invertebrates in the Bering Sea, Aleutian Islands and northeastern Pacific Ocean through about 1975. The principal value of this report with respect to the current project is that it shows that highest harvests of demersal fishes (primarily pollock) occur along the continental shelf of the Bering Sea immediately adjacent to Unimak Pass.

124. Lowry, L.F., K.J. Frost, and J.J. Burns. 1982a. Investigations of marine mammals in the coastal zone of western Alaska during the summer and autumn. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 37 pp.

The authors conducted aerial and boat surveys of coastal areas in western Alaska from Akun Island north to Barrow. Records of their observations are presented, along with information on foods of marine mammals collected at various locations. Sightings of marine mammals near Akun Island and foods eaten by several harbor seals collected there are the only data specifically pertinent to the Unimak Pass study area.

125. Lowry, L.F., K.J. Frost, D.G. Calkins, G.L. Swartzman, and S. Hills. 1982b. Feeding habits, food requirements, and status of Bering Sea marine mammals. Final Rep. to North Pacific Fish. Manage. Council by Alaska Dep. Fish & Game, Anchorage. 291 pp.

This report provides an extensive summarization of available data on food preferences and requirements of all Bering Sea marine mammals. Thorough discussions of population status, diet composition, and food requirements of each species are presented. Species of marine mammals are ranked in categories of great, moderate, or little potential for interaction with commercial fishery resources. Data from the Unimak Pass study area is included in the analyses, but the studies are not specific to this area alone. Data presented are useful as background information on Unimak Pass marine mammals.

126. Macy, P., J. Wall, N. Lampsakis, and J. Mason. 1978. Resources of non-salmonid pelagic fishes of the Gulf of Alaska and eastern Bering Sea. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Vol. 1-3.

This three-volume set is a comprehensive review of about 450 references describing non-salmonid pelagic fishes in the eastern Bering Sea and Gulf of Alaska. Part 1 presents species accounts for 24 fishes, Part 2 compiles distributional and relative abundance records, and Part 3 (by N. Lampsakis) consists of appendices. This review provides useful background information for the present study as well as actual catch records in the vicinity of the eastern Aleutian Islands.

127. Malloy, L. 1985. Peninsula/Aleutians management area, eastern Aleutian Islands herring food and bait fishery. Alaska Dep. Fish & Game, Kodiak. 12 pp.

A herring food/bait fishery has operated annually in the eastern Aleutian Islands since 1981 (and previously during 1929-1938). The area fished extends from Tigalda Island to Makushin Bay (Unalaska Island) but occurs primarily near Unalaska and Akutan bays. The current harvest level is 3200 mt. Herring are caught steadily from 17 July-15 September, but their daily availability is variable due to movement patterns. Annual changes in the age composition of the catch suggest that a single strong year class (1977) of herring accounts for much of the harvest since 1981.

128. McBride, J., D. Fraser, and J. Reeves. 1982. Information on the distribution and biology of the golden (brown) king crab in the Bering Sea and Aleutian Islands area. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center Processed Rep. 82-02. 22 pp.

This report describes the distribution and abundance characteristics of golden king crab populations in the study area and other parts of the southeastern Bering Sea based on foreign trawler observer data. Crabs are distributed throughout the outer shelf and slope regions of the eastern Bering Sea and the Aleutian Islands; highest concentrations are in the Aleutians.

129. McDonald, J., H.M. Feder, and M. Hoberg. 1981. Bivalve mollusks of the southeastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1155-1204.

This paper discusses bivalves of the southeastern Bering Sea; it includes a small part (northeast corner) of the Unimak Pass study area. It shows that bivalve mollusks and other infaunal species have patchy distributions that are associated with sediment sizes and sorting ranges, percentages of mud in sediments, and water depth. The variation in year-class composition of specific stations indicates variable annual recruitment success of different areas on the shelf. The data presented suggest that the prevalence of older bivalve mollusks in the middle zone of the eastern Bering Sea results from the exclusion of predatory bottom fishes by the low water temperatures.

130. McMurray, G., A.H. Vogel, P.A. Fishman, D.A. Armstrong, and S.C. Jewett. 1984. Distribution of larval and juvenile red king crabs (*Paralithodes camtschatica*) in Bristol Bay. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 145 pp. (In press.)

This is the final report of a sampling program for crustacean larvae on the North Aleutian Shelf of the southeastern Bering Sea. The program's goal was to better define the relationship between larval distribution and juvenile recruitment of red king crabs in the Bristol Bay region. Results suggested that "refuge" benthic habitats for settled larvae were important to juvenile survival, and that the early life stages of crabs were most sensitive to oil. Sampling sites approach the study area to the east.

131. McRoy, C.P. 1968. The distribution and biogeography of *Zostera marina* (eelgrass) in Alaska. Pacific Sci. 22(4):507-513.

Zostera marina, eelgrass, is a common inhabitant of lagoons and bays along the Alaska coast, occurring from the lagoons on the north coast of the Seward Peninsula to the southern limit of Alaska and beyond. The author reports three sites of eelgrass occurrence in the eastern Aleutians study area.

132. McRoy, C.P., and J.J. Goering. 1974. The influence of ice on the primary productivity of the Bering Sea. In: D.W. Hood, and E.J. Kelley (eds.), Oceanography of the Bering Sea. Univ. Alaska Inst. Mar. Sci., Fairbanks. Occas. Pub. No. 2. pp. 403-421.

This paper reports phytoplankton productivity, biomass (chlorophyll-a), temperature and salinity on a transect from Unimak Pass to the ice edge in April, 1971. Surface chlorophyll-a was less than 1 mg/m^3.

133. McRoy, C.P., J.H. Goering, and W. E. Shiels. 1972. Studies of primary production in the eastern Bering Sea. In: A.Y. Takenouti (ed.), Biological oceanography of the northern North Pacific Ocean (Motoda Commemorative Volume). Idemitsu-Shoten, Tokyo. pp. 199-216.

Data are included for phytoplankton productivity and biomass (chlorophyll-a) in the surface waters of Unimak Pass. In Unimak Pass productivity averaged 243 mgC/m3-day and biomass was 76.0 mg chlor-a/m3. All measurements were in June in 1968 and 1970. Nitrate and ammonia uptake were also measured at one station in Unimak Pass; the ratio of carbon uptake to nitrogen uptake at this station was 6:7.

134. McRoy, C.P., D.W. Hood, L.K. Coachman, J.J. Walsh, and J.J. Goering. 1986. Processes and resources of the Bering sea shelf (PROBES): The development and accomplishments of the project. Continental Shelf Research 5(1/2):5-21.

This paper describes the development and the results of the PROBES (Processes and Resources of the Bering Sea Shelf) project conducted in the southeastern Bering Sea. Little of the sampling took place within the Unimak Pass study area, but findings suggest much about the area as an avenue of passage for vertebrates and of transport of water and plankton. The authors' abstract notes: "The project spanned 10 years from early conceptual stages and meetings to its final cruises and reports. Over all the field years 2727 stations were logged in the Bering Sea which involved 20 principal investigators plus 147 others as associates, students and technicians. Results are available in a series of publications and data reports."

135. Minoda, T., and R. Marumo. 1975. Regional characteristics of distribution of phyto- and zooplankton in the eastern Bering Sea and Chukchi Sea in June-July, 1972. In: D.W. Hood and Y. Takenouti (eds.), Bering Sea oceanography: An update. Univ. Alaska Inst. Mar. Sci. Rep. No. 75-2, Fairbanks. pp. 83-95.

Regional distribution of phyto- and zooplankton in the eastern Bering Sea and Chukchi Sea is described based on the data collected by the Oshoro Maru in the summer of 1972. Zooplankton biomass in the eastern Bering Sea is very high to the north of the Alaska Peninsula (114.7 g wet weight/m^2, 0 m-bottom), but low south of St. Lawrence

Island (10.5 g/m^2, 0 m-bottom). Plankton biomass becomes high again at the Bering Strait (46.9 g/m^2, 0 m-bottom). Most samples were in the Bering Sea proper; only a few were taken in the vicinity of (north of) Unimak Pass.

136. Mitchell, E.D. 1979. Comments on magnitude of early catch of east Pacific gray whale (Eschrictius robustus). Rep. Int. Whal. Comm. 29:307-314.

The author suspects, following review of aboriginal whaling practices by Pacific coast natives, that "virgin" populations of gray whales may have been larger than the better-documented "initial" population levels present at the start of commercial whaling in 1846. Substantial harvests of whales by natives occurred from at least the 1700's to the 1920's. Included in this harvest were animals taken by Aleuts in the eastern Aleutian Islands, including not only gray whales but also right and minke whales. This provides some evidence that all three species probably inhabited the study area before the start of commercial whaling.

137. Moiseev, P. (ed.). 1963. Soviet fisheries investigations in the northeast Pacific. Parts 1-5. Transl. from Russian by Israel Prog. Sci. Transl. 1968.

This 5-volume series is a collection of 99 papers describing the Soviet research expedition in the eastern Bering Sea, 1958-1960. Most of their sampling efforts lie adjacent to our current study area, but the reports provide useful background information about many subjects: oceanography, geology, sediments, plankton, benthic invertebrates, fishes, and marine mammals.

138. Morgan, L. (ed.). 1980. The beginnings. Alaska Geographic 7(3):18-29.

This volume of Alaska Geographic magazine focuses on the Aleutian Islands. It contains chapters on geology, weather, biota, Aleuts and their history and recent history. Chapters are authored by experts in the respective disciplines or by the editor.

139. Motoda, W., and T. Minoda. 1974. Plankton of the Bering Sea. In: D. W. Hood and E. J. Kelley (eds.) Oceanography of the Bering Sea. Univ. Alaska Inst. Mar. Sci., Occ. Pub. No. 2. Fairbanks. pp. 202-42.

Based largely on material obtained during cruises of the Oshoro Maru during 1954 to 1970, a list of phytoplankton and zooplankton species in the Bering Sea was recorded and compiled with reference to published papers and unpublished manuscripts. An inventory of more than 300 species resulted.

In early to mid-summer, boreal-oceanic diatom communities occupy a large part of the western and central Bering Sea and eastern shelf;

temperate-neritic diatoms are distributed along the Aleutian Islands. Subarctic oceanic copepods are predominantly distributed in the western and central Bering Sea; an arctic copepod species Calanus glacialis is present on the eastern shelf, along the continental shelf edge and around Bowers Bank; and Centropages abdominalis is found in the neritic water around Unimak Pass. Most copepods show clear depth preference, 80 percent of the biomass in the 150-m water column occurring in the upper 80 m.

The density of the surface diatom standing crop ranged from 1 x 10^5 to 10^9 cells/m3. The summer zooplankton biomass in the Bering Sea has varied from year to year (large in 1958, 1962, 1965 and 1968), showing certain periodic variations with intervals of two to three years. The average zooplankton biomass was 36.8 g/m2, except in shallow parts of Bristol Bay. Fifty percent of the zooplankton biomass observed in the upper 80 m of the Bering Sea in early to mid-summer consisted of two herbivorous copepods, Calanus cristatus and C. plumchrus. There is a tendency for inverse relationship in abundance reported between phytoplankton and zooplankton in the upper layer, except off the coast of the Kamchatka Peninsula.

140. Muench, R.D., J.D. Schumacher, and R. Sillcox. 1979. Northwest Gulf of Alaska shelf circulation. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 7:232-248.

This work relates oceanic advective and diffusive processes to potential pollution problems from OCS petroleum development. Field activities included moored current measurements and water mass analysis using temperature and salinity data from the continental shelf west from about Seward, Alaska to Unimak Pass and offshore to the outer boundary of the Alaskan Stream off Kodiak Island. Estimates of the fields of water motion that exert primary control over trajectories of spilled oil and over diffusion processes along the trajectories are provided. Oil introduced into the environment is likely to be dispersed throughout the water column and possibly scavenged by suspended particulate matter. Understanding transport processes requires an analysis of the velocity field and its driving mechanisms.

141. Murie, O.J., and V.B. Scheffer. 1959. Fauna of the Aleutian Islands and Alaska Peninsula. U.S. Dep. Int., Fish and Wildl. Serv., N. Am. Fauna No. 61. Wash., D.C. 406 p.

This is a major reference outlining the status and distribution of mammals, birds, fishes, and invertebrates found in the Aleutian Islands from 1936-1938. Species accounts are given for all mammals and birds found during the survey, and collections and observations taken by previous scientists in the Aleutians are also included. Species, family, or order accounts are also presented for marine algae, marine invertebrates, freshwater invertebrates, land invertebrates, and fishes collected in the Aleutian Islands and surrounding waters. Many references are made to the Fox Islands and other areas within the Unimak Pass study area.

142. Nakamura, K., K.H. Jacob, and J.N. Davies. 1977. Volcanoes as possible indicators of tectonic stress orientation--Aleutians and Alaska. Pure Appl. Geophys. 115:87-112.

The authors apply a new method--analysis of flank eruptions for polygenetic volcanoes--to the study of Aleutian and Alaska volcanoes. They conclude that the evidence implies several things about the tectonics of island arcs and back-arc regions in Alaska: (1) volcanic belts of some island arcs are under compressioned stress in the direction of plate convergence, and (2) stresses of two kinds are produced, each characterized by its own magma chemistries.

143. Nasu, K. 1974. Movement of baleen whales in relation to hydrographic conditions in the northern part of the North Pacific Ocean and the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Publ. No. 2 pp. 345-361.

The author reports on the relationship of fin and gray whale sightings in the Bering Sea and North Pacific Ocean and hydrographic regimes present in the area. Mixing zones between different water masses were identified as one possible indicator of whale abundance. These zones occurred along offshore oceanographic fronts and along the edges of coastal current systems. The Unimak Pass study area falls within the area analyzed by this report but it is not specifically referred to in any detailed manner.

144. Nelson, J. 1976. Field observations on Unimak Island (Pass) 15 September to 22 October 1976. U.S. Fish and Wildl. Serv. Unpubl. Field Rep. Anchorage, AK. 25 pp.

This report contains species accounts of all birds observed during a visit to southwestern Unimak Island, and information on migration watches conducted from Cape Sarichef. Also included are recommendations for future work and present conditions of the site, then occupied by U.S. Coast Guard employees. Interesting observations included southward migrations through Unimak Pass of large numbers of Arctic Loons, Glaucous-winged Gulls, kittiwakes, and female and immature Steller's Eiders. All of the observations taken were within the Unimak Pass study area.

145. Nelson, C. H., D. M. Hopkins, and D. W. Schell. 1974. Cenozoic sedimentary and tectonic history of the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.). Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 485-516.

The Bering Sea consists of an abyssal basin that became isolated from the Pacific Ocean by the development of the Aleutian Ridge near the end of Cretaceous time and by formation of a large epicontinental shelf area that first became submerged near the middle of the Tertiary Period. The authors postulate that the sediment eroded from

Alaska and from Siberia during Cenozoic time has been trapped in subsiding basins on the Bering shelf and abyssal basins during the Tertiary, collected in continental rise and abyssal plain deposits of the Bering Sea during Pleistocene periods of low sea level, and transported generally northward from the Bering shelf through the Bering Strait into the Arctic ocean during periods of high sea level in the Pleistocene and Holocene. Filling of subsiding basins on the shelf was dominated by continental sedimentation on the early Tertiary and by marine deposition in the later Tertiary. Uplift of the Alaska Range increased the drainage area of the Yukon River two-fold or more and established the Yukon as the dominant source of river sediments (90 percent) reaching the Bering Sea. This greatly accelerated sedimentation in the basins.

146. Nerini, M. 1984. A review of gray whale feeding ecology. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale (Eschrichtius robustus Lilljeborg, 1861). San Francisco and New York, Academic Press. pp. 423-450.

This chapter reviews information on the feeding methods, foods, and trophic interactions of gray whales. Only a small amount of information is presented on gray whales near the Unimak Pass study area, but food taken along the north side of the Alaska Peninsula is probably similar to that potentially taken in the Unimak Pass area. Bottom-feeding by gray whales appeared to be the prevalent feeding method in the southern Bering Sea. Gray whales were frequently sighted trailing mud during northbound migrations in this area, and may feed near Unimak Pass as well.

147. Niebauer, H.J. 1980. Recent fluctuations in meteorological and oceanographic parameters in Alaska waters. Univ. Alaska Inst. Mar. Sci. Sea Grant Rep. 79-12. 34 pp.

This report outlines some of the relatively large-scale fluctuations in sea surface temperatures (SST), surface and 700-mb winds, ice coverage, and the interrelationships between these parameters in the Gulf of Alaska and the Bering Sea over the last 15 years. Autocorrelation of SST time series suggests that the Bering Sea "remembers" what the SST was at least two years past, but the Gulf of Alaska "remembers" less than two years; the difference is probably related to differences in current strengths of the two seas. The eastern Aleutians is included in the area analyzed.

148. Niebauer, H. J. 1981. Recent fluctuations in sea ice distribution in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 133-140.

The eastern Bering Sea shelf is ice covered in winter but ice free in summer. Time series of weekly percent ice coverage are presented, illustrating details of this phenomenon for the period

1973-79. Advances and retreats of the ice edge are correlated with fluctuations in sea and air temperatures, with surface winds, and with regional meteorological events. The period 1973-79 is shown to be a time of extreme fluctuations with 1973-76 characterized by below-normal temperatures and above-normal ice cover under northerly winds, while 1976-79 was a period of strong rise in temperatures and retreat of the ice pack under winds shifting to southerly.

149. Nishiyama, T., and T. Haryu. 1981. Distribution of walleye pollock eggs in the uppermost layer of the southeastern Bering Sea. In: D.W. Hood and J. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 993-1012.

Distribution patterns of walleye pollock eggs in surface waters (0.25 m) in the southeast Bering Sea were studied in April 1978. The eggs were widely distributed and were most abundant over the 60-100 m continental shelf. Very few were found southwest of the shelf and slope near Unimak Pass. Areas of egg abundance coincided with the $2.5-3^{o}C$ bottom isotherm.

150. Nishizawa, S., and S. Tsunogai. 1974. Dynamics of particulate material in the ocean. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 173-189.

The mean concentration of particulate organic carbon in the upper 50-m layer of the Bering Sea ranges from 65 to 300 g C/liter and is highest along the Aleutian Island Arc and the continental rise. This range is much higher than is typically found in southern areas, reflecting the high level of primary production in the Bering Sea. The concentration of carbon nearly always increases exponentially towards the sea surface, with a marked maximum usually at the air-sea interface. The phenomenal increase of particulate carbon towards the sea surface occurs concomitantly with a similarly distinct decrease in the concentration of chlorophyll, a situation generally common to most oceans and seas. Recent extensive examinations of data collected from various areas in the North Pacific and adjacent seas revealed that the average particle concentration in deeper layers is closely correlated with the average particle concentration in the upper 50-m layer. This seems to imply that a major fraction of particulate material in deeper layers is derived directly from the surface layer of that area.

151. NMFS (National Marine Fisheries Service). 1975-1981. Cruise results. RV Oregon Cruise Nos. OR-75-3, OR-78-3, OR-79-3, OR-80-3; RV Chapman Cruise No. CH-81-04. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Kodiak Facility, Kodiak, AK.

Between 1975-1981, five trawl surveys for shrimp and other demersal organisms were conducted in the major bays of Unalaska Island: Beaver Inlet, Unalaska, Makushin, Scan, Pumicestone, Three Island, Bluberry, Usof and Chernofski. Sampling effort consisted of a 30-min or 1 nautical mile tow with a 61 foot, high-opening shrimp trawl. The trawl was towed 1-1.5 feet above the seabottom and a tickler chain was used. Results of these surveys have not been reported but some summary tables of shrimp catches are included in vessel cruise reports. Considerable annual variability in shrimp abundance was observed. Cruise reports also list raw catch data for fishes and other invertebrates caught in trawls and these data were tabulated for the present study. These data have been computerized at the Northwest and Alaska Fisheries Center, Kodiak Facility (P. Anderson, NAFC, Kodiak, pers. comm.).

152. Nof, D., and S.H. Im. 1985. Suction through broad oceanic gaps. J. Phys. Oceanogr. 15:1721-1732.

By use of a theoretical model, the authors predict that a separated current encountering a gap on its right-hand side is always sucked in its entirety through the gap, no matter how wide the gap. Application of this theory to the Unimak Pass is considered. Using historical data, it is shown that the locations and positions of the currents located near and at the Pass agree with the model predictions.

153. NPFSC (North Pacific Fur Seal Commission). 1962. Report on investigations from 1958 to 1961. North Pacific Fur Seal Comm. Washington, D.C. 183 pp.

This report compiles all information on population dynamics, distribution, and food selection of northern fur seals gathered by the commission during the years mentioned. Unimak Pass is noted as an important migration pathway and concentration area for fur seals and some information on prey taken by this species here is included. Pollock, squid, capelin, and sand lance were listed as important prey species of fur seals in the Bering Sea. Although most of the report is concerned with data collected on the rookery islands, some information, particularly concerning food habits, is applicable to the Unimak Pass study area. Extensive tables are included which present much of the raw data upon which the report is based.

154. NPFSC (North Pacific Fur Seal Commission). 1969. Report on investigations from 1964 to 1966. North Pacific Fur Seal Comm., Washington, D.C. 161 pp.

This paper reports on the extension of field studies of the northern fur seal conducted by the commission from 1958 on. It includes research on the population dynamics of the northern fur seal stock, based on tagging performed on the rookery islands and counts of animals at the rookeries. Also included is information on the food habits of fur seals in pelagic waters, including animals taken in the Bering Sea and Unimak Pass. Distribution of fur seals at sea and interchange among rookeries is also discussed. Extensive tables accompany the report and present much of the raw data upon which the discussions are based.

155. NPFSC (North Pacific Fur Seal Commission). 1971. Report on investigations in 1962-63. North Pacific Fur Seal Comm., Washington, D.C. 96 pp.

This report is a supplement to the Fur Seal Commission report on investigations from 1958 to 1961. It includes research on the population dynamics of the northern fur seal stock, based on tagging performed on the rookery islands and counts of animals at the rookeries. Also included is information on the food habits of fur seals in pelagic waters, including animals taken in the Bering Sea and Unimak Pass. Distribution of fur seals at sea and interchange among rookeries is also discussed. Extensive tables are included which present much of the raw data upon which the report is based.

156. NWAFC (Northwest and Alaska Fisheries Center). 1982. Cruise results - Cruise No. CH-82-03 NOAA R/V Chapman and Cruise No. PSM-82-01 Chartered Vessel PAT SAN MARIE. U.S. Dep. Commer., NOAA, NMFS. Seattle, WA. 18 pp.

Demersal trawling was conducted in areas from Unimak Pass north along the 100-fathom contour to a latitude of approximately St. Matthew Island and east to the Alaska mainland. Biological information and water temperature data were recorded at each station. Dominant species collected within Bristol Bay were yellowfin sole, red king and Tanner crab.

157. Nysewander, D.R., D.J. Forsell, P.A. Baird, D.J. Shields, G.J. Weiler, and J.H. Kogan. 1982. Marine bird and mammal survey of the eastern Aleutian Islands, summers of 1980-81. U.S. Fish and Wildl. Serv., Unpubl. Rep. Anchorage, AK. 134 pp.

Field studies were conducted by small boat and land-based observations in the easternmost Aleutian Islands to assess the use of coastal areas by birds and identify seabird nesting concentrations. Summaries of findings are presented by island (and islet) and overall summaries by species are presented as well. Permanent plots to census puffins and other burrow-nesting species were established and

censused, and recommendations for future census work are given. All work was accomplished within the Unimak Pass study area.

158. O'Clair, C.E. 1981. Disturbance and diversity in a boreal marine community: The role of intertidal scouring by sea ice. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1105-1130.

Using data collected with systematically sampled belt transects and arrays of randomly placed quadrats, intertidal communities on rocky shores in the Pribilof Islands, frequently scoured by ice, were compared with intertidal communities on rocky shores of islands in the southeastern Bering Sea that are rarely scoured by ice.

Species richness tended to increase with time from the last scouring episode. Species richness at the Pribilof Islands was significantly lower than at Amak and Akun islands (whose shores had not been recently scoured by ice). Species-area curves of Mollusca for the Pribilof Islands leveled off at fewer species than did species-area curves for Amak and Akun islands. Curves of the distribution of biomass among species of Mollusca showed a greater concentration of dominance among a few species in the Pribilof Islands than at Amak and Akun islands.

Intertidal organisms find refuge from ice scour primarily in crevices in bedrock and spaces beneath and between boulders. The effect of perturbations on the intertidal community structure will depend largely upon the degree to which the refuge is altered in such a way as to exclude marine organisms.

159. O'Clair, C. C., J. L. Hanson, R. T. Myron, J. A. Gharrett, T. R. Merrell, Jr., J. S. MacKinnon, and N. I. Calvin. 1979. Reconnaissance of intertidal communities in the eastern Bering Sea and the effects of ice-scour on community. Rep. to U.S. Dep. Commer., NOAA, OCSEAP.

Intertidal communities that have and have not recently been exposed to ice scouring were examined. Species richness and dominance were discussed. The most important characteristic of ice-stressed coasts that allows species to remain in the system appeared to be the availability of refuges from ice scouring. (See also O'Clair 1981.)

160. Okada, K. 1983. Biological characteristics and abundance of the pelagic pollock in the Aleutian Basin. In: 1983 Groundfish Symposium. Int. North Pacific Fish. Comm. Bull. (In press.)

This report summarizes mid-water surveys conducted by Japan in the Aleutian Basin, 1977-1979. Pollock constituted most of the catch (99%) followed by smooth lumpsucker, jellyfish, squid and capelin. Life history information for pollock is presented: length, age, growth, distribution, diet, maturity, sex, population size. Though much of this information pertains to fish caught far north of the

Aleutian Islands, the data are relevant to the present study because they decribe the mid-water fish community in summer and winter in the deep waters adjacent to the study area.

161. Otto, R.S. 1981. Eastern Bering Sea crab fisheries. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 1037-1066.

This paper describes the history, size, and current status of the crab fisheries in the eastern Bering Sea. No data specific to the eastern Aleutians is presented, but distributional maps show the red king crab and Tanner crab to occur throughout the study area.

162. Otto, R.S., and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (Lithodes acquispina) in the Bering Sea and Aleutian Islands. Proc. Int. King Crab Symp., Jan. 1985, Anchorage, AK. pp. 123-135.

Detailed research on golden king crab biology began in 1981 in response to the growing contribution of this species to western Alaskan king crab landings. Much of the data described were collected through cooperation with the fishing industry. Available information on the size at maturity and the timing of spawning are presented. Results show that: 1) spawning occurs over a protracted period extending at least from February to August, 2) there is an appreciable lag time between hatching and extrusion of a subsequent clutch of eggs, 3) there are differences in reproductive biology of crab from closely adjacent areas, and 4) the biotic potential of golden king crab is considerably less than that of Paralithodes spp. Results are discussed in the light of their management consequences. (Authors' abstract.)

163. Overland, J.E. 1981. Marine climatology of the Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. I. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 15-22.

The author reports the climate of the Bering Sea to be strongly related to the presence and movement of sea ice. In winter, weather elements are continental and arctic in character, being replaced by maritime influences from the south in summer. In winter this results in north to easterly winds, a tendency for clear skies, and substantial diurnal temperature range. Summer is characterized by a progression of storms through the Bering rather than by fixed weather types, producing increased cloudiness, reduced diurnal temperature range, and winds rotating through the compass with a slight tendency for southwestly.

164. Park, P.K., L.I. Gordon, and S. Alvarez-Borrego. 1974. The carbon dioxide system of the Bering Sea. In: D.W. Hood and E.J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 107-147.

Existing CO_2 system data show that the surface carbon dioxide concentration varies between $1\text{-}4 \times 10^{-4}$ atmospheres. It is affected by photosynthesis of marine plants, changes in water temperatures, biochemical oxidation, upwelling, upward divergence of deep water by cyclonic gyrals, changes in the depth of the surface mixed layer, and by CO_2-rich river runoff. In addition, the impact of open leads and polynyi on the dynamics of CO_2 air-sea exchange is emphasized by the non-equilibrium nature of the open water with respect to the atmospheric CO_2 and by rapid heat flux between the air and the water. Subsurface water has a high CO_2 concentration, about 13×10^{-4} atmospheres at 800-m depths. Supersaturation by carbonate minerals, calcite and aragonite exists near the surface, and undersaturation occurs in the deep waters. Most undersaturation occurs at 1000-m depths with 55 percent saturation for calcite and 35 percent saturation for aragonite. A linear relationship exists between the AOU (apparent oxygen utilization) and phosphate concentrations below the euphotic zone.

165. Pearson, C.A., H.O. Mofjeld, and R.B. Tripp. 1981. Tides of the eastern Bering Sea shelf. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 111-130.

This paper presents a state-of-knowledge description of the tides of the eastern Bering shelf, supported by recent acquisition of substantial pressure-gauge and current-meter data. Information presented includes cotidal and tidal ellipse charts, tidal amplitudes, semidiurnal and diurnal tides, and descriptions of two existing tidal models. Good qualitative agreement was found between the models and observations.

166. Phillips, M. 1976. Field observations on Unimak Island, 21 April to 27 May 1976. U.S. Fish and Wildl. Serv. Unpubl. Rep. Anchorage, AK. 23 pp.

Although some data is presented on relative bird abundances, short species accounts, and observations of a Red-faced Cormorant colony, most of this field report is devoted to recommendations for future field work on Unimak Island. Work was accomplished on the southwest end of Unimak Island, within the Unimak Pass study area. Interesting observations included large numbers (400) of sea lions hauled out on rocks near Cape Sarichef and 20,000 murres in the waters of the pass.

167. Rauzon, M. 1976. Field observations on Unimak Island, 1 to 17 July, 1976. U.S. Fish and Wildl. Serv. Unpubl. Field Rep. No. 76-076. Anchorage, AK. 12 pp.

Short species accounts and lists of birds and mammals seen during the visit to southwestern Unimak Island are included in the report. Much of the report is devoted to recommendations for future work on the island. Observations of most interest include feeding concentrations of larids and other seabirds in tide rips off the coast of Unimak Island. All of the observations taken were within the Unimak Pass study area.

168. Robertson, D.E., and K.H. Abel. 1979. Natural distribution and environmental background of trace heavy metals in Alaskan shelf and estuarine areas. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 5:660-698.

The authors provide baseline information on heavy metal concentrations in seawater, sediments, and selected organisms of the Alaska outer continental shelf. Sampling locations for water, sediments and biota include several sites in the Unimak Pass area, but none west of there in the Aleutians.

169. Rogers, D., and K. Schnepf. 1985. Feasibility of using scale analysis methods to identify Bering Sea herring stocks. North Pacific Fish. Manage. Council Document No. 30. Anchorage, AK. 48 pp.

The origin of herring stocks harvested in the 1984 food/bait fishery at Dutch Harbor was determined by scale-pattern analysis. Most fish were from the Togiak stock (79-100% by age class), with about 10% each from Port Moller and Nelson Island stocks. No fish from the south side of the Alaska Peninsula (Simeonof Island stock) were represented in the Dutch Harbor catch which suggests a negligible exchange between herring stocks in the Bering Sea and Gulf of Alaska.

170. Ronholt, L. 1963. Distribution and relative abundance of commercially important pandalid shrimps in the northeastern Pacific Ocean. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 449. 28 pp.

Pandalis borealis, the dominant shrimp in the southern Bering - northern Gulf of Alaska region, was caught in depths of mostly 40-80 fathoms off the Alaska Peninsula and eastern Aleutians. Sampling sites in the eastern Aleutians included locations among the Shumagin Islands and just west of Unalaska Island.

171. Ronholt, L. 1986. Unpublished results of 1983 Aleutian groundfish survey. Pers. comm.

National Marine Fisheries Service (U.S. Dep. Commer., NOAA) conducted their second comprehensive survey of groundfish resources in Aleutian Island waters in 1983-84; tabularized data for portions of this survey are available. Planned and completed NMFS surveys along the north and south sides of the Aleutians are:

1. 1980 - Ronholt et al. 1982 and 1986, Wilderbuer et al. 1985
2. 1983 - North side (tabularized data available)
3. 1984 - South side (not available yet)
4. 1986 - North side
5. 1987 - South side

172. Ronholt, L., H. Shippen, and E. Brown. 1978. Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass: A historical review. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 2:1-955.

This report is an historical review of commercial exploitation and exploratory research on demersal fish and shellfish resources in the Gulf of Alaska, 1948-1976. Of particular interest to the present project are the results of demersal resource assessments obtained on Research Cruises 618, 619, and 744. Portions of these cruises included the region adjacent to the south side of Unimak Pass and Tigalda Island. Data presented include the catch per unit effort of major fishes and invertebrates.

173. Ronholt, L., F. Shaw, and T. Wilderbuer. 1982. Trawl survey of groundfish resources off the Aleutian Islands, July-August 1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-23. 84 pp.

This particular report describes the U.S. portion of a joint U.S.-Japan survey of groundfish resources in Aleutian Island waters. See Ronholt et al. (1986) for an expanded analysis of this data set which includes both U.S. and Japanese data.

174. Ronholt, L., K. Wakabayashi, T. Wilderbuer, H. Yamaguchi, and K. Okada. 1986. Results of the cooperative U.S.-Japan groundfish resource assessment survey in Aleutian Islands waters, June-November 1980. U.S. Dep. Commer., NOAA Tech. Memo. (in press).

In 1980 the National Marine Fisheries Service and Japan conducted a joint survey of groundfish resources in Aleutian Islands waters. Objectives of the survey were to describe the distributions and relative/absolute abundances of principal demersal fishes and invertebrates. In 435 trawls, 132 fish species were collected; pollock and grenadier were the dominant fishes, accounting for 48% of the total fish biomass. Other abundant fishes were Pacific ocean perch, Pacific cod, and Atka mackeral. Squid were the dominant

invertebrate (88% of total invertebrate biomass). Approximately 63 trawls were located in the present study area. Distribution, abundance, depth stratification, length, weight and age of major species are indicated.

175. RPI (Research Planning Institute, Inc.). 1986. The southern coast of the Alaska Peninsula: Geomorphology and sensitivity to spilled oil. Final Rep. to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK. 61 pp. + App.

This report examines the sensitivities of coastal environments and wildlife to spilled oil in the region from Akutan Island in the eastern Aleutians to Pavlof Bay on the south side of the Alaska Peninsula. Literature reviews and field studies provided background information. The superimposition of biological resource data onto coastal geomorphic maps provides an integrated approach for depicting sensitivities of the various coastal areas. The mapping technique used, called the Environmental Sensitivity Index, has been applied to approximately three-fourths of the Alaska shoreline. A series of large-scale, color-coded maps accompanies the report; these maps illustrate shoreline types, biological data (species distributions), and socioeconomic features east of Akutan Pass in the eastern Aleutians area.

176. Royer, T. C. 1981a. Baroclinic transport in the Gulf of Alaska. Part 1: Seasonal variations of the Alaska Current. J. Mar. Res. 32(2): 239-249.

Temperature and salinity sections which intersect the Alaska Current were used to determine the baroclinic, geostrophic current on 21 occasions from 1975 to 1977. A sinusoidal curve-fitting technique is applied to these Alaska Current estimates and others available in the literature to statistically test the flow for an annual signal. The mean baroclinic transport relative to 1500 db is estimated to be 9.2×10^6 m^3 s-1 with seasonal signal of 1.2×10^6 m^3 s-1. The maximum is in March and minimum in September. Maximum speeds in excess of 100 cm/s are estimated and, typically, more than 80% of the transport is within 60 km of the shelf break. Thus, near Kodiak Island, the Alaska Current can be considered as a narrow, high speed jet. A distinctive characteristic of this and many other high-latitude baroclinic flows is that the horizontal density gradient is primarily a function of the horizontal salinity gradient, with the thermal gradient contributing to a lesser degree. For the Gulf of Alaska this salinity gradient could be created through runoff and coastal wind convergence.

177. Rugh, D.J. 1984. Census of gray whales at Unimak Pass, Alaska, November-December 1977-1979. In: M.L. Jones, S. Leatherwood and S.L. Swartz (eds.), The gray whale (*Eschrichtius robustus* Lilljeborg, 1861). San Francisco and New York, Academic Press. pp. 225-248.

Systematic migration watches for fall migrant gray whales were reported. Interpolated estimates of total whale passage ranged up to 16,928, estimated during the prime census year of 1978. All sightings of whales at Cape Sarichef occurred within 3.7 km from shore, with median sighting distance at only 0.5 km from shore. Whales migrated south through the pass from late October to early January but primarily during the last two weeks of November and the first three weeks of December. The majority of work reported was accomplished within the Unimak Pass study area.

178. Rugh, D.J., and H.W. Braham. 1979. California gray whale (*Eschrichtius robustus*) fall migration through Unimak Pass, Alaska, 1977: a preliminary report. Rep. Int. Whal. Comm. 29:315-320.

During 82.5 hours of systematic observations at Cape Sarichef, on the eastern shore of Unimak Pass from 20 November to 9 December 1977, 2055 gray whales were counted moving southward through the pass. Extrapolations to account for hours not censused and movements before and after the survey resulted in an estimate of 15,099 $\pm$ 2341 whales migrating through the pass in fall. This estimate matched the total population estimate based on counts farther south. This paper provides preliminary evidence that the bulk of the gray whale population utilizing the Bering Sea, and probably a majority of the entire gray whale stock, moves southward through Unimak Pass on its annual migration back to wintering areas on the Pacific coast of North America.

179. Schneider, K.B. 1981. Distribution and abundance of sea otters in the eastern Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 837-845.

The author traces the history of sea otter abundance in the southeastern Bering Sea, including all areas within the Unimak Pass study area. Most of the information presented resulted from a series of aerial surveys designed to document sea otter presence. Sea otters were most abundant on the north side of the Alaska Peninsula, but there are several groups of breeding sea otters in the Fox Islands as well. This paper provides a thorough yet concise summary of information on sea otter distribution and abundance in the study area up to 1981.

180. Schumacher, J. D. 1982. Transport processes in the North Aleutian Shelf. Draft final rep. to U.S. Dep. Commer., NOAA, OCSEAP. Juneau, AK.

The author describes the behavior of currents and bottom pressure observed in the Unimak Pass area between March and August 1980. The data are interpreted in the context of atmospheric pressure gradient, geostrophic wind, and CTD data from the area, and hydrographic and current behavior data from the adjacent North Aleutian Shelf. Mean flow was northwestward through the pass (reversals were common) and seemed to be strongly influenced by the Kenai Current of the northern Gulf of Alaska. A front was detected in the vicinity of the pass. The results lent support to the hypothesis that the Kenai current was linked with flow around the perimeter (near shore) of the SE Bering Sea shelf.

181. Schumacher, J. D., and T. H. Kinder. 1983. Low-frequency current regimes over the Bering Sea shelf. J. Phys. Oceanogr. 13: 607-623.

The authors present wind, current, bottom pressure, and hydrographic observations from Unimak Pass and the adjacent shelf. Mean flow was from the Gulf of Alaska into the Bering Sea and resulted largely from the Kenai Current. Shorter period fluctuations were bi-directional and coherent with divergence along the coast. Observations along the northern side of the Alaska Peninsula indicated Kenai Current water had an impact on the local salt content in the Bering Sea coastal domain, and together with freshwater discharge maintained a stronger horizontal density gradient in the vicinity of the 50-m isobath. Associated with this front was a moderate (1 to 6 cm/s) mean flow. Wind forcing, manifested both as coastal divergence and as a source of strong mixing, was evident at shorter periods. Results substantiated previous studies but they also revealed subtle features including impact of freshwater discharge not associated with gauged rivers, importance of gaps in the mountains to the generation of pressure gradent winds, and the nature of processes which destroy and establish the inner front and the typically two-layered middle shelf domain structure.

182. Schumacher, J.D., and P.D. Moen. 1983. Circulation and Hydrography of Unimak Pass and the shelf waters north of the Alaska Peninsula. NOAA Tech. Mem. ERL PMEL-47. 75 pp.

See Schumacher and Kinder 1983.

183. Schumacher, J. D., C. A. Pearson, and J. E. Overland. 1982. On exchange of water between the Gulf of Alaska and the Bering Sea through Unimak Pass. J. Geophys. Res. 87(C8):5785-5795.

The authors present the first long-term current and bottom pressure observations from Unimak Pass, Alaska, and adjacent locations on the Gulf of Alaska and Bering Sea shelves. Vector mean current recorded between March and August 1980 was about 12 cm/s toward 284oT or onto the Bering Sea shelf; however, magnitude decreased from about 20 cm/s to about 6 cm/s between the first and second halves of the record. At shorter periods (3-10 days), current fluctuations in the pass were strongly coherent with the pressure difference measured along the axis of the pass, and this was coherent with geostrophic wind estimates. The results indicated that wind-induced sea level perturbation was the dominant forcing mechanism for fluctuations. Relations among current, bottom pressure, pressure difference, and geostrophic wind time series also showed that dynamic variation on the Gulf of Alaska shelf was primarily responsible for current fluctuations in the pass. Hydrographic data indicated that a baroclinic current existed along the Gulf of Alaska coast, and this flow became the long-term mean flow through the pass. The authors suggest that this feature was the extension of the Kenai Current. The historic supposition that water is transported from the Gulf of Alaska into the Bering Sea was verified; however, the waters are of coastal origin rather than from the Alaska Stream.

184. Schumacher, F. D., and R. K. Reed. 1980. Coastal flow in the northwest Gulf of Alaska. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 6:118-149.

Recent data from the northwest Gulf of Alaska show a coastal current flowing westward along the Kenai Peninsula (mainly within 30 km of shore), entering Shelikof Strait, and exiting to the southwest of Kodiak Island. This flow, which the authors call the Kenai Current, has a large seasonal variation in baroclinic transport and maximum surface speed; transport is typically about 300,000 m3/s but exceeds 1,000,000 m3/s in fall, with concurrent speed increases from 15-30 cm/s to over 100 cm/s. The coastal flow is apparently distinct from the offshore Alaskan Stream; its seasonal signal is mainly related to a cross-shelf pressure gradient, which responds to an annual hydrological cycle. Current records from Shelikof Strait substantiate the presence of an annual signal and indicate that wind forcing has maximum effect from December through February, but it does not appear to augment flow at other times.

185. Schumacher, J.D., and R.K. Reed. 1983. Interannual variability in the abiotic environment of the Bering Sea and the Gulf of Alaska. In: W.S. Wooster (ed.), From year to year: Interannual variability of the environment and fisheries of the Gulf of Alaska and the eastern Bering Sea. Washington Sea Grant Program, Univ. Washington, Seattle. pp. 111-133.

The authors discuss year-to-year differences in physical oceanographic parameters in the Bering Sea and the Gulf of Alaska, attributing most of the variability to meteorological differences among years. Water movement and transport through Unimak Pass as a consequence of meteorological influences is discussed.

186. Sears, H.S., and S.T. Zimmerman. 1977. Alaska intertidal survey atlas. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Auke Bay Lab., Auke Bay, AK.

This atlas depicts littoral habitats and associated biota along the Gulf of Alaska and Bering Sea coasts. The depictions are based largely on aerial survey observations; they show information on three littoral parameters: stratum composition, beach slope, and biological cover. Ground-truthing at sites throughout the study area were performed. The littoral zones of islands throughout the eastern Aleutians study area are included.

187. Serobaba, I. 1968. Spawning of the Alaska pollock, Theragra chalcogramma in the northeastern Bering Sea. J. Ichthy. 8:789-798.

Pollock spawning grounds extend from Unimak Island along the 50-300 m isobaths to longitude 179°W. Spawning occurs from the end of February through June. Eggs were most abundant on the north side of Unimak Pass, March-May 1965.

188. Sharma, G. D. 1971. Bristol Bay: Model contemporary graded shelf. In: D.W. Hood, et al. (eds.), Oceanography of the Bering Sea. Phase 1. Turbulent upwelling and biological productivity mechanisms in the southeastern Bering Sea and Aleutian islands. Univ. Alaska Inst. Mar. Sci. Rep. No. R-71-9, Fairbanks.

This report discusses sediment distribution in the eastern Bering Sea and Aleutian Islands region and the factor responsible for the observed distributions. Sediment sources for the southeastern Bering Sea shelf are mainly freshwater streams emptying into the region, but some sediments are transported from south of the Aleutians. The narrow shelf along the Aleutian chain receives sediments from the islands themselves as well as from Alaskan Stream transport from the North Pacific.

189. Sharma, G.D. 1974. Contemporary depositional environment of the eastern Bering Sea. Part 1. Contemporary sedimentary regimes of the eastern Bering Sea. In: D. W. Hood and E. J. Kelley (eds.), Oceanography of the Bering Sea, with emphasis on renewable resources. Univ. Alaska Inst. Mar. Sci. Occas. Pub. No. 2. pp. 517-540.

The eastern Bering Sea receives sediments from various sources. The Yukon and Kuskokwim rivers and the relatively young, rugged coastline account for the continental sediment contribution. Appreciable amounts of biogenous sediments and large amounts of suspended sediments brought by incoming North Pacific water are also deposited in the Bering Sea. Locally, volcanic ash transported by the wind has been reported by some investigators. In the shallow shelf area, the sediments are dispersed in the water column and transported and graded by frequent storms. The coastal and shelf area in the Bering Sea represent a high-energy depositional environment. The water movement is the major control for the sediment transport and deposition in the eastern Bering Sea.

190. Shaul, A., J. McCullough, and L. Melloy. 1984. 1984 salmon and herring annual report, Alaska Peninsula-Aleutian Islands areas. Alaska Dep. Fish & Game, Anchorage. 230 pp.

This report presents tables of summary statistics regarding the 1984 harvests of salmon and herring in the Alaska Peninsula-Aleutian Island areas. Tables of subsistence harvests, daily commercial catches, age data, and escapement counts in the eastern Aleutian Islands are useful for the present study.

191. Shaul, A. 1985. Salmon report to the Alaska Board of Fisheries. Alaska Peninsula-Aleutian Islands Management Area. Alaska Dep. Fish and Game, Div. Comm. Fish, Juneau. 25 pp.

This annual report summarizes the commmercial salmon harvest at Unalaska which is the only island in the Aleutians with a developed commercial salmon fishery. The pink salmon is the major salmon species in the area; their run occurs from about 20 July to 25 August, peaking during the last week in July until 10 August. Annual catches of all salmon species in the Aleutians have averaged about 540,000 fish (range 0-2,611,000). Annual variation can be high; for example, catches of pink salmon were 2,309,700 in 1984 and 300 in 1985.

192. Shaw, D.G., and E.R. Smith. 1981. Hydrocarbons of animals of the Bering Sea. In: D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press, Seattle. pp. 383-388.

Samples of biological materials including pelagic animals and marine birds and mammals were collected in the Bering Sea for hydrocarbon determination. No hydrocarbons from petroleum or terrigenous plant sources were detected in any of the animal tissues analyzed. The analyses show that the source of hydrocarbons in the Bering Sea pelagic environment is biosynthesis in that environment. This is in keeping with the current understanding of productivity and carbon flow in this area. (From authors' abstract.)

193. Skud, B. 1977. Drift, migration and intermingling of Pacific halibut stocks. Int. Pacific Halibut Comm., Sci. Rep. 63. 42 pp.

Halibut stocks in the northeast Pacific region intermingle at all stages of their life history, but a large-scale distributional pattern for southern stocks involves the northward drifting of eggs and larvae into the Gulf of Alaska with a few being carried as far west as the Bering Sea. After the larvae settle to the seafloor, the juveniles move southward, eventually returning to nursery areas or feeding grounds. Upon reaching maturity the adults return to their spawning grounds, thus completing the cycle. The southward movements of tagged juvenile halibut from the Bering Sea into the Gulf of Alaska lend support to the above general concept of movements.

194. Sowls, A.L., S.A. Hatch, and C.J. Lensink. 1978. Catalog of Alaskan seabird colonies. U.S. Fish and Wildl. Serv. Biological Services Program FWS/OBS-78/78. Anchorage, AK. 32 pp. + maps.

Short summaries of the breeding biology and distributional patterns of all colonial seabirds precede an extensive series of detailed maps illustrating the locations of all known colonies prior to 1978. Colony sites are located on 1:250,000 USGS maps with corresponding tables listing population estimates for each species and colony. Data collection and summarization is ongoing for this catalog. New colony population estimates and site locations are currently located on a computer database located at the U.S. Fish and Wildlife Service in Anchorage, with hardcopy printouts of map overlays and updated tables available upon request.

195. Spaulding, M.L., T. Isaji, E. Anderson, A.C. Turner, K. Jayko, and M. Reed. 1986. Ocean circulation and oil spill trajectory simulations for Alaskan waters: Spill trajectory simulations for Shumagin Oil and Gas Lease Sale No. 86. Rep. by Applied Science Associates, Inc., to U.S. Dep. Commer., NOAA, OCSEAP. Anchorage, AK. 123 pp.

This paper reports on computer simulation of oil spill trajectories from launch points in the northwestern Gulf of Alaska and Cook Inlet. The wind drift component of oil spill movement dominates that due to the residual or tidal current fields. Landfalls of trajectories are a direct function of distance from the closest shoreline, and, for nearshore release, are generally down-current (southwesterly) relative to the launch sites. Spill trajectories showed relatively little seasonal variation for 60 simulations performed, though winter spills are slightly more energetic. Landfalls in the Unimak Pass area were commonly predicted for spills on the shelf immediately south of the western parts of the Alaska Peninsula. The vast majority of trajectories released in Unimak Pass land in the immediate vicinity of the pass; though the northerly net flow through the pass only weakly effects the trajectories.

196. Stevens, B.G., and R.A. MacIntosh. 1985. Report to industry on the 1985 eastern Bering Sea crab survey. U.S. Dep. Commer., NOAA, NMFS, Northwest and Alaska Fish. Center, Processed Rep. 85-20.

This report summarizes the National Marine Fisheries Service trawl survey (1985) data results for commercially important crabs in

the eastern Bering Sea. The survey area is mostly north of the Unimak Pass study area, but touches on the study area immediately north of the pass.

197. Strauch, J.G., Jr., and G.L. Hunt, Jr. 1982. Marine birds. In: M.J. Hameedi (ed.), Proceedings of a synthesis meeting: the St. George Basin environment and possible consequences of planned offshore oil and gas development, Anchorage, Alaska, April 28-30, 1981. U.S. Dep. Commer., NOAA, OMPA, Juneau, AK. 162 pp.

The authors present a summary of recent information on distribution, abundance, and habitat use of the St. George lease area and surrounding areas by marine birds. Included are many discussions and range maps including the eastern Aleutian Islands, providing information on breeding colonies, pelagic distribution, and use of coastal habitats by marine birds. Ecology of marine bird populations in the area is also presented, including trophic relationships, reproductive biology, phenology of bird use, and productivity and growth of bird populations. Discussions of potential effects of OCS development center on direct and indirect effects of oil pollution on the birds themselves and their food supplies, and the effects of increased human disturbance on marine bird habitat use and reproduction. Future research needs outline data gaps and assess problems in ranking priorities for further work. Although the actual St. George lease area is mostly outside the area of interest for Unimak Pass studies, much of this paper is applicable to development concerns here as well.

198. Swan, N.P., and W.J. Ingraham, Jr. 1984. Numerical simulation of the effect of interannual temperature fluctuations on fish distribution in the eastern Bering Sea. U.S. Dep. Commer., NOAA Tech. Mem. NMFS F/NWC-57. 60 pp.

The effects of extreme interannual temperature fluctuations on the Bering Sea ecosystem were examined using the Dynamical Numerical Marine Ecosystem Simulation (DYNUMES) model. Simulations indicated differing responses to temperature fluctuations among different species groups of fishes. Actual data from yellowfin sole and pollock catches were examined in a cold and warm year; the catch data supported simulation results.

199. Swift, J. H., and K. Aagaard. 1976. Upwelling near Samalga Pass. Limnol. Oceanogr. 21: 399-408.

Recent summer hydrographic data from the vicinity of Samalga Pass in the eastern Aleutians show upwelling of relatively saline water, poor in oxygen and rich in nutrients. A steady state oxygen model in which the photosynthetic production of oxygen in the euphotic zone is balanced by an upwelling of low-oxygen water yields an upper bound on the vertical velocity of 7×10^{-3} sl. Examination

of various possible driving mechanisms for the upwelling, including winds and entrainment, suggests that the upwelling is driven by subsurface convergence.

200. Sykes, L. R. 1971. Aftershock zones of great earthquakes, seismicity gaps, earthquake prediction for Alaska and the Aleutians. J. Geophys. Res. 76:8012-8041.

Aftershocks of shallow earthquakes larger than magnitude 7 in the Aleutians, southern Alaska, southeast Alaska, and offshore British Columbia from 1920 to 1970 were relocated by computer in an attempt to delineate the rupture zones of large earthquakes. Plate tectonic theory indicates that gaps in activity for large earthquakes for the past 10's to 100's of years are likely sites of future large earthquakes. Three prominent gaps of this type are delineated: one in southeast Alaska; another in southern Alaska near the epicenters of the great earthquakes of 1899 and 1900; and one in the far western Aleutians. These gaps deserve high priority for study and instrumentation. Nearly the entire Alaska-Aleutian zone from 145°W to 171° W has broken since 1938 in a series of large earthquakes. Shocks with long rupture zones tend to occur along those parts of the Alaska-Aleutian zone that are relatively simple tectonically. The ends of many aftershock zones of large earthquakes are located at the intersection of major transverse features with the Aleutian arc. Large earthquakes rarely, if ever, reoccur along the same part of a fault zone in less than several tens of years, i.e. within a time less than that for substantial strain accumulation.

201. Takenouti, A. Y., and K. Ohtani. 1974. Currents and water masses in the Bering Sea: A review of Japanese work. <u>In</u>: D.W. Hood and E. J. Kelley (eds.), Oceanography of the Bering Sea, Univ. Alaska Inst. Mari. Sci. Occas. Pap. No. 2. Fairbanks pp. 39-57.

The authors show that about half of the volume transport of the Alaskan Stream enters the Bering Sea through Aleutian Island passes and the rest from west of Attu Island. The highly stratified Alaskan Stream water loses its characteristic structure upon entering the Bering Sea during its first step of transformation from Eastern to Western Subarctic water. A general counterclockwise circulation and small eddies prevail in the Bering Sea. The continental shelf of the eastern Bering Sea is characterized by various types of vertical temperature and salinity structures. Freshwater dilution of the surface layer, the instrusion of warm saline water near the bottom, and strong vertical mixing associated with winter cooling cause formation of dichothermal water. In regions where a conspicuous halocline is present as a barrier to winter convection activity, cold bottom water is absent.

202. Thorsteinson. L.K. (ed.). 1984. Proceedings of a synthesis meeting: The North Aleutian Shelf environment and possible consequences of offshore oil and gas development. U.S. Dep. Commer. NOAA, OCSEAP. Anchorage, AK. 159 pp.

This report provides a discussion of the ecological processes and major trophic relationships of plants and animals potentially effected by oil and gas exploration in the North Aleutian Shelf area. Major chapters include the Transport and Fate of Spilled Oil, Coastal Habitats and Species, and Fishery Resources. Input from experts in each area was synthesized and data important to the understanding of local ecological processes was summarized in each chapter. Part of the Unimak Pass study area overlaps the area studied in detail in this report.

203. Thorsteinson. F., and T. Merrell. 1964. Salmon tagging experiments along the south shore of Unimak Island and the southwestern shore of the Alaska Peninsula. U.S. Fish and Wildl. Serv. Special Sci. Rep.-Fish. No. 486. 15 pp.

Adult salmon were tagged south of Unimak Island, mid-June to mid-July 1961. A westerly migration followed by a northeasterly migration was demonstrated by tag recoveries. Sockeye were recovered mainly in Bristol Bay; chum were caught along the Bering coast from Bristol Bay to the Yukon River; and pink were recovered relatively close to the tagging area.

204. Trapp, J.L. 1975. The distributions and abundances of seabirds along the Aleutian Islands and Alaska Peninsula, fall 1974. U.S. Fish and Wildl. Serv., Aleutian Islands Nat. Wildl. Ref., Adak, Alaska. Unpubl. Field Rep. 39 pp.

Quantitative observations were taken on seabird abundance along 84 shipboard transects through the Aleutian Islands and along the Alaska Peninsula from 7 August to 4 October 1974. Information on mean and relative abundance and occurrence rate is presented in tables and bar graphs. The distribution and abundance of each species is described briefly. Mention is made in several species accounts of movements and concentrations of seabirds in various passes, including passes in the eastern Aleutian Islands.

205. USCOE (U.S. Army Corps of Engineers). 1979. Working draft environmental impact statement for World War II debris removal and cleanup. Aleutian Islands and lower Alaska Peninsula, Alaska. Prepared by Tetra Tech, Inc. for Alaska District Corps of Engineers. 265 pp. + App. A through J.

This impact statement discusses the physical, chemical, biological, and socioeconomic environment of the Alaska Peninsula, Aleutian Islands, and nearby waters. The environmental factors are considered in the context of a proposed cleanup of debris left by World War II activities. Positive and negative aspects of the cleanup are evaluated.

206. USFWS (U.S. Fish and Wildlife Service). 1974. Preliminary reports of biological data on proposed harbor sites at Unalaska, Alaska. Bur. Sports Fisheries and Wildlife, Anchorage, Alaska. 11 pp. + Figs. and Tables.

Inventories of aquatic plants, benthos, fish, birds, and marine mammals were made at seven potential small-boat harbor sites near Unalaska. All except one of the harbor sites appeared biologically productive.

207. Veltre, D., and M. Veltre. 1982. Resource utilization in Unalaska, Aleutian Islands, Alaska. Alaska Dep. Fish & Game, Div. Subsistence. Tech. Paper No. 58. 131 pp.

This report describes the subsistence use of resources primarily at the Aleutian community of Unalaska. Past and current uses of fish and invertebrates are described; of particular use in the present study are maps showing current fishing locations for salmon and halibut in Unalaska Bay.

208. Wada, S. 1980. Japanese whaling and whale sightings in the North Pacific 1978 season. Rep. Int. Whal. Comm. 30:415-424.

Using Japanese sightings data from 1965 to 1978, indices of abundance were calculated by species and year for the entire North Pacific area covered by the Japanese whaling fleet. Although the number of sightings for some species were inadequate, general trends in distribution and abundance are discussed. Maps depicting whale abundance by 10-degree blocks provide some information pertinent to the Unimak Pass study area.

209. Waldron, K. 1981. Ichthyoplankton. In: D.W. Hood and J. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1, U.S. Dep. Commer., NOAA, OMPA. Univ. Washington Press. Seattle. pp. 478-493.

This report presents ichthyoplankton data collected during studies by Japan, USSR, and the U.S. during 1955-1980. Of the 60 species collected, the most common were sculpins, cods, greenlings and pricklebacks. In spring, pollock larvae were much more abundant than other species between the Aleutian Islands and about 60°N and centered over the continental slope. Winter sampling efforts for ichthyoplankton are rare.

210. Walsh, J.J., and C.P. McRoy. 1986. Ecosystem analysis in the southeastern Bering Sea. Continental Shelf Research 5(1/2):259-288.

The authors present an overview of a seven-year study of the food-chain dynamics of the outer and middle shelves of the southeastern Bering Sea. This study, called Processes and Resources of the Bering Sea Shelf (PROBES), examined interannual variations in biotic and abiotic parameters and attempted to establish the causes. The PROBES study area extended southward to the extreme northern edge of the eastern Aleutians area, but included little sampling in the eastern Aleutians area. Hypothetical trajectories of pollock eggs and larvae from spawning pollock in the Unimak Pass area are considered.

211. Walters, G., and M. McPhail. 1982. An atlas of demersal fish and invertebrate community structure in the eastern Bering Sea: Part 1, 1978-81. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-35. 122 pp.

Numerical classification techniques (cluster analysis) were used to describe the community structure of demersal fish and invertebrates in the eastern Bering Sea. Summer trawl data were gathered from 1978-1981, with the 1979 data set including sample sites adjacent to the current study area. The 1979 data indicated three communities in the eastern Bering Sea: (1) a mainland inshore group dominated by yellowfin sole and asteroids, (2) a broad continental shelf group dominated by pollock, yellowfin sole, snow crab and Pacific cod, and (3) a continental slope group dominated by Greenland turbot. Communities (2) and (3) occur just north of Unimak Pass.

212. Walters, G., G. Smith, P. Raymore, and W. Hirschberger. 1985. Studies of the distribution and abundance of juvenile groundfish in the northwestern Gulf of Alaska, 1980-1982: Part II, Biological characteristics in the extended region. U.S. Dep. Commer., NOAA Tech. Memo NMFS F/NWC-77. 95 pp.

Juvenile groundfish were studied to determine annual variations in distribution and abundance, to evaluate the feasibility of measuring year-class strength, and to obtain life history information. While most trawl sampling was conducted east of our area of current interest, catches of juvenile groundfish around Unalaska Island are reported--of the fishes caught there, 1-year old pollock and flathead sole were most abundant. Considerable annual variation in distribution and abundance was documented.

213. Weber, D.D. 1967. Growth of the immature king crab Paralithodes camtschatica (Tillesius). Int. North Pacific Fish. Comm. Bull. 21:21-53.

A major part of this study was sited in the study area--in the shallow waters of Iliuliuk Bay near Unalaska, Alaska. Caged crabs and sampling for immatures in the wild were used in the experiment. From a combination of the progression of modes in successive length-frequency distributions and observations on molting, an attempt was made to identify age groups and determine age-size relationships. The growth curve derived was similar for the sexes through the first four years of life. Thereafter, female crabs grew more slowly than males and completed the immature phase in slightly less than six years. Male crabs attained sexual maturity in five years. (Adapted from author's abstract.)

214. Wilderbuer. T., K. Wakabayashi, L. Ronholt, and H. Yamaguchi. 1985. Survey report: cooperative U.S.-Japan Aleutian Islands groundfish trawl survey-1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-93.

This report provides data analyses and an appendix which lists trawl catches by station in the present area, but see Ronholt et al. (1986) for an annotation of this data set.

215. Wilimovsky, N. 1964. Inshore fish fauna of the Aleutian archipelago. In: Science in Alaska, 1963. Proc. 14th Alaska Science Conf., Am. Assoc. Advance. Sci., Alaska Div. pp. 172-190.

This brief report lists fish species collected in the intertidal zone of the Aleutian Islands; 140 species were caught, mostly in intertidal pools at low tide. Sculpin dominated the fauna, with 45 species. Wilimovsky comments that no other fauna in the wörld contain such a high proportion of sculpin species.

216. Wilson. J.R., and A.H. Gorham. 1982a. Underutilized species. Vol. I: Squid. Alaska Sea Grant Rep. 82-1, Univ. Alaska, Fairbanks.

This short report describes squid distribution in the world and in Alaskan waters. It provides analyses of selected National Marine Fisheries Service (NMFS) trawl survey data, foreign catch data, and foreign observer program data for squid catches in the northwestern Gulf of Alaska and the southeastern Bering Sea, including the eastern Aleutians. Distributions of catch rates of major species and unidentified squids are shown.

217. Wilson, J.R., and A.H. Gorham. 1982b. Alaska underutilized species, Vol. II: Octopus. Alaska Sea Grant Rep. 82-3, Univ. Alaska, Fairbanks.

This brief report describes world and Alaska distributions of octopuses. It looks at examples of NMFS trawl survey data, data from divers and biologists, foreign catch data, and foreign observer program data to provide a picture of octopus distribution and general abundance in the southeastern Bering Sea and the northern Gulf of Alaska, including the eastern Aleutians study area. A brief review of the giant octopus Octopus vulgaris is provided.

218. Yesner, D.R., and J.S. Aigner. 1976. Comparative biomass estimates and prehistoric cultural ecology of the southwest Umnak region, Aleutian Islands. Arctic Anthropology 8:91-112.

This paper reports on biomass of animal remains in archaeological sites on southwest Umnak Island, and compares them to present abundance ratings of avian fauna in the region. Birds were not a major dietary component of ancient Aleuts, however their remains have been well preserved over the centuries. Certain species, such as Short-tailed Albatrosses, appeared in greater proportion in the remains of middens than appear today, due to their recent (1800's) exploitation by man. Appearance of species in remains seemed to indicate that Aleut hunters concentrated efforts on flocked species found in bays and passes in the Umnak Island area.

219. Zimmerman, S.J., and R.R. Merrell, Jr. 1976. Baseline characterization, littoral biota, Gulf of Alaska and Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. 6:75-484.

The authors provide a characterization of the intertidal and shallow subtidal biota in the region from Yakutat in the eastern Gulf of Alaska to Cape Newenham in northern Bristol Bay. Two objectives were to determine the distribution of the major habitat types (sandy, muddy, rocky, etc.) along the coastline and to determine the densities and distribution of biotic populations of these habitat types. The majority of biota in the littoral zone are non-motile and are unable to avoid repeated exposure as oil or similar compounds come ashore.

3. SUBJECT INDEX

LOWER TROPHIC LEVELS

FISH

BIRDS

YUKON DELTA COASTAL PROCESSES STUDY

by

William R. Dupré

Department of Geology
University of Houston
Houston, Texas 77004

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 208

January 1980

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The overall objective of this study is to provide information on the depositional environments and associated geologic processes that characterize the Yukon-Kuskokwim Delta complex (Fig. 1). These data, in turn, can aid in evaluating the potential environmental impacts of exploration for hydrocarbons in the Norton Sound region.

The specific objectives of this study are directly related to the initial phase of selecting offshore leases. They include:

1) Provide information on the age of faulting and volcanism in the region to aid in determining the potential seismic risk.

2) Provide information on the distribution of permafrost in the region to aid in determining the probability of offshore permafrost.

3) Map the depositional environments of the modern Yukon Delta, including offshore facies, with an evaluation of the potential geologic hazards (e.g. liquefaction susceptibility, erosion and sedimentation potential) which characterize each depositional environment.

4) Study the seasonality of coastal processes in the Norton Sound region, emphasizing the patterns and rates of ice movement during the winter months as determined from satellite imagery.

CURRENT STATE OF KNOWLEDGE

The suspended sediment load of the Yukon River is the 18th largest in the world (Inman and Nordstrom 1971), providing over 90% of the sediment presently entering the northern Bering Sea (Lisitsyn 1966). The Yukon and Kuskokwim rivers have combined to form the seventh largest delta plain in the world (Inman and Nordstrom 1971), yet despite its size, relatively little is known of its Quaternary history or the processes by which it was formed.

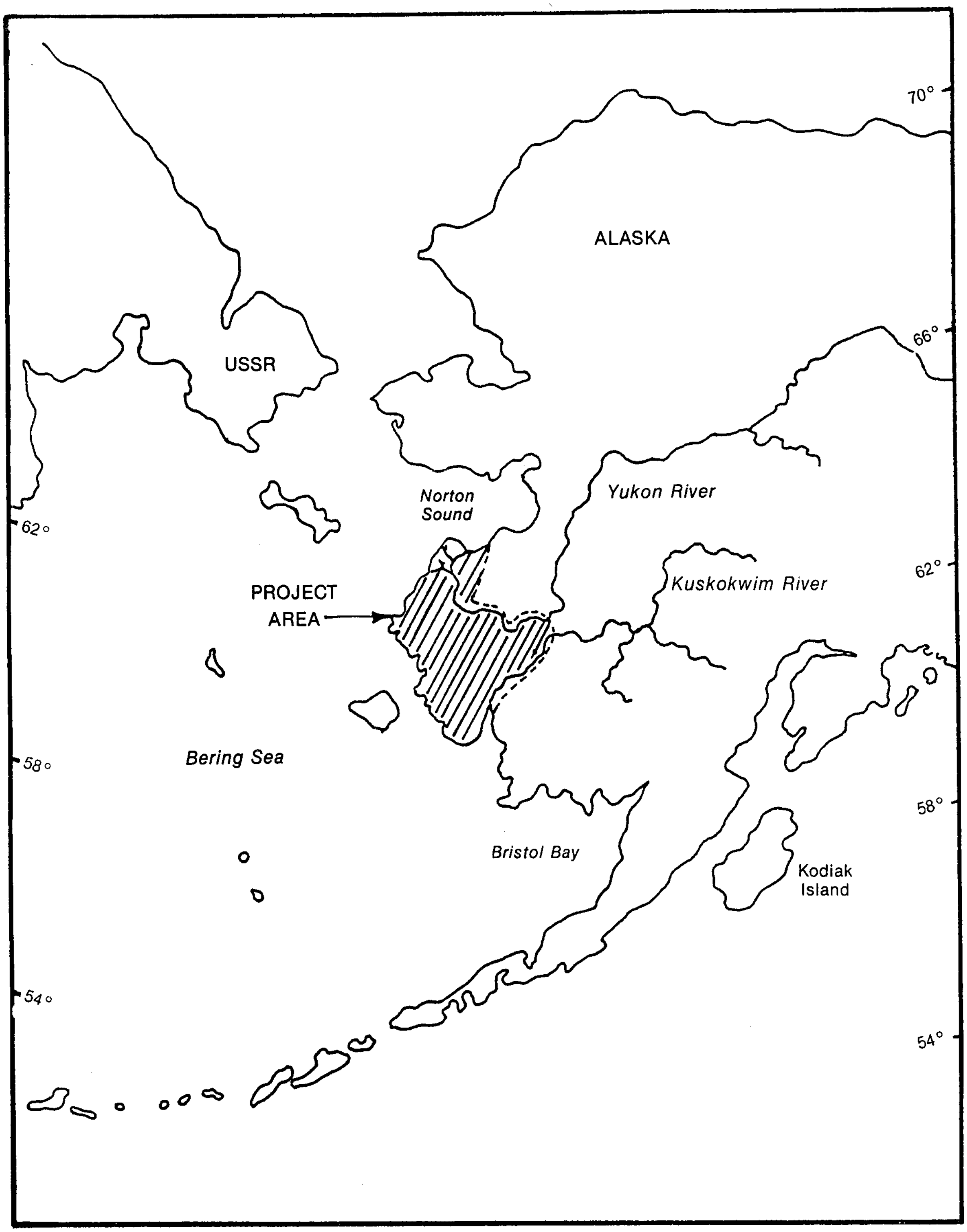


Figure 1.--Location of project area, Yukon Delta Coastal Processes Study (OCSEAP Research Unit 208).

A significant amount of work has been done on the Cenozoic tectonic history of the region (e.g., Patton 1973; Nelson et al. 1974; Marlow et al. 1976). There have also been numerous studies of Quaternary sediments on the northern Bering Sea shelf (e.g., Moore 1964; McManus et al. 1974, 1977; Nelson and Creager 1977; Drake et al. 1979), as well as the Holocene sediments at the mouth of the Yukon River (Matthews 1973). In addition, Thor and Nelson (1979) provided a synthesis of the geologic processes and hazards in the Norton Sound region.

With the exception of the work of Matthews, however, none of these studies sampled anything but the most distal portions of the Yukon Delta. In addition, the geologic mapping of the subaerial delta complex has been largely restricted to regional reconnaissance mapping (e.g., Hoare 1961; Hoare and Coonrad 1959a, 1959b; Hoare and Condon 1966, 1968, 1971a, 1971b). This is the first study to deal in detail with the depositional environments and processes of both the delta plain and the associated offshore facies.

STUDY AREA

The combined Yukon-Kuskokwim Delta complex (Fig. 2) is an area of unique natural resources covering over 54,000 square kilometers. It has a large native population living in large part on a subsistence economy. The delta provides access to most of the spawning areas for salmon in the region. It is, in addition, one of the most significant breeding grounds for migratory birds in North America.

The delta region is largely a flat, featureless plain consisting of wet and dry tundra interrupted by innumerable lakes. Many of the lakes have coalesced laterally to form very large bodies of water (e.g., Baird Inlet) connected to the sea by a series of ancient river channels. The flatness of the delta complex is interrupted by numerous small Quaternary shield volcanoes, the major uplifted massifs of the Askinuk and Kuzilvak mountains, and the Quaternary volcanic complex that forms Nelson Island.

The coastline is extremely varied, in part because of the complex geology along the coast, and in part because of the lateral variability of sediment sources and tidal range. For example, broad tidal flats, locally bordered by short barrier islands, flank the macrotidal Kuskokwim Delta, whereas the microtidal Yukon Delta is fringed by distributary mouth bars and interdistributary tidal flats. Sandy beaches are present near Hooper Bay, where Wisconsinan(?) sediments provide the source of sediments, whereas steep gravel beaches and rocky headlands form along the cliffed shorelines at Cape Romanzof, Point Romanof, and Nelson Island where Cretaceous bedrock crops out. Most of the remaining coastline consists of low, eroding bluffs cut into poorly consolidated Pleistocene deposits.

SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

Geologic mapping in the delta complex (including the delineation of potentially active faults) consisted of the compilation of existing geologic maps, interpretation of aerial photography and satellite (Landsat) imagery, and field work. Regional reconnaissance mapping by Dr. Joe Hoare and associates at the U.S. Geological Survey was available for most of the delta region at a scale of 1:250,000. In addition, photographic coverage of the entire delta region taken in 1952-54 is available, as is more recent coverage (1973, 1976) for much of the coastline. Landsat imagery was also very useful for regional geologic mapping.

Field work during the summers of 1975-78 included the description of vegetation assemblages and collection of numerous grab samples and short cores to describe the various depositional environments, the establishment and reoccupation of coastal benchmarks to measure the short-term rates of shoreline change, and the collection of organic-rich material for radiocarbon dating. The radiocarbon dating (University of Texas Radiocarbon Laboratory, Austin) aided in establishing the probable age of most recent faulting in the delta region. Part of the field work also involved obtaining several cores from two volcanic lakes in the delta region using a modified Livingston piston corer from a floating platform. These cores are being analyzed by Dr. Tom Ager (USGS, Reston, Virginia) to determine the frequency of explosive volcanism in the region (via ash content), the sources and rates of sedimentation, and evidence of climatic change (via pollen analysis).

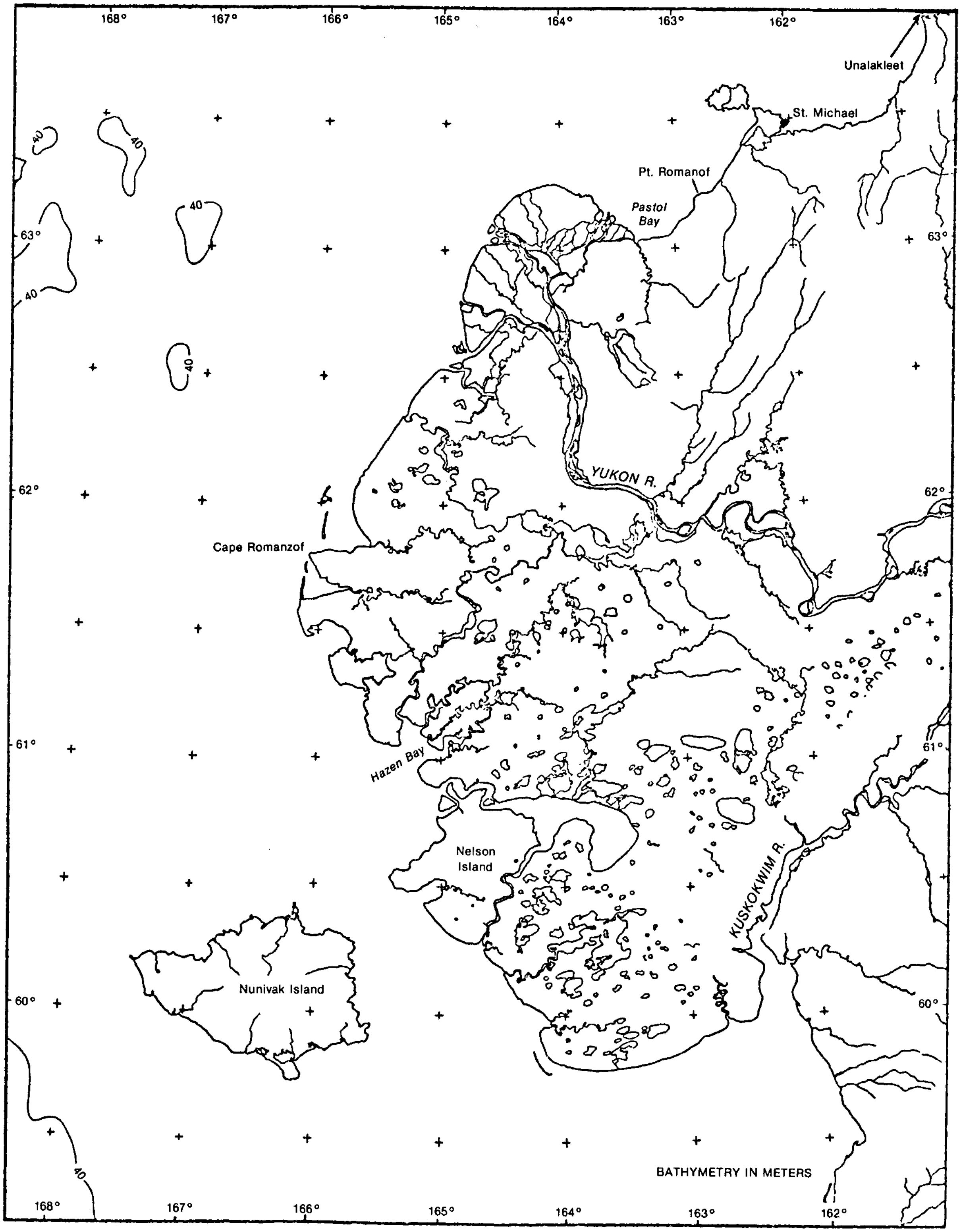


Figure 2.--Yukon-Kuskokwim Delta complex.

The delineation of offshore depositional environments was done mainly by interpretation of satellite imagery, bathymetric maps, and offshore cores provided by the USGS (Menlo Park, California). The Landsat imagery was particularly useful in delineating the sub-ice channels during periods of freeze-up and breakup. Existing bathymetric data (mainly vintage 1899), were compared with traverses obtained by RV Karluk (USGS cruise, 1978) to estimate long-term rates of erosion and sedimentation of the delta front. In addition, the locations of the sub-ice channels from 1899 to 1978 were compared by the use of the Landsat imagery, allowing an estimation of the rates of lateral migration (and associated erosion and sedimentation).

The Karluk also collected 22 vibracores off the front of the modern Yukon delta. These cores, in combination with numerous box cores taken farther offshore by C. Hans Nelson (USGS, Menlo Park, California) and sediments described by McManus et al. (1977) allow a better understanding of the patterns of sedimentation in the region.

Sequential Landsat imagery (1973-77) was used to study the patterns of ice formation from freeze-up to breakup in the Norton Sound region. Sidelap of images taken on successive days allowed the calculation of daily rates and directions of ice floe movement. The resultant patterns of ice movement were compared with synoptic weather data obtained from daily surface synoptic weather charts, as well as available bathymetric data and information on ice gouging (Thor and Nelson 1979).

RESULTS

The results with direct implications to the earlier phases of site selection are:

1) There is widespread geomorphic evidence of Quaternary faulting, with some faults cutting Holocene fluvial deposits. Some of these faults are continuations of major fault systems, hence the magnitude of the potential seismic event may be large, even though the historical seismicity is rather low.

2) There is no evidence of explosive volcanic activity in the delta region having occurred during the Holocene, and some suggestion that it may not have occurred within the last 24,000 years. It seems likely, therefore, that the risk from volcanism is minimal.

3) Pleistocene sediments beneath most of Norton Sound contained thick, ice-bound permafrost that was actively forming as recently as 10,000 years ago; some may remain offshore as relict permafrost. Offshore permafrost in modern sediments is less likely and, if present, will be thin, discontinuous, and restricted to water depths less than 1 m.

4) A map of the depositional environments of the modern Yukon Delta (Fig. 3) illustrates the differences between this delta and those previously described. Each depositional environment is characterized as to dominant process(es) and potential geologic hazards. A more detailed discussion of the modern depositional environments is provided by Dupré and Thompson 1979 (provided in the Appendix).

5) A preliminary map of offshore sediment characteristics (Fig. 5) provides some information as to the degree of sediment reworking and the possible paths of sediment (and pollutant) transport.

6) A preliminary zonation of ice hazards in Norton Sound (Fig. 6) illustrates the relatively systematic variations in patterns and rates of ice movement during the winter. A more detailed study of ice movement in the Norton Sound region is provided by Ray and Dupré (1981).

DISCUSSION

Tectonic Framework

The Yukon-Kuskokwim Delta complex is located within the Koyukuk volcanogenic province, which has been characterized by recurrent faulting and syntectonic volcanic activity throughout the Mesozoic and Cenozoic (Patton 1973). Most of the major faults in the region (e.g., the Kaltag fault) formed and were most active during the late Cretaceous and early

Tertiary (Hoare, 1961); however, many of these structures have remained active, albeit at reduced levels of activity, to the present (e.g., Hoare 1961; Patton and Hoare 1968; Grim and McManus 1970).

Most of the newly recognized faults, photo-linears, and measured joint sets within the Quaternary deposits are parallel to or are extensions of previously mapped faults. There is no evidence of the Kaltag fault passing through the modern lobe of the Yukon Delta, as previously suggested by Hoare and Condon (1971); however, this may simply be the result of masking by the relatively young (<2,500 years old) delta. Alternatively, the Kaltag may splay into a series of southwest-trending faults which transect the Andreski Mountains and continue across the delta plain.

The age of the most recent faulting remains uncertain; at least some of the faults appear to cut Holocene deltaic and fluvial deposits. The recentness of fault movement, as based on geologic criteria, is consistent with the work on microseismicity in the region by Biswar and Gedney (OCSEAP Rsearch Unit 483), as well as the abundance of fault scarps detected by Johnson and Holmes (cited in Nelson 1978). Therefore, it seems clear that the selection of potential transportation corridors must take into account the possibility of significant ground movement along at least some of the fault zones in the area. In addition, all site investigations must evaluate the potential for ground shaking and liquefaction due to such an event, even though the historical seismicity is relatively low. This is particularly important because almost all of the Holocene fluvial and deltaic sediments are characterized by grain size distributions that suggest they are highly susceptible to liquefaction.

The Quaternary volcanism probably occurred over a wide period of time, as evidenced by the various degrees of weathering and slope modification; however, paleomagnetic data indicate that almost all of the basalts are normally polarized, hence are less than 700,000 years old (Hoare and Condon 1971b). A core taken from a volcanic lake in the middle of the delta complex contains an ash deposit which is approximately 3,500 years old. However, the composition of the ash suggests it was derived from a distant source (e.g., Alaska Peninsula). No other evidence of volcanism is preserved in the core, which probably records an interval of approximately 24,000 years, suggesting either that the most recent volcanism in the region was far removed from the lake or that it predates the core. The latter seems most likely, as cores taken from a volcanic lake near St. Michael, east of the delta, also show a lack of locally derived pyroclastic material (Dr. Tom Ager, USGS, pers. commun.). Thus it seems likely that the risk due to volcanic activity should be considered minimal.

Permafrost

The presence of permafrost in the Yukon-Kuskokwim Delta region is well established by an abundance of geomorphic criteria, including polygonal ground, palsas, thermokarst lakes, solifluction lobes, and string bogs. The type and extent of permafrost are further documented by field studies, unpublished drillers reports, and a study by the U.S. Geological Survey (Williams 1970). Previous annual reports from RU 208 have described the extent and variability of permafrost in some detail, and will not be repeated here. Rather, the concern at present is to discuss the possibility of offshore permafrost in the region.

The modern lobe of the Yukon Delta and associated chenier plain are relatively young geologic features, having formed approximately 2,500 years ago. There is evidence of permafrost forming in much of the interior parts of the modern delta plain, yet it appears to be discontinuous and relatively thin (2-3 m?). There is little evidence of permafrost presently forming along the prograding margin of the delta plain. If permafrost is actively forming in modern deltaic sediments offshore, it is certain to be thin, discontinuous, and restricted to sediments in water depths of less than 1 m, coincident with the distribution of bottomfast ice.

The possibility of relict permafrost existing offshore is more difficult to predict. Norton Sound was emergent until as recently as 10,000 years ago, when it was flooded during the last glacio-eustatic rise in sea level (C. Hans Nelson, USGS, unpubl. data). Thus, until recently, Pleistocene sediments similar to those which presently cover much of the delta region were exposed offshore. The Pleistocene sediments on land are characterized by extensive permafrost (including large ice wedges and massive ice) locally up to 200 m thick. The permafrost began to degrade following the submergence of Norton Sound, but some may remain offshore as relict permafrost, depending on 1) the original thickness of the permafrost, 2) the nature of the Pleistocene sediments, 3) the thermal properties of the overlying water mass, and 4) the possible presence of Holocene river channels (cf. Hopkins 1978).

More detailed seismic studies and exploratory drilling are necessary before a more definitive statement can be made as to the presence of offshore permafrost in the Norton Sound region. Nevertheless, it is clear that most of Norton Sound was underlain by thick, ice-bound permafrost which was actively forming as recently as 10,000 years ago. Thus a very real possibility exists for the presence of relict ice-bound permafrost underlying parts of Norton Sound. This possibility seems especially high east of the modern delta, between Apoon pass and St. Michael, where the shoreline is rapidly eroding Pleistocene sediments at rates of approximately 17 m/year. It seems likely that in this area the thick permafrost exposed along the shoreline extends for some distance offshore.

Depositional Environments of the Modern Yukon Delta

The modern Yukon Delta has several depositional environments that are lacking in deltas formed in more temperate climates. These depositional environments are but one indication of the extreme seasonality of coastal processes which probably characterize many high-latitude continental shelves. Table 1 is a preliminary attempt to assess the relative importance of these processes within each environment. The ability to predict the types of processes as well as the sediment characteristics and geotechnical properties which characterize each environment, should greatly aid in minimizing both the costs and environmental impacts of siting both offshore and onshore structures.

The subaerial morphology of the Yukon Delta is similar to that of lobate, high-constructional deltas described by Fisher et al. (1969) as typical of bedload-dominated rivers emptying into shallow depositional basins. An examination of the subaqueous morphology of the delta, however, suggests that such a classification fails to recognize some of the unique aspects of the Yukon Delta.

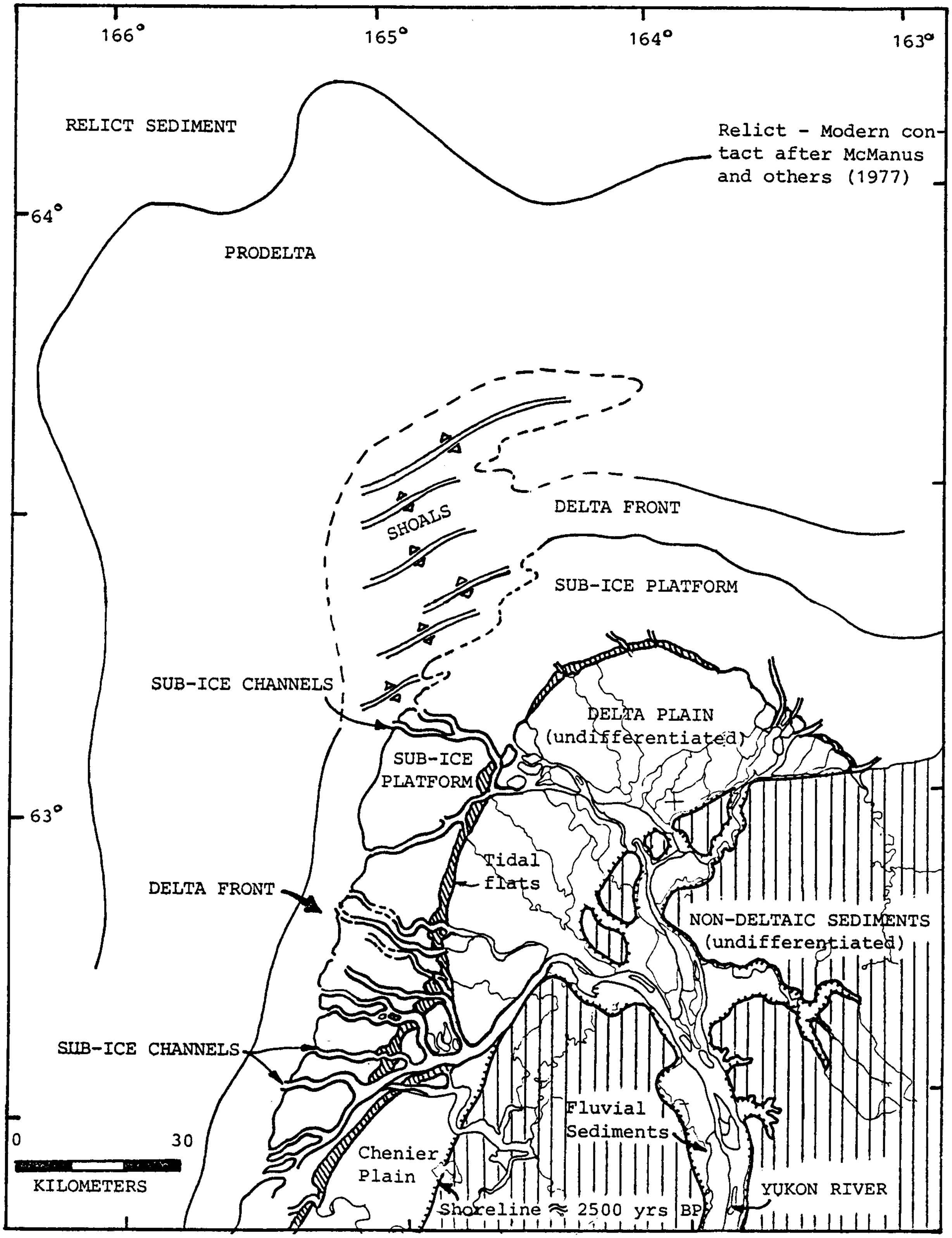


Figure 3.--Depositional environments of the Yukon Delta.

Table 1.--Preliminary summary of nontectonic geological hazards of the modern Yukon Delta.

Depositional environments	Flooding	Ice scour	Sedimentation	Erosion	Permafrost	Liquefaction
Delta plain						
Active distributary	High	Moderate	High	High	None	High
Abandoned distributary	Moderate	Low	Moderate	High	Low-Mod	Mod-High
Interdistributary marsh	Moderate	Low	Low-Mod	Low	Low-Mod	Mod-Low
Coastal marsh	High	Moderate	High	Variable	Low	Low
Delta margin						
Distributary mouth bar	High	Moderate	High	Low-Mod	Low	Mod-High
Tidal flats	High	Mod-High	High	Low	Low	Variable
Sub-ice platform	N/A	Mod-Low	Variable	Variable	None	Variable
Sub-ice channels	N/A	Low	High	High	None	High
Delta front	N/A	High	Variable	Variable	None	Mod-High
Prodelta	N/A	Mod-Low	Moderate	Mod-Low	None	Low-Mod

The delta plain is fringed by prograding tidal flats and distributary mouth bars, similar to many previously described deltas. The Yukon is unusual, however, in that the delta front and prodelta are offset from the prograding shoreline by a broad platform (here referred to as the sub-ice platform), typically 1-3 m deep and locally up to 30 km wide. The resultant subaqueous profile (see Appendix Fig. 5) is quite unlike those of wave- and river-dominated deltas described by Wright and Coleman (1973). In addition, the platform is crossed by a series of subaqueous (sub-ice) channels which extend up to 20 km beyond the mouths of the major distributaries.

The sub-ice platform and associated sub-ice channels appear to be related to the presence of shorefast ice which fringes the delta for almost half of the year. Several workers (e.g., Reimnitz and Bruder 1972; Reimnitz and Barnes 1974; Walker 1974) have noted that patterns of nearshore sedimentation along the Arctic coast of Alaska are strongly influenced by the presence of shorefast ice. Naidu and Mowatt (1975) suggested that this is unique to deltas formed by polar rivers in the Arctic. I believe that these smaller arctic deltas, as well as larger deltas such as the Yukon, Mackenzie, and Lena, actually represent a separate type of ice-dominated delta, morphologically distinct from the wave-, river-, and tide-dominated deltas previously described in the literature (e.g., Galloway 1975). The Yukon Delta may provide a model for such an ice-dominated delta (Dupré and Thompson 1979; see Appendix).

Delta Plain

The delta plain consists of a complex assemblage of active and abandoned distributary channels and channel bars, natural levees, inter-distributary marshes, and lakes (Fig. 4); however, for the purpose of this report, it will remain undifferentiated. Much of the older, more inland parts of the delta plain show clear evidence of permafrost, but it appears to be discontinuous and relatively thin (2-3 m?). Flooding is a major hazard on much of the delta plain, as are erosion and sedimentation associated with the meandering active distributary channels. In addition, much of the sediment deposited in the channels and channel bars consists of relatively well-sorted sands and silts with a high susceptibility for liquefaction.

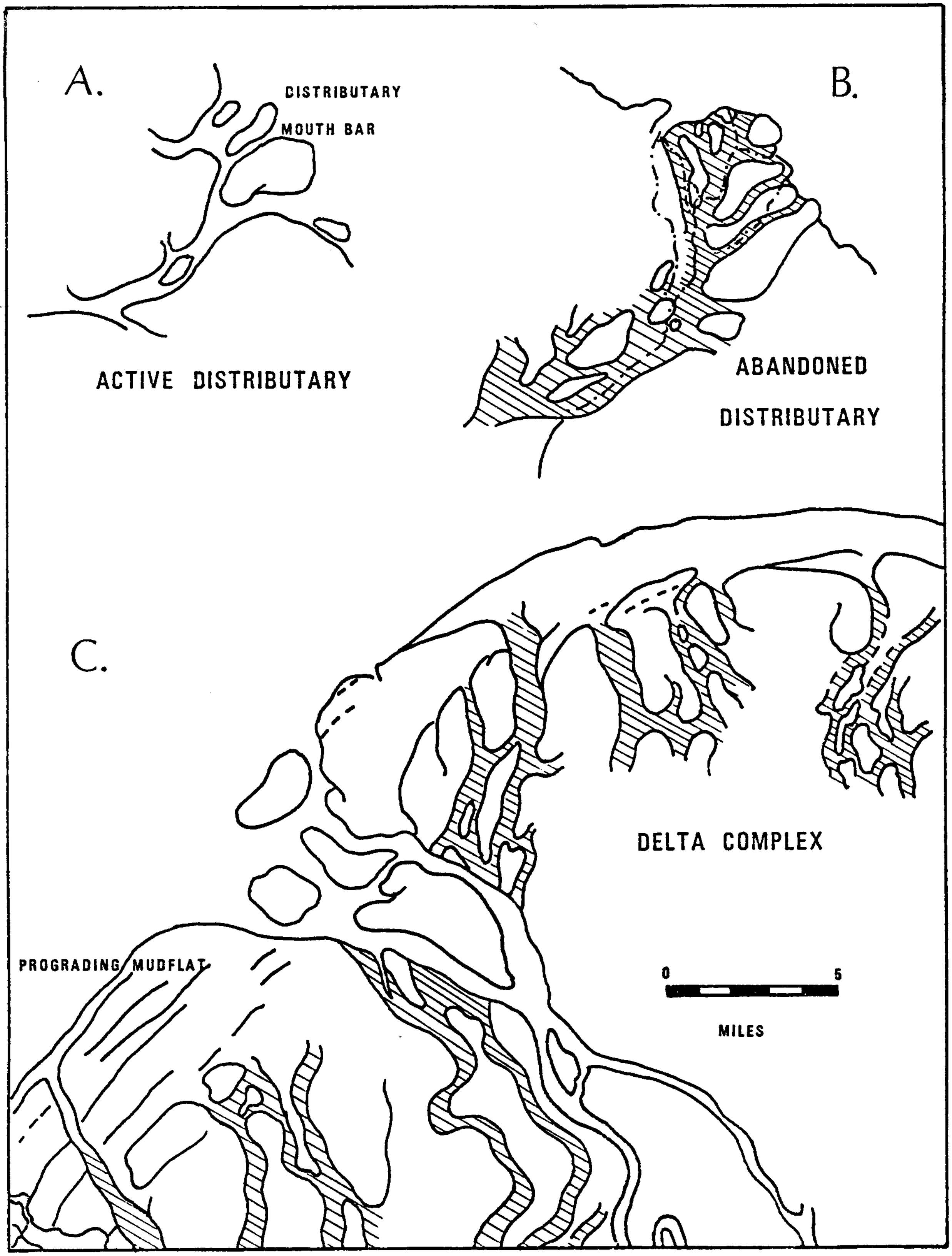


Figure 4.--Depositional environment within the delta plain of the modern Yukon Delta.

Delta Margin

The delta margin is a term used here informally to include the prograding tidal flats and distributary mouth bars as well as the sub-ice platform and associated sub-ice channels.

The tidal flats are typically 100-1,000 m wide where they occur along the prograding margin of the modern delta. They consist of poorly sorted sandy silts with a low liquefaction susceptibility in areas of relatively low wave energy (on the northern side of the delta), and moderately sorted silty sands with a moderate susceptibility for liquefaction in areas of higher wave energy (on the western side of the delta). Rates of net erosion and deposition are relatively small; locally, however, rates of shoreline progradation may be up to 50 m/year. In addition, some of the tidal flat areas are eroding at rates of up to 5 m/year.

The distributary mouth bars are typically middle-ground bars which form at the mouths of the major distributaries. They generally consist of moderately to well-sorted sand and silty sand with a relatively high susceptibility for liquefaction. They are dominantly prograding features, but some erosion may occur during storms or where adjacent to laterally meandering sub-ice channels.

The sub-ice channels are the offshore extensions of the major distributary channels, and are most common on the western margin of the delta. These subaqueous channels are typically 0.5 to 1 km wide and 5-15 m deep, and extend up to 20 km beyond the shoreline. The channels are presently actively transporting sediment (at least during parts of the year), as evidenced by the seaward-migrating sand waves up to 1 m high in the channels (D. Thor, USGS, pers. commun.). The presence of the well-sorted channel sands, combined with the relatively steep channel margins, results in a high potential for liquefaction. This is further substantiated by the abundance of liquefaction-induced deformation features observed in cores obtained from channel deposits by the RV Karluk (USGS cruise, 1978). The channels appear to be actively changing their course by a combination of lateral meandering and avulsion. Lateral rates of channel migration up to 50 m/year have been measured from bathymetric maps and Landsat imagery. Thus the potential exists for erosion of adjacent platform deposits to depths of 5-15 m (equal to the depth of the channels), perhaps during a single flood. Similarly, rapid sedimentation may be expected on the subaqueous point bar deposits.

The sub-ice platform has an extremely gentle slope (typically 1:1,000 or less) and shallow water depths (1-3 m) extending up to 30 km beyond the shoreline. The sub-ice platform on the western margin of the delta is dominated by the proximity of numerous sub-ice channels, hence subaqueous levee deposits are common. In contrast, the platform on the northern side of the delta appears to be characterized by more reworking of sediment, with undulatory ridges and troughs especially common near the outer edge of the platform.

Unlike most deltas, there is an offshore increase in the percentage of sand on the sub-ice platform (Appendix Fig. 7) due to the increased reworking of sediment on the outer edge of the platform. The liquefaction potential of these sands may not be as high as first expected, however, because much of the sand is relatively densely packed due to the higher wave energy on the outer platform. In contrast, the sandy levee deposits probably have a high potential for liquefaction. There is little net erosion or deposition on the platform, as it is largely an area of sediment erosion and bypass. The main exception is near sub-ice channels, where erosion can be both substantial and unpredicted.

The delta front is a term used here to describe the relatively steep (typically greater than 1:500) zone that fringes the delta in water depths of approximately 3-14 m. It is an area of relatively rapid deposition in the western portions of the delta due to the proximity of the major sub-ice channels which empty much of their sediment load on the delta front. Up to 6 m of sediment appears to have accumulated in this area during the last 80 years. Most of that deposition was as a series of storm-induced (?) sand layers typically 5-20 cm thick, thus the amount of deposition during any given event is probably relatively small. The northwestern margin of the delta front consists of a series of large (2-5 m high) shoals, locally up to 50 km long. These shoals appear to be migrating laterally into Norton Sound, resulting in a complex pattern of long-term erosion and sedimentation. The delta front along the northern margin of the delta appears to be eroding, with up to 4 m of sediment having been removed during the past 80 years. The amount of sediment removed during a single storm remains uncertain.

Most of the delta front along the western margin of the delta is in the zone of wave buildup and appears to consist of relatively well-sorted, fine-grained sand with a relatively high susceptibility for liquefaction. Similarly, the linear shoals consist of moderately well sorted sand with a relatively high susceptibility for liquefaction. The sediment characteristics of the delta front along the northern margin of the delta are less well known, hence their susceptibility for liquefaction remains uncertain.

The prodelta is characterized by extremely gentle slopes (typically 1:2,000) marking the distal edge of the deltaic sediments, which extend up to 100 km offshore. Sediment is initially deposited from suspension in this environment; however, water depths are still relatively shallow (10-20 m) hence much of the sediment is subsequently reworked. Evidence of such reworking is clearly demonstrated by the unusual pattern of textural parameters (Fig. 5). The southwestern margin of the prodelta sediments (adjacent to the largest distributaries) consists of well-sorted silty sand, grading northward to moderately sorted silty sand and eastward to poorly sorted sandy silt and silt.

The potential hazards due to sedimentation and/or erosion appear to be minimal in these deposits, as it seems unlikely that the resuspension of sediment occurs to any great depth. The liquefaction susceptibility of these sediments may be relatively high, particularly in the silty sands and sands of the western part of the prodelta. Because these sands are relatively thin (typically less than 2 m; Nelson and Creager 1977), however, they would probably have little effect on deep-seated structures. The silts in the northern part of the prodelta are thicker (up to 8 m), but they may be too poorly sorted to liquefy.

Sediment Dispersion Patterns

Most of the sediment introduced into Norton Sound is transported by the Yukon River during the summer, much during the relatively short interval of breakup. Some of the sediment is deposited in prograding tidal flats and distributary mouth bars along the coast, but most is transported offshore as bedload with the sub-ice channels and as suspended sediment within the sediment plume of the Yukon. Some of the sediment is deposited on the

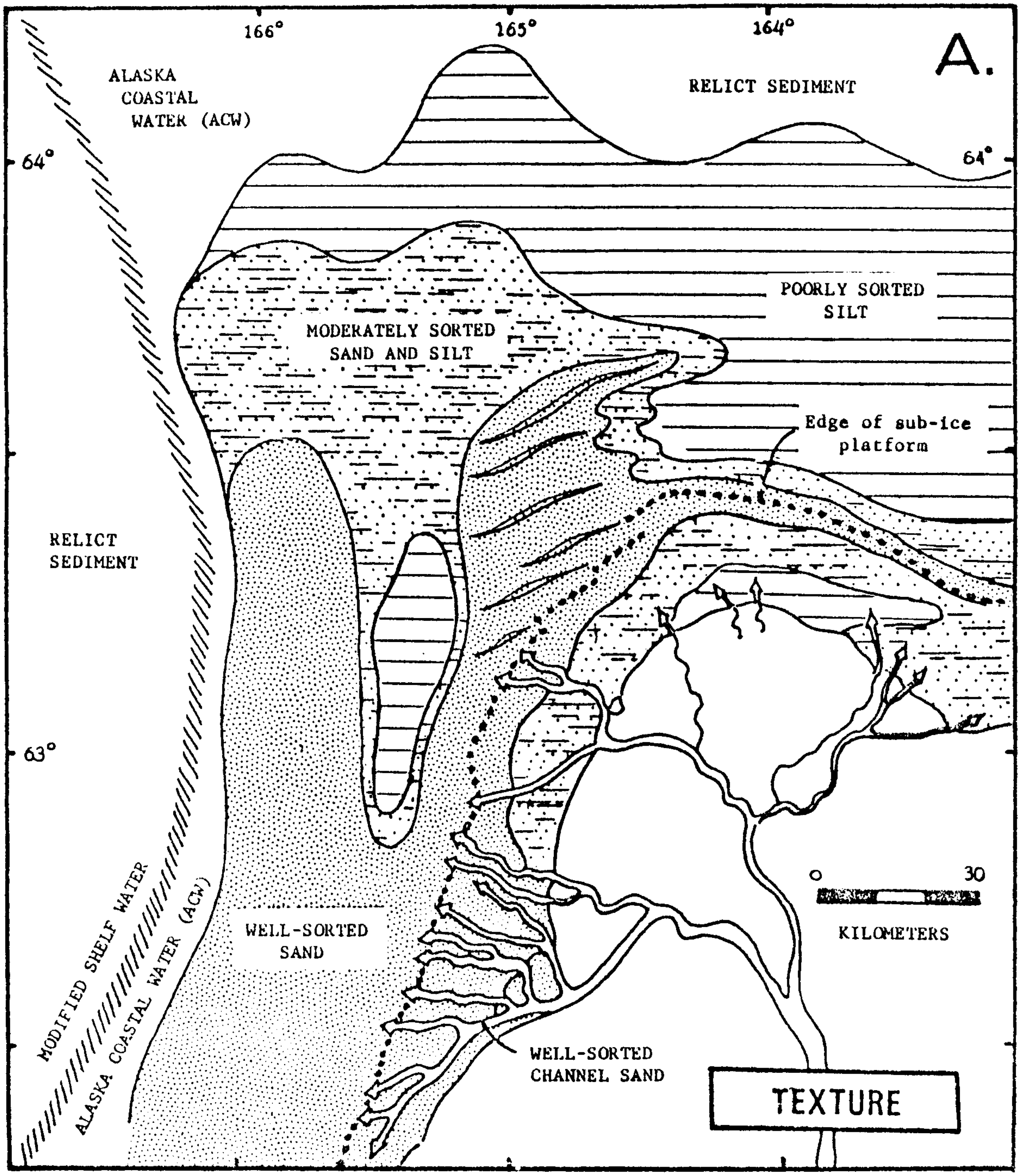


Figure 5A.--Schematic representation of sediment characteristics based on published data (McManus et al. 1977), unpublished data (C. Hans Nelson, U.S. Geological Survey), and extrapolation on the basis of offshore morphology.

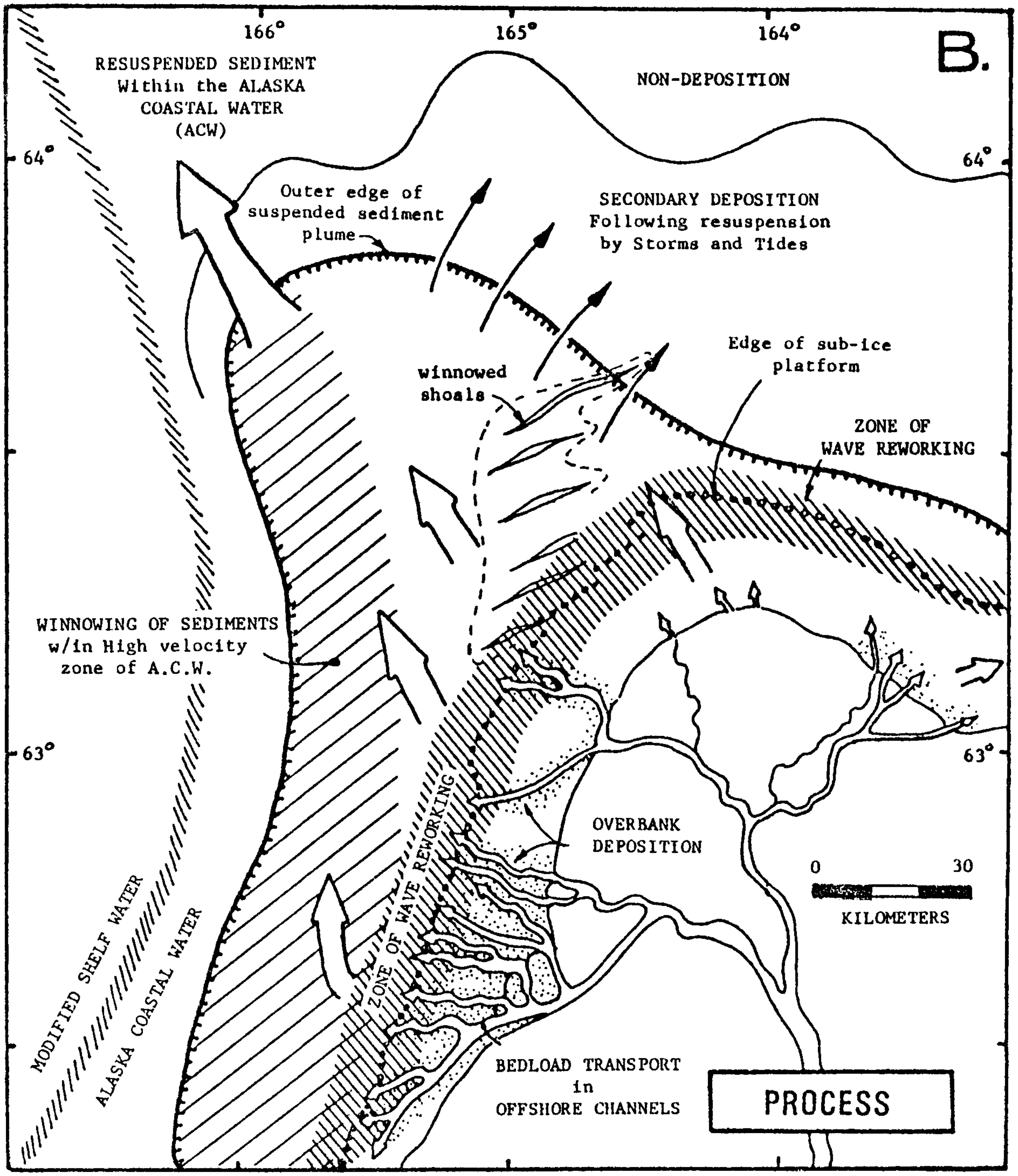


Figure 5B.--Hypothetical diagram of dominant processes, other than those related to ice, based on grain size data, Landsat imagery, and offshore bathymetry. Large arrows indicate direction of suspended sediment transport within the initial suspended sediment plume; smaller arrows indicate direction of resuspended sediment into Norton Sound.

subaqueous levees adjacent to the channels, but much of the bedload appears to be deposited up to 20 km beyond the shoreline at the delta front. In addition, the suspended sediment plume may extend up to 75 km offshore. Once the sediment is initially deposited it may be extensively reworked by a variety cf processes. The result (Fig. 5) is quite unlike the more typical graded shelf pattern where sediments become progressively finer grained and more poorly sorted offshore.

The sediment on the western portion of the sub-ice platform is typically coarser grained and better sorted than sediment to the northeast; this is due to the proximity of the main distributary channels and the longer fetch and greater wave energy on the western margin of the delta. The sediment on the outer edge of the sub-ice platform is better sorted than closer to the shore because of the reworking by waves, and perhaps accelerated sub-ice currents as well. The delta front is generally within the zone of wave buildup, hence consists largely of relatively well sorted sands reworked by wave-induced currents. Similarly, the linear shoals of the delta front consist of relatively well sorted sands which appear to be migrating to the northeast, perhaps due to storm-induced currents or a bifurcation of the Alaska Coastal Water. Sediment initially deposited from suspension on the western margin of the prodelta is periodically resuspended by a variety of processes (e.g., tides and storms) and reworked. Much of the sediment may remain within the Alaska Coastal Water to be ultimately deposited in the Chukchi Sea, up to 1,000 km to the northwest (McManus et al. 1977; Nelson and Creager 1977). In other cases, the resuspended sediment appears to be transported to the northeast, perhaps in response to storm-induced currents, to be deposited in the central part of Norton Sound.

The sediment supply into Norton Sound is virtually cut off during the winter due to the reduced flow of the Yukon River. Nevertheless, Drake et al. (1979) documented significant amounts of suspended sediment beneath the ice canopy. This implies that sediment is being resuspended during winter as well, although the exact processes and directions of sediment transport remain unclear.

In summary, the patterns of sediment dispersion in the Yukon Delta region of Norton Sound are complicated by the shallowness of the depositional basin, the extensive reworking of sediment, and the extreme seasonality of marine processes. This increases the necessity of obtaining much more information before it will be possible to make accurate predictive models of pollutant paths.

Ice Hazards in the Norton Sound-Yukon Delta Region

The patterns of ice formation, movement, and deformation in the Norton Sound region were studied with the use of Landsat and NOAA satellite imagery for the years 1973-77. The results document not only the marked seasonality of marine processes throughout the year, but also the significant role of bathymetric and meteorologic conditions in controlling the patterns and rates of ice movement in the region. The results have been summarized in a map of generalized ice hazards (Fig. 6), similar in many ways to the maps done for the entire Bering Sea by Stringer (1978). The following is a brief summary of the types of ice-related hazards that characterize each of the zones. The reader is referred to Ray and Dupré (1981) for a more detailed discussion of the ice-dominated regime of Norton Sound.

Zone Ia is a zone of shorefast ice that extends to the outer edge of the sub-ice platform of the Yukon Delta, approximately coincident with water depths of 2-3 m. Over-ice flow (aufeis) occurs throughout the winter in areas of bottomfast ice near the major distributaries (see hatching in Fig. 6). Sub-ice currents beneath the floating fast ice may result in some resuspension of sediments in the sub-ice channels and on the outer edge of the sub-ice platform. This is a relatively stable zone throughout the winter, but large sheets of ice may break off during spring breakup. Zone Ib is a slightly less stable area characterized by floating fast ice during most of the winter, but ice can be completely lacking and replaced by a large area of open water under some conditions (e.g., 13-15 March 1976). Zone Ic is the zone of shorefast ice that fringes most of Norton Sound. It is largely floating fast ice, and is more variable in extent and less stable, as large sheets of ice may break off repeatedly throughout the winter.

Zone IIa is a broad, seaward-accreting stamukhi zone formed by the convergence and deformation of ice formed mainly in Norton Sound. The configuration of the outer margin of this zone appears to be controlled by

Stuart Island to the east and a series of offshore shoals to the west; it is approximately coincident with the 14-m isobath. It is characterized by extensive ice shearing and a relatively high intensity of ice gouging of the sea floor (as delineated by Thor and Nelson 1979). Zone IIb is located west of the delta in water depths from 3 to 14 m. It is a relatively unstable area characterized by ice deformation and accretion to the shorefast ice (zone Ia) during periods of onshore (westerly) winds and an offshore movement of ice and the development of a large, open water area (polyna) during periods of offshore (easterly) winds. It is characterized by a moderately high intensity of ice gouging.

Zone III is an area of seasonal pack ice formed mainly in situ, within Norton Sound. The ice typically moves south and west in response to the predominant northeasterly winds throughout the winter, but it may drift slowly in response to oceanic currents during periods of low winds. The southern portion of this zone is characterized by widespread shearing of ice, and is approximately coincident with the area of very high density of ice gouging delineated by Thor and Nelson (1979). The western boundary is approximately coincident with the 20-m isobath, separating pack ice formed in Norton Sound from the thicker pack ice formed farther to the north. Pack ice from the Bering and Chukchi seas enters the sound only rarely, when especially strong northwesterly winds blow.

Zone IV consists of seasonal pack ice formed in the northern Bering and Chukchi seas. It typically moves to the south in response to northerly winds for most of the winter; however, short-lived periods of northerly ice movement can occur during the passage of low pressure systems. The ice typically begins to consistently move to the north in late April or early May. Zone IVa is the "racetrack," characterized by intervals of extremely rapid, southerly movement of pack ice (up to 45 km/day) following major ice deformation events north of Bering Strait (described by Shapiro and Burns 1975). This zone is characterized by highly fractured nilas ice during periods of relative quiescence. The eastern margin is approximately coincident with the 22-m isobath. The western margin is more variable, as it appears to be controlled by the geometry of ice piling up on the northern side of St. Lawrence Island. The rapid movement is evidence of the lack of grounded ice, as well as the lack of ice gouging (as delineated by Thor and

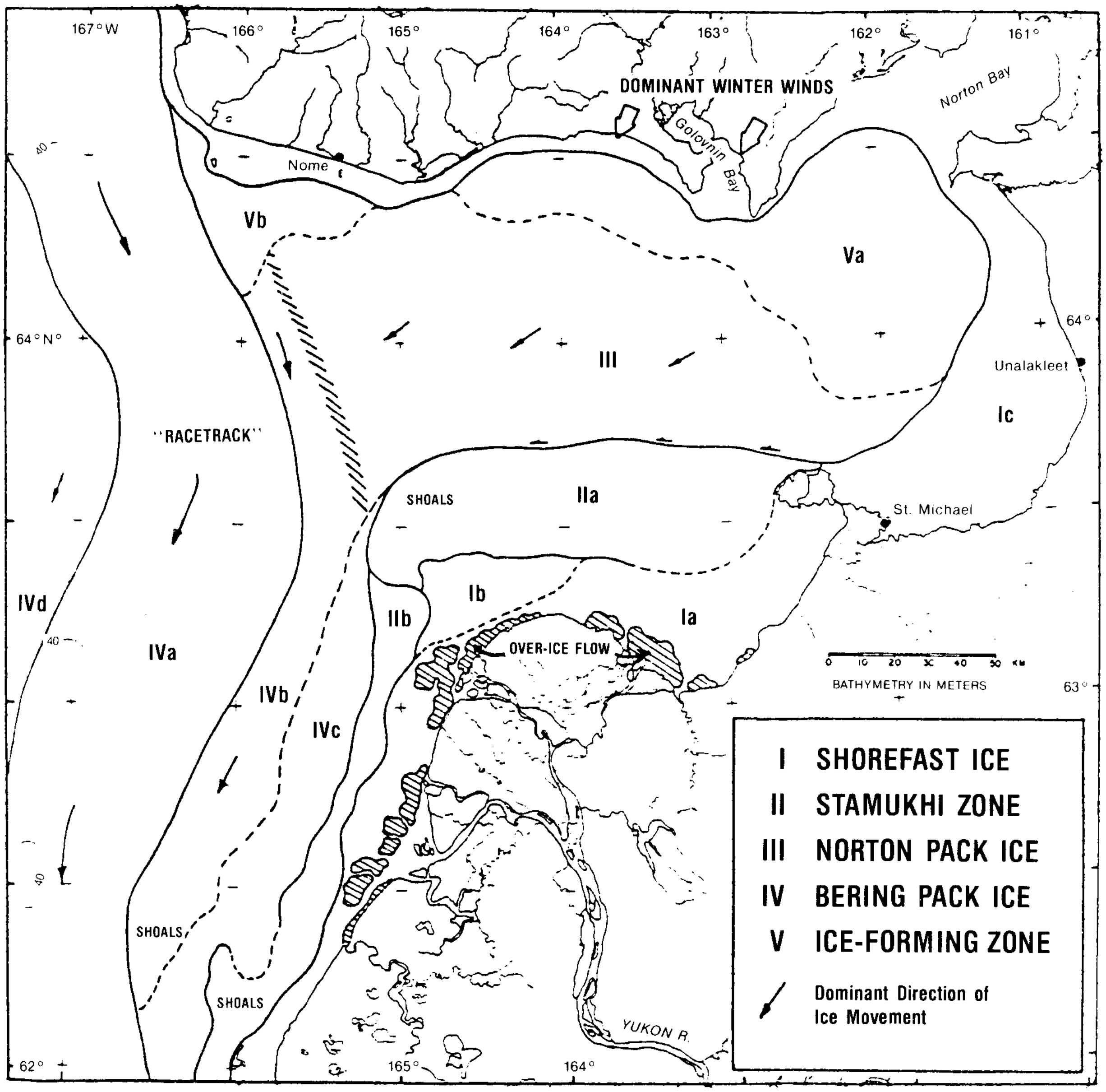


Figure 6.--Zonation of ice hazards in the Yukon Delta-Norton Sound region based mainly on Landsat and NOAA satellite imagery, supplemented by information on ice gouging by Thor and Nelson (1979).

Nelson 1979). Zone IVb is in water depths of 20 to 22 m, and is characterized by less rapid ice movement than in the racetrack. Some grounded ice may occur in this zone, particularly in the area of shoals southwest of the delta. Zone IVc is in water depths of 14 to 20 m, and is characterized by open water during periods of easterly winds, and by onshore moving pack ice during periods of westerly winds. It differs from zone IIb mainly by its mobility; i.e., it rarely forms a stamukhi zone accreted to the shorefast ice. Nonetheless, some grounded ice and ice gouging occur in this zone, as well. Zone IVd is similar to zone IVb, and was not studied in detail.

Zones Va and Vb are zones of ice divergence formed by persistent offshore winds (cf. Muench and Ahlnas 1976). These are typically areas of open water where ice is actively forming for most of the winter.

CONCLUSIONS

1. The Yukon-Kuskokwim Delta region is characterized by widespread evidence of Quaternary tectonism. Evidence of Holocene faulting, and the relatively high susceptibility for liquefaction of most of the fluvial and deltaic sediments, impose potentially serious geologic constraints on the selection of offshore sites and design of offshore structures. The risk from explosive volcanic activity, however, appears minimal.

2. Pleistocene sediments beneath most of Norton Sound contained thick, ice-bound permafrost that was actively forming as recently as 10,000 years ago; some may remain offshore as relict permafrost. Offshore permafrost in modern sediments is less likely and, if present, will be thin, discontinuous, and restricted to water depths less than 1 m.

3. The depositional environments of the Yukon Delta differ from most previously described deltas, mainly by the presence of a broad, shallow sub-ice platform and associated sub-ice channels. The potential for rapid erosion by these actively meandering subaqueous channels is especially serious, as is the relatively high susceptibility for liquefaction of much of the offshore sediments.

4. The shallowness of Norton Sound, combined with the marked seasonality of marine and fluvial processes, has resulted in a complex pattern of sediment resuspension and reworking. This makes the predicted paths of sediment (and pollutant) transport more complex than might be expected in deeper basins in more temperate climates.

5. Satellite imagery, used in combination with available weather data, has documented relatively systematic patterns of ice movement controlled largely by local winds and offshore bathymetry. This has allowed the subdivision of the Norton Sound region into zones, each characterized by a particular type of ice and ice movement.

IMPLICATIONS AND RECOMMENDATIONS FOR FUTURE STUDY

Implications

The selection of offshore sites and the design of offshore structures must take into account the potentially high seismic risk based on the evidence of nearby Holocene faulting. In addition, the possibility for seismically induced and wave-induced liquefaction is relatively high for much of the Norton Sound region underlain by well-sorted deltaic sediments. Other potential geohazards include rapid erosion and sedimentation associated with sub-ice channels, the mobility and deformation of seasonal pack ice, the extent and variability of shorefast ice, and the possibility of offshore permafrost beneath part of Norton Sound. Lastly, predicting the paths of sediment and/or pollutants is complicated by the seasonal variability of coastal processes and the shallowness of the depositional basin, which cause extensive reworking and redistribution of sediment.

Recommendations for Future Study

Many of the potential geologic hazards which must be considered in the course of developing Norton Basin relate to the Quaternary deposits and the processes by which they formed (including those active today). Some of the problems require substantial additional study. They include the following:

1) LIQUEFACTION

Most of the sediments on the delta margin and delta front consist of well-sorted sands and silts which may have a high potential for liquefaction. These sediments commonly occur in the sub-ice channels, the outer edge of the sub-ice platform, and on the delta front in the western part of the delta. This is based not only on grain size analyses, but also on the abundance of liquefaction-induced deformation features noted in cores from the Karluk, particularly where sub-ice channel facies were cored.

Recommendation: Look at the relationship between the potential for liquefaction as a function of depositional environment, emphasizing the correlation between grain size, liquefaction-induced features, and environment. If the correlation exists (and I believe strongly that it does), spend more effort in obtaining more information on the geotechnical properties of sediments in the various environments and a more detailed map of the distribution of the depositional environments (noting well the distribution of the sub-ice channel and delta front facies, as well as the thickness of the Holocene sediments).

2) SUB-ICE CHANNELS

These channels appear to be restricted to ice-dominated deltas, hence they may present some unexpected problems. They are actively meandering, with erosion on the cut banks and deposition on the subaqueous point bars. The channels are up to 0.5 km wide and up to 10 m deep, and appear to be areas of active sediment transport as well, with sand waves up to 1 m high locally. There is, therefore, potential for scour and fill in these channels, especially during spring breakup.

Recommendation: Compile existing Landsat and bathymetric data on the geometry and distribution of these channels, including any evidence on the rates of channel migration by comparing the old maps with the newer data. Consider in situ monitoring before, during, and after breakup to determine the amount of scour and fill that might occur (alternatively, obtain vibracores in the channels to determine the thickness of the channel fill deposits, which should approximate the depth of scour during flooding). Also consider in situ monitoring of currents in the channels during storms and under the ice, as they may serve as conduits for return flows resulting in flushing of sediments.

3) DELTA FRONT

The delta front is a relatively steeply dipping area from water depths of 3 to 15 m, which appears to be an area of relatively active deposition in the western part of the delta, near the mouths of the major distributaries. It appears to be an area of erosion, however, on the northern parts of the delta, judging from preliminary comparisons of 1899 bathymetry with data collected from the RV *Karluk* (USGS cruise, 1978). In addition, the northwestern part of the delta front appears to consist of a series of migrating linear shoals, with resulting complicated patterns of erosion and deposition. This is also an area where liquefaction-induced slope failures are likely to occur.

Recommendation: Make a detailed comparison of the pre-1978 bathymetry with that collected by the RV *Karluk* to determine the direction and rates of movement. If the rates are such as to represent potential hazards, more detailed bathymetric data should be collected (this is probably necessary in any case, as the existing data are quite insufficient). In addition, obtain side-scan data on the delta front, looking for evidence of liquefaction-induced slump features, and vibracores to determine the geotechnical properties of the sediments.

4) OFFSHORE PERMAFROST

There is abundant evidence that much (most?) of Norton Sound was underlain by thick, ice-bound permafrost that was actively forming as recently as 10,000 years ago. Thus a very real possibility exists for the presence of relict ice-bound permafrost underlying parts of Norton Sound today.

Recommendation: Delineate the distribution of Holocene and Pleistocene deposits beneath Norton Sound, perhaps with the use of high-resolution seismic profiling, coupled with test drilling to determine the geotechnical properties of the sediments, including the presence, if any, of relict, ice-bound permafrost.

5) SEASONAL VARIABILITY OF MARINE PROCESSES

It has become increasingly apparent that the processes of sediment transport and deposition (and resuspension) are far more complex than previously thought. The extreme seasonality of processes, including those associated with river influx, wind and waves, oceanic and tidal currents, and ice must be studied in more detail if predictive models of sediment (and pollutant) transport are to be properly developed.

Recommendation: Fund a series of coordinated, interdisciplinary studies of in situ monitoring of processes during several periods of the year. Such a program could be patterned as follows:

a) Winter-dominated period: This would include both laboratory studies of weather patterns and ice movement as detectable on satellite imagery, and field studies to measure ice thickness and patterns of ice movement and deformation, as well as sub-ice processes such as oceanic currents and tides in a variety of environments such as sub-ice channels, the delta front, and prodelta.

b) Breakup: This period is of extreme importance in establishing and maintaining many of the environments which appear unique to ice-dominated coastal zones. In situ monitoring of currents and sediment transport on top of the fast ice and below the ice canopy, both in sub-ice channels and in the sub-ice platform, would be necessary.

c) River-dominated period: This period is dominated by the high sediment discharge of the Yukon. Studies emphasizing the pattern of sedimentation during this time would be extremely useful. Offshore wave and current meters would be installed.

d) Storm-dominated period: Late summer-early fall is a period dominated by the combined effects of decreasing sediment input and increasing storm frequency (hence sediment reworking). In situ monitoring of offshore processes is particularly important during this period.

e) Freeze-up: It would also be useful to study the processes by which the shorefast ice forms and expands over the sub-ice platform and associated channels. This would require in situ monitoring from late October to early November.

BIBLIOGRAPHY

Barnes, P. W., and E. Reimnitz. 1973. The shorefast ice cover and its influence on the currents and sediment along the coast of northern Alaska. Am. Geophys. Union, EOS Transactions 54:1108. (Abstract)

Beikman, H. M. 1974. Preliminary geologic map of the southwest quadrant of Alaska. USGS Open File Map (2 sheets).

Carey, S. W.. 1958. A tectonic approach to continental drift. Pages 177-355 in Continental Drift. University of Tasmania.

Creager, T. S., and D. A. McManus. 1967. Geology of the floor of Bering and Chukchi seas - American studies. Pages 32-46 in D. M. Hopkins (ed.), The Bering Land Bridge. Stanford University Press, CA.

Drake, D. E., C. E. Totman, and P. L. Wiberg. 1979. Sediment transport during the winter on the Yukon prodelta, Norton Sound, Alaska. J. Sediment. Petrol. 49:1171-1180.

Fisher, W. L., et al. 1969. Delta Systems in the Exploration for Oil and Gas: A Research Colloquium. Bureau of Economic Geology, Univ. Texas, Austin.

Galloway, W. E. 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. Pages 87-98 in M. L. Broussard (ed.), Deltas: Models for Exploration. Houston Geol. Society.

Grim, M. S., and D. A. McManus. 1970. A shallow-water seismic-profiling survey of the northern Bering Sea. Mar. Geol. 8:293-320.

Hamilton, T. D., and S. C. Porter. 1975. Itkillik glaciation in the Brooks Range, Northern Alaska. Quat. Res. (N.Y.) 5:471-497.

Hayes, M. O. 1975. Morphology of sand accumulation in estuaries. Pages 3-22 in L. E. Cronin (ed.), Estuarine Research. Vol. II, Geology and Engineering. Academic Press, New York.

Hill, D. E., and J. C. F. Tedrow. 1961. Weathering and soil formation in the arctic environment. Am. J. Sci. 259:84-101.

Hoare, J. M. 1961. Geology and tectonic setting of lower Kuskokwim-Bristol Bay region, Alaska. Bull. Am. Assoc. Pet. Geol. 45:594-611.

Hoare, J. M., and W. H. Condon. 1966. Geologic map of the Kwiguk and Black Quadrangles, western Alaska. USGS Misc. Geol. Investig. Map I-469.

Hoare, J. M., and W. H. Condon. 1968. Geologic map of the Hooper Bay Quadrangle, Alaska. USGS Misc. Geol. Investig. Map. I-523.

Hoare, J. M., and W. H. Condon. 1971a. Geologic map of the St. Michael Quadrangle, Alaska. USGS Misc. Geol. Investig. Map I-682.

Hoare, J. M., and W. H. Condon. 1971b. Geologic map of the Marshall Quadrangle, western Alaska. USGS Misc. Geol. Investig. Map I-668.

Hoare, J. M., and W. L. Coonrad. 1959a. Geology of the Bethel Quadrangle, Alaska. USGS Misc. Geol. Investig. Map I-285.

Hoare, J. M., and W. L. Coonrad. 1959a. Geology of the Russian Mission Quadrangle, Alaska. USGS Misc. Geol. Investig. Map I-292.

Hopkins, D. M. 1978. Offshore permafrost studies, Beaufort Sea, Alaska. U.S. Dep. Commer., NOAA/OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Q. Rep. April-June:253-261.

Inman, D. L., and C. E. Nordstrom. 1971. On the tectonic and morphologic classification of coasts. J. Geol. 79:1-21.

Knebel, H. J., and J. S. Creager. 1973. Yukon River: evidence for extensive migration during the Holocene Transgression. Science 79:1230-1231.

Lisitsyn, A. P. 1966. Recent sedimentation in the Bering Sea. U.S.S.R. Acad. Sci. Inst. Oceanography. (Translated from Russian by Israel Prog. Sci. Transl, 1969, 614 pp.)

MacKay, J. R. 1971. The origin of massive icy beds in permafrost, western Arctic coast, Canada. Can. J. Earth Sci. 8(4):397-422.

Marlow, M. S., et al. 1976. Structure and evolution of Bering Sea shelf south of St. Lawrence Island. Am. Assoc. Pet. Geol. 60:161-183.

Matthews, M. D. 1973. Flocculation as exemplified in the turbidity maximum of Acharon Channel, Yukon River delta, Alaska. Ph.D. thesis, Northwestern Univ., 88 pp.

McManus, D. A., K. Venkatarathnam, D. M. Hopkins, and C. H. Nelson. 1974. Yukon River sediment on the northernmost Bering Sea shelf. J. Sed. Petrol. 44:1052-1060.

McManus, D. A., V. Kolla, D. M. Hopkins, and C. H. Nelson. 1977. Distribution of bottom sediments on the continental shelf, northern Bering Sea. U.S. Geol. Surv. Prof. Pap. 759-C, 31 pp.

Moore, D. G. 1964. Acoustic reflection reconnaissance of continental shelves: eastern Bering and Chukchi seas. Pages 319-362 in R. L. Moore (ed.), Papers in Marine Geology. MacMillan Co., New York.

Muench, R. D., and K. Ahlnas. 1976. Ice movement and distribution in the Bering Sea from March to June, 1974. J. Geophys. Res. 81(24): 4467-4476.

Nelson, C. H. 1978. Faulting, sediment instability, erosion, and depositional hazards of the Norton Basin seafloor. U.S. Dep. Commer., NOAA/OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annu. Rep. Year Ending March 1978, 12:187-429.

Nelson, C. H., and J. S. Creager. 1977. Displacement of Yukon-derived sediment from Bering Sea to Chukchi Sea during Holocene time. Geology 5:141-146.

Nelson, C. H., D. M. Hopkins, and D. W. Scholl. 1974. Cenozoic sedimentary and tectonic history of the Bering Sea. Pages 485-516 in D. W. Hood and E. J. Kelley (eds.), Oceanography of the Bering Sea. Inst. Mar. Sci., Univ. Alaska, Fairbanks, Occas. Publ. 2.

Patton, W. W., Jr. 1973. Reconnaissance geology of the northern Yukon-Koyukuk Province, Alaska. U.S. Geol. Surv. Prof. Pap. 774-A, 17 pp.

Patton, W. W., Jr., and J. M. Hoare. 1968. The Kaltag fault, west-central Alaska. U.S. Geol. Surv. Prof. Pap. 600-D:D147-D153.

Péwé, T. L. 1948. Terraine and permafrost of the Galena Air Base, Galena, Alaska. U.S. Geol. Surv. Permafrost Prog. Rep. 7, 52 pp.

Péwé, T. L. 1975. Quaternary geology of Alaska. U.S. Geol. Surv. Prof. Pap. 835, 145 pp.

Ray, V. M., and W. R. Dupré. 1981. Pages 263-278 in D. W. Hood and J. A. Calder (eds.). The Eastern Bering Sea Shelf: Oceanography and Resources. Vol. 1. U.S. Dep. Commer., NOAA, Off. Mar. Pollut. Assess., Juneau, Alaska.

Reed, J. C., and J. E. Sater (eds.). 1974. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America, Alexandria, VA. 750 pp.

Reimnitz, E., and P. Barnes. 1974. Sea ice as a geologic agent on the Beaufort Sea shelf of Alaska. Pages 301-353 in J. C. Reed and J. E. Sater (eds.), The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America, Alexandria, VA.

Reimnitz, E., and K. F. Bruder. 1972. River discharge into an ice-covered ocean and related sediment dispersal, Beaufort Sea, coast of Alaska. Bull. Geol. Soc. Am. 83:861-866.

Reimnitz, E., L. J. Toimil, and P. W. Barnes. 1977. Stamukhi zone processes: implications for developing the Arctic coast. Pages 513-518 in Proceedings of the Offshore Technology Conference, May 2-5, 1977. OTC Paper 2945.

Scholl, D. W., E. C. Buffington, and D. M. Hopkins. 1968. Geologic history of the continental margin of North America in the Bering Sea. Mar. Geol. 6:297-330.

Scholl, D. W., and D. M. Hopkins. 1969. Newly discovered Cenozoic basins, Bering Sea shelf, Alaska. Bull. Am. Assoc. Pet. Geol. 53:2067-2078.

Shapiro, L. H., and J. J. Burns. 1975. Satellite observations of sea ice movement in the Bering Strait regions. Pages 379-386 in Weller and S. A. Bowling (eds.), Climate of the Arctic. Geophys. Inst., Univ. Alaska, Fairbanks.

Shepard, F. P., and H. R. Wanless. 1971. Our Changing Coastlines. McGraw Hill, New York. 579 pp.

Smith, M. W. 1976. Permafrost in the Mackenzie Delta, Northwest Territories. Geol. Surv. Can. Pap. 75-28, 34 pp.

Stringer, W. J. 1978. Morphology of Beaufort, Chukchi and Bering seas nearshore ice conditions by means of satellite and aerial remote sensing. U.S. Dep. Commer., NOAA/OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Rep., Phys. Stud. 2. 376 pp.

Taber, S. 1943. Perennially frozen ground in Alaska; its origin and history. Bull. Geol. Soc. Am. 54:1433-1548.

Thor, D. R., and C. H. Nelson. 1979. A summary of interacting, surficial geologic processes and potential geologic hazards in the Norton Basin, northern Bering Sea. Pages 377-385 in Proceedings of the 11th Annual Offshore Technology Conference. OTC paper 3400.

Toimil, L. J. 1977. Morphologic character of the "2 meter bench," Colville River delta. In P. W. Barnes and E. Reimnitz (eds.), Geologic Processes and Hazards of the Beaufort Sea Shelf and Coastal Regions. U.S. Dep. Commer., NOAA/OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Q. Rep. October-December 1977.

Walker, H. J. 1973. The nature of the seawater-freshwater interface during breakup in the Colville River delta, Alaska. Pages 473-476 in Permafrost: The North American Contribution to the Second International Conference. Natl. Acad. Sci., Washington, DC.

Williams, J. R. 1970. Groundwater in the permafrost regions of Alaska. U.S. Geol. Surv. Prof. Pap. 696, 83 pp.

Wright, L. D., and J. M. Coleman. 1973. Variations in morphology of major river deltas as functions of ocean wave and river discharge regimes. Bull. Am. Assoc. Pet. Geol. 57:370-398.

APPENDIX

THE YUKON DELTA: A MODEL FOR DELTAIC SEDIMENTATION IN AN ICE-DOMINATED ENVIRONMENT

THE YUKON DELTA: A MODEL FOR DELTAIC SEDIMENTATION IN AN ICE-DOMINATED ENVIRONMENT

W. R. Dupré and R. Thompson
University of Houston

This paper was presented at the 11th Annual Offshore Technology Conference in Houston, Texas, 30 April-3 May 1979 (OTC Paper 3434).

ABSTRACT

Field mapping in the Yukon Delta region of western Alaska, combined with laboratory analysis of sediment and Landsat imagery, has provided insights into the role of climate and tectonics on deltaic processes on high-latitude continental shelves. The climatic and tectonic influences on sediment type, in combination with the role of river and sea ice in controlling patterns of sediment transport and deposition, suggest that the Yukon Delta may provide a model for deltaic sedimentation in an ice-dominated environment.

The combination of an arctic and subarctic climate and extensive Cenozoic tectonism has resulted in the production of a mineralogically immature suite of silts and sands (typically feldspathic litharenites) with a relative paucity of clays. The textural and mineralogical composition of these sediments will, in turn, influence their geotechnical properties as well as post-depositional compaction and diagenetic effects.

The processes of sediment transport and deposition in the Yukon Delta vary systematically throughout the year. There exists an ice-dominated, river-dominated, and storm-dominated regimen, each consisting of a characteristic set of processes. These processes can constitute geologic hazards which vary with season and depositional environment, thereby significantly affecting the siting of offshore facilities.

The geometry of the delta and its various depositional environments is strongly influenced by the effects of sea ice. A comparison of the sub-aqueous profile of the Yukon Delta with those of previously described wave- and river-dominated deltas reveals a broad "sub-ice platform" typically less than 2 m deep and up to 30 km wide separating the intertidal deposits from the prograding delta front. This platform, as well as associated "sub-ice channels" which extend tens of kilometers offshore from the major distributaries, constitute major differences with previously described deltas. Thus, the Yukon may represent a distinct class of ice-dominated delta, similar in many respects to deltas presently forming in the Arctic. Failure to recognize the unique characteristics of ice-dominated deltas can result in serious errors in the estimation of the reservoir potential of deltaic sediments deposited under similar climatic conditions.

INTRODUCTION

The prospect of oil and gas exploration in Norton Sound (Fig. 1) has focused increased attention on the Yukon Delta, both as an area that might be significantly affected by such development, and as a possible analogue for older, Yukon-derived deltaic sediment which might serve as possible reservoir rocks in Norton Basin. Preliminary studies demonstrate that the depositional environments and related processes associated with the Yukon Delta differ markedly from those of most previously described deltas. The purpose of this paper is to describe these environments and processes, as they may provide a possible model for a newly defined class of ice-dominated deltas. Parts of the model are speculative; however, it may provide a basis for future discussion on the role of ice in deltaic sedimentation on high-latitude continental shelves.

METHODS

Field work during the summers of 1975 through 1978, and interpretation of bathymetric and topographic maps, aerial photographs, and Landsat imagery, have provided an overview of the major depositional environments of the Yukon Delta as well as processes which characterize each environment. Sediment from most of the depositional environments was analyzed using the Rice University Automated Sediment Analyzer. This system uses a large settling tube to analyze the sand, a smaller settling tube to analyze the coarse silt, and a hydrophotometer to analyze the fine silt and clay. Additional grain size information was also available for a limited number of samples from the delta front and prodelta environments (McManus et al. 1977) and from a large, sub-ice channel (Matthews 1973). X-ray photographs of numerous cores were examined to provide additional information on sedimentary structures and bioturbation, particularly in intertidal deposits. In addition, point counts were made of grain mounts of sand collected from a variety of environments to determine the effects of provenance and climate on the composition of the sediment.

GEOLOGIC SETTING

The Yukon River drains an area of approximately 855,00 km^2, providing a water discharge of approximately 6,220 m^3/sec and a sediment load of approximately 88 million tons/year, representing almost 90% of the total sediment presently entering the Bering Sea (Lisitsyn 1972). The source area is a region of continuous to discontinuous permafrost dominated by mechanical weathering (including the effects of glaciation). The result of such weathering processes should be a sediment high in silt and with a relative paucity of clays (e.g., Taber 1943; Hill and Tedrow 1961), and this is confirmed by size analysis of Yukon sediments (Fig. 2). The source area has a complex history of Cenozoic tectonism, which, in combination with the relative lack of chemical weathering, has resulted in the production of a compositionally immature suite of sands (typically feldspathic litharenites). Thus both the texture and composition of the sediments strongly reflect the climatic and tectonic setting of the drainage basin.

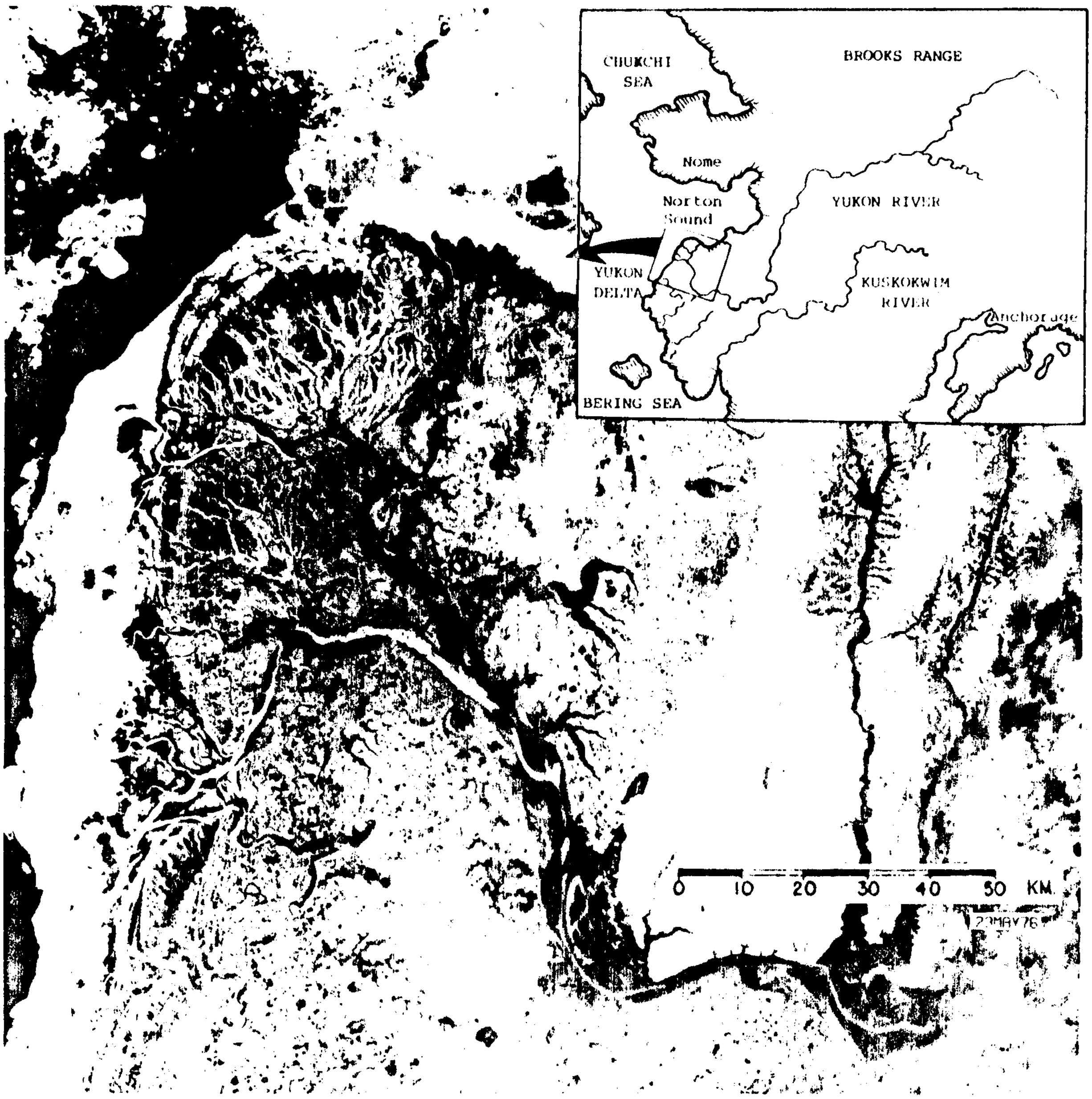


Figure 1.--Location map and Landsat image of the modern lobe of the Yukon Delta taken during breakup.

The modern delta of the Yukon River is a relatively young geologic feature, having formed since approximately 2,500 years ago, when the river course shifted to where it presently enters Norton Sound (Dupré 1978). Norton Sound is a broad re-entrant of the northern Bering Sea, characterized by low rates of tectonic subsidence and extremely shallow water depths (generally less than 20 m). The shallowness of the depositional basin has allowed extensive reworking of the deltaic sediments by a variety of processes, including waves, wind- and tide-induced currents, and oceanic currents, as well as processes associated with ice movement. The relative importance of these processes varies systematically throughout the year, allowing the definition of ice-dominated, river-dominated, and storm-dominated regimens (Fig. 3).

SEASONALITY OF COASTAL PROCESSES

The ice-dominated regimen begins with freeze-up along the coast in late October or November. Shorefast ice extends from 10 to 30 km offshore, where it is terminated by a series of pressure ridges and shear ridges (stamukhi zone of Reimnitz et al. 1977) formed by the interaction of the shorefast ice with the highly mobile, seasonal pack ice (Fig. 4A). This typically occurs in water depths of 5 to 10 m, and is an area of intense ice gouging. Gouging may result in the resuspension of sediment, which is then available for reworking and redistribution by relatively weak, sub-ice currents, some of which may be induced by vertical movement of the floating fast ice (Barnes and Reimnitz 1973).

River breakup typically occurs in late May, marking the beginning of the river-dominated regimen. During breakup, much of the sediment bypasses the nearshore zone by a combination of over-ice flow and sub-ice flow through a series of channels which extend up to 30 km offshore (Fig. 4B). Once the shorefast ice melts or drifts offshore, sedimentation is dominated by normal deltaic processes under the influence of the high discharge of the Yukon River. The dominant northeasterly winds are usually weak and blow over a relatively limited fetch, hence the wave energy along the coast is generally low during this time of year.

Increasingly frequent southwesterly winds and waves associated with major storms during the late summer mark the beginning of the storm-dominated regimen. The relatively long fetch and high winds result in high wave energy particularly on the western side of the delta. High wave energy and rapidly decreasing sediment discharge from the Yukon result in significant coastal erosion and reworking of deltaic deposits in the late summer. This continues until freeze-up when ice-related processes regain their dominance.

The northwesterly flowing Alaska Coastal Water impinges on the western side of the delta throughout the year, although there are large seasonal variations in its lateral extent (Coachman et al. 1975). High flow velocities in the Alaska Coastal Water appear responsible for a large amount of fine-grained sediment bypassing Norton Sound for final deposition in the Chukchi Sea, 500-1,000 km to the northwest (Nelson and Creager 1977). Similarly, tides with a range of 1-1.5 m and tidally induced currents are

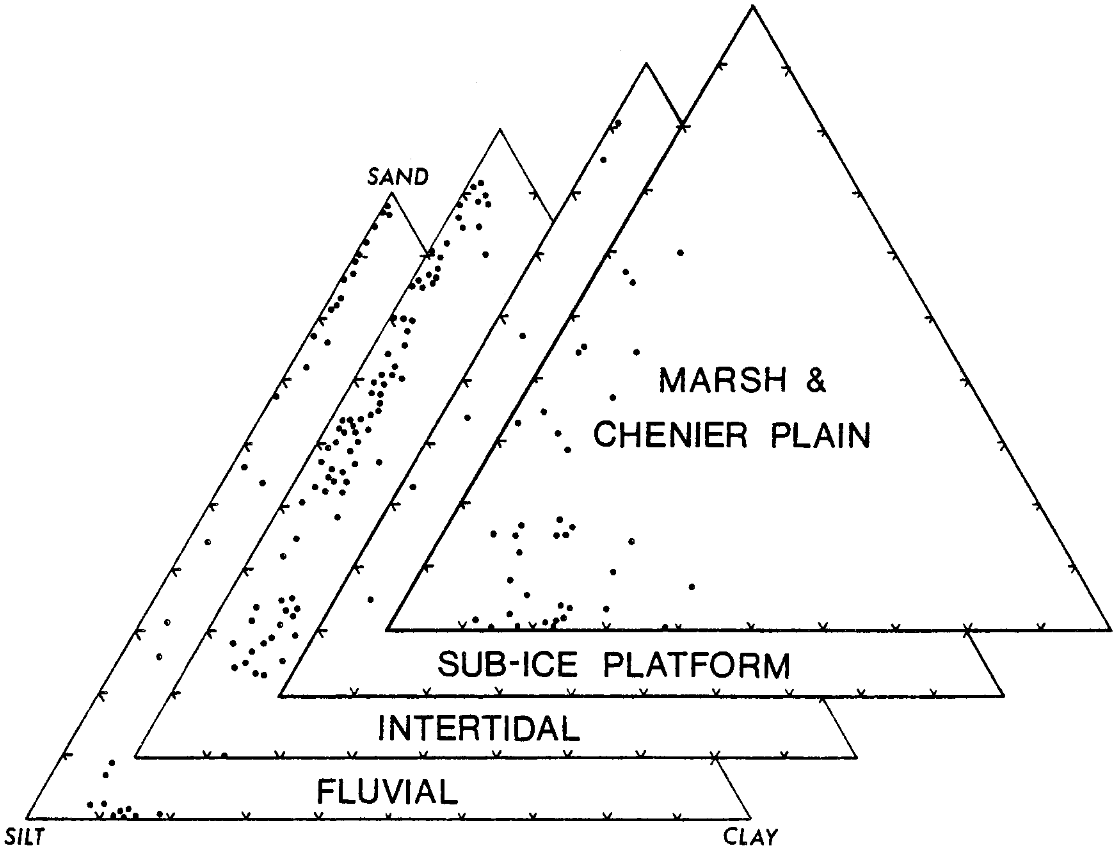


Figure 2. Grain size characteristics of sediments from the delta plain and delta margin of the Yukon Delta.

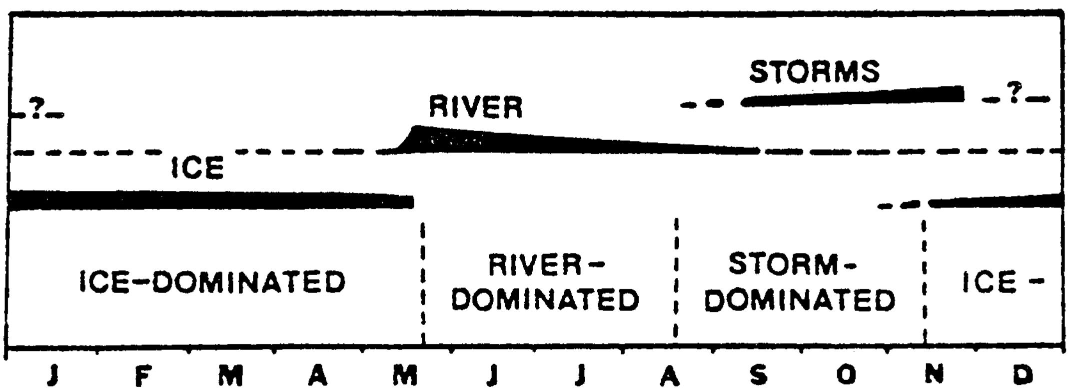


Figure 3.--Seasonal variability of coastal processes in the Yukon Delta region of Norton Sound.

active throughout the year, but their significance remains unclear. It seems likely that both the flow within the Alaska Coastal Water and the tidally induced currents are most important in transporting sediment resuspended by other processes (e.g., storm waves, ice gouging).

DEPOSITIONAL ENVIRONMENTS

The subaerial morphology of the Yukon Delta is similar to lobate, high-constructional deltas described by Fisher and others (1969) as typical of bedload-dominated rivers emptying into shallow depositional basins. This is consistent with the geologic setting of the Yukon Delta. However, a more careful examination of the subaqueous morphology suggests that such a classification fails to recognize some of the unique aspects of the Yukon Delta.

The delta plain is fringed by prograding tidal flats and distributary mouth bars, similar to many previously described deltas. The Yukon Delta is unusual, however, in that the delta front and prodelta are offset from the prograding shoreline by a broad platform (here referred to as a sub-ice platform), locally up to 30 km wide. The result is a subaqueous profile (Fig. 5) quite unlike those of wave- and river-dominated deltas described by Wright and Coleman (1973).

The broad platform (and associated subaqueous channels) appears related to the presence of shorefast ice which fringes the delta for almost half the year. Several workers (e.g. Reimnitz and Bruder 1972; Reimnitz and Barnes 1974; Walker 1974) note that patterns of nearshore and sedimentation along the north slope of Alaska are strongly influenced by the presence of shorefast ice. Naidu and Mowatt (1975) suggest that this is unique to deltas formed by polar rivers in the Arctic. We believe that these smaller arctic deltas, as well as larger deltas such as the Yukon, Mackenzie, and Lena, actually represent a separate type of ice-dominated delta, morphologically distinct from the wave-, river-, and tide-dominated deltas previously described in the literature (e.g., Galloway 1975). The Yukon Delta may provide a model for such an ice-dominated delta (Fig. 6).

The delta plain contains a complex assemblage of active and abandoned distributaries, levees, interdistributary marshes, and lakes. The active distributaries have low to moderate sinuosity. The river has two main distributaries (1.5 km wide and 10-15 m deep), and numerous smaller distributaries (some as small as 20 m wide and 2-5 m deep) typically spaced every 1-2 km along the coast. Point bars and midchannel bars are common, particularly along the larger distributaries. Channel and bar deposits are typically composed of moderately to well sorted sand and silty sand, grading upwards and laterally into organic-rich, poorly sorted silt and mud deposited on natural levees and in meander swales.

The distributaries frequently shift their course via channel avulsion, often precipitated by ice jams resulting in the deposition of an abandoned channel fill typically consisting of organic-rich sandy silt and silt. Abandoned channels are highly prone to flooding and are frequently reoccupied by distributaries, resulting in a complex delta stratigraphy.

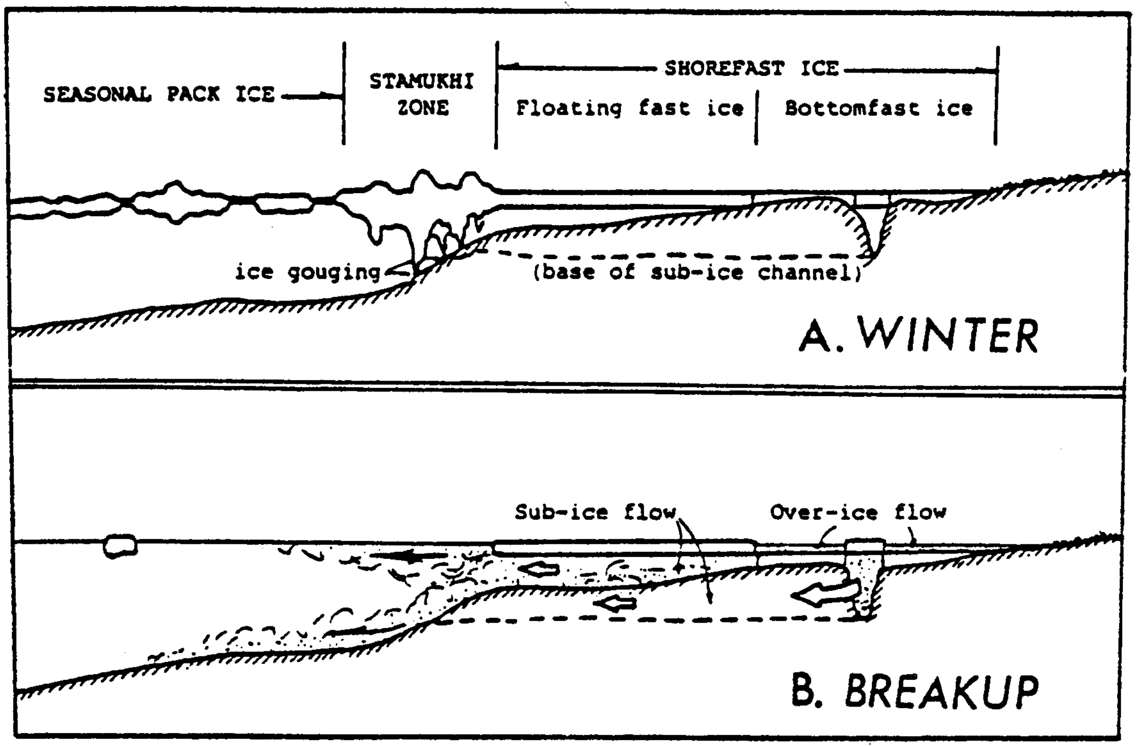


Figure 4.--Ice zonation in the winter (A) and its effect on sediment dispersion during breakup (B).

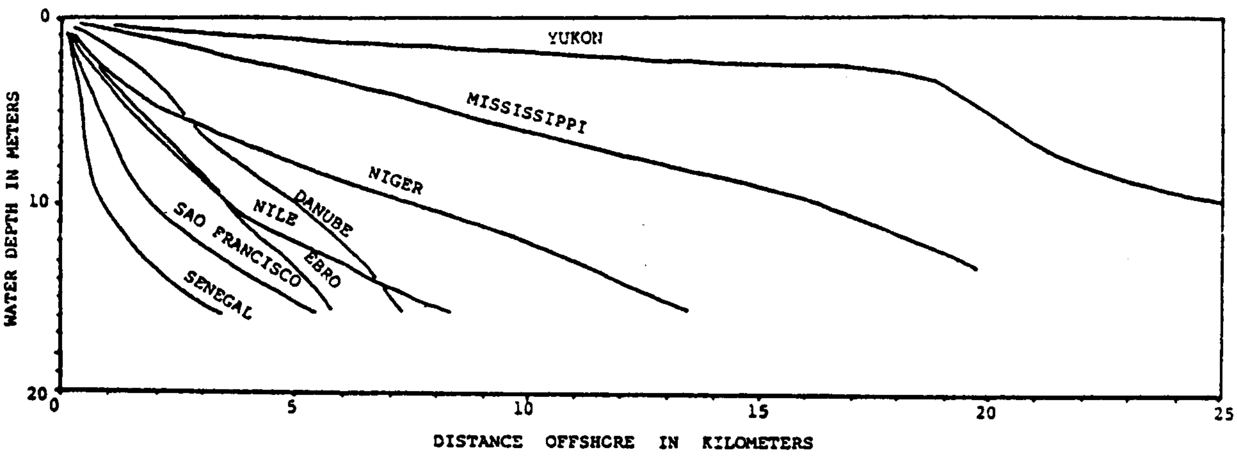


Figure 5.--Comparison of the subaqueous profiles of wave- and river-dominated deltas (Wright and Coleman 1973) with that of the Yukon Delta.

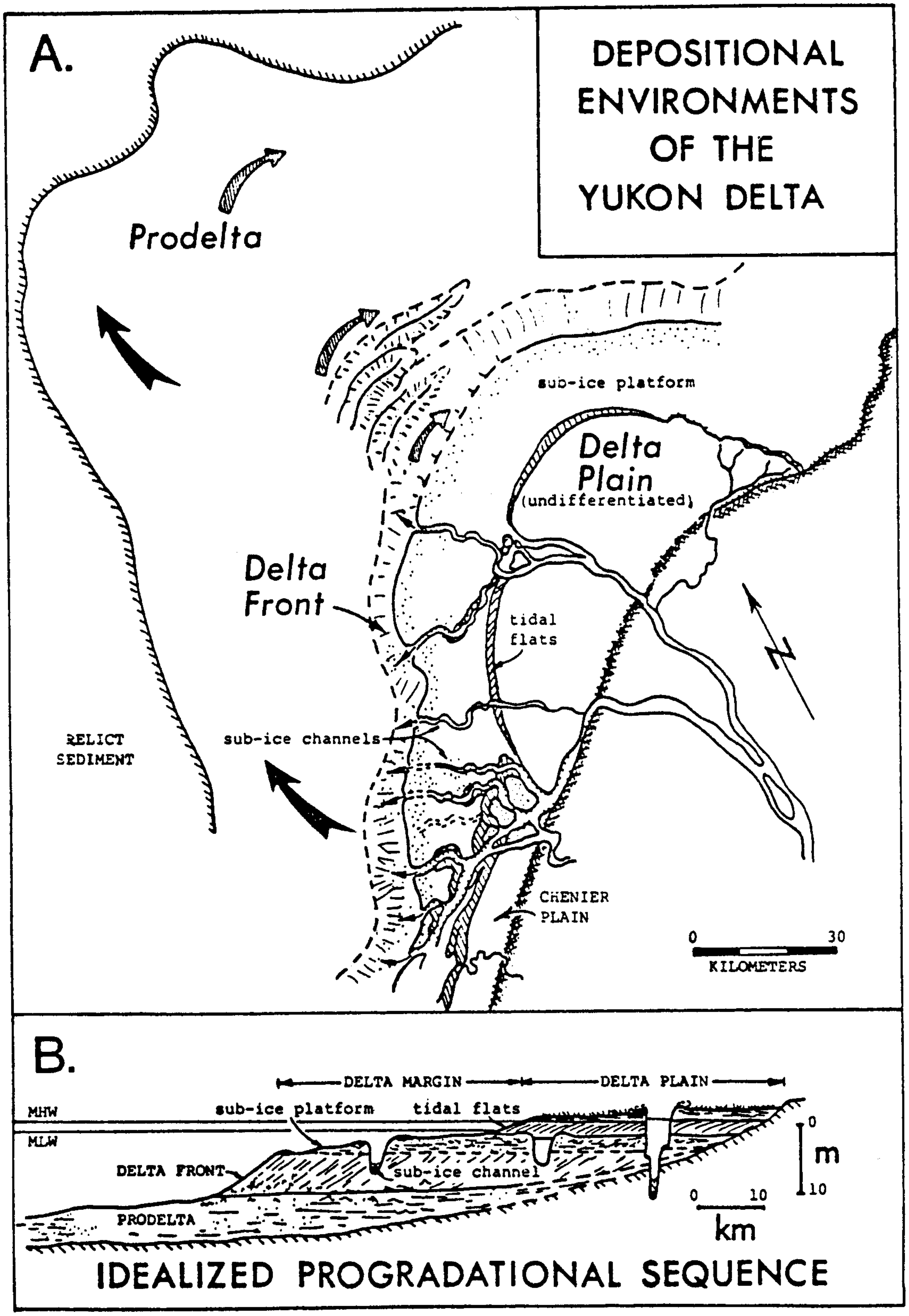


Figure 6.--Depositional environments of the Yukon Delta and idealized progradational sequence.

Interdistributary areas in the older, inactive parts of the delta are largely marshes characterized by poorly sorted silt and mud. Freshwater peats may be up to 1 m thick in the oldest parts of the delta. Some shallow lakes occur between natural levees, but most are in the process of being filled with vegetation. Incipient permafrost development has resulted in the formation of peat mounds (palsen) in many former lake beds. Interdistributary areas along the coast are characterized by marshes of salt-tolerant grasses and sedges, typically forming over actively prograding tidal deposits. Low washover ridges record short intervals of shoreline erosion, probably during major storms.

The delta margin is a term used informally here to include rapidly prograding tidal flats and distributary mouth bars as well as the sub-ice platform and associated offshore channels. Tidal flats are typically 100-1,000 m wide where they occur along the prograding margin of the delta. The flats consist of poorly sorted sandy silt in areas of relatively low wave energy (on the northern side of the delta) to moderately and poorly sorted silty sand in areas of higher wave energy (on the western side of the delta). The tidal flat deposits commonly form a fining-upwards sequence (approximately 1 m thick) of mixed bedded, ripple and parallel-laminated silty sand and silt. Primary sedimentary structures are often obscured, however, by extensive bioturbation, especially in areas of high silt content. Detrital peat is locally abundant, particularly in the upper parts of the prograding sequences. The tidal flats show abundant evidence of ice scour and ice plucking similar to that described by Dionne (1969); however, the preservation potential of such features may be small.

Middle-ground bars commonly occur at the mouths of the larger distributaries. These are characterized by moderately to well-sorted sand in areas of high wave energy and by poorly sorted silty sand in areas of low wave energy. In addition, individual bars are typically coarser grained and better sorted in the more proximal parts, getting finer grained on their more distal edge. Sedimentary structures are mostly ripple and parallel laminations, with little detrital peat or evidence of bioturbation.

Unlike most deltas, the major distributaries continue offshore after bifurcation at the shoreline. These offshore extensions of the distributaries (here referred to as sub-ice channels), are 0.5 to 1 km wide and 5 to 15 m deep; they extend up to 30 km across the sub-ice platform. The channels have a low to moderate sinuosity with most showing clear evidence of lateral migration and the deposition of subaqueous point bar deposits. These deposits are probably characterized by a fining-upwards sequence (up to 15 m thick) consisting of an erosional channel base overlain by moderately sorted, fine to very fine sand grading upwards to moderately sorted sand and silty sand deposited on subaqueous levees. Landsat imagery shows evidence of these channels being areas of active bedload transport throughout most of the summer; they may also serve as conduits for sub-ice currents during the winter months as well.

The sub-ice platform (or 2-meter bench of Toimil 1977) has an extremely gentle slope (typically 1:1,000 or less) extending 10-30 km offshore. The average depth over most of the platform is 1-2 m; however, there commonly is an erosional(?) trough up to 5 m deep near the outer edge of the platform, particularly along the northern edge of the delta. Unlike the nearshore sediment of most deltas, the platform appears to be characterized by an offshore increase in the percentage of sand (Fig. 7), ranging from poorly sorted sandy silt nearshore to poorly and moderately sorted sand and silty sand near the outer edge of the platform. This is similar to trends reported off the north slope of Alaska by Barnes and Reimnitz (1973).

The sub-ice platform appears to be an area of sediment bypassing and reworking throughout much of the year. Sediment bypasses the inner part of the platform during river breakup initially by over-ice flow (similar to that described by Reimnitz and Bruder 1972 and Walker 1974), as well as by sub-ice flow in the offshore channels crossing the platform. Sediment is deposited from suspension during the summer months; however, much of that sediment is reworked during storms and perhaps during the winter months as well. The entire platform is sufficiently shallow to be reworked by waves, but most of the larger waves break at the outer margin. This suggests that the outer margin of the platform is an area of relatively high wave energy, providing one mechanism to explain the offshore increase in sand. In addition, the reduced cross-sectional area of the water column overlying the sediment may act to accelerate sub-ice currents of various origins. The inner part of the platform is frozen to the bottom with bottomfast ice; however, the outer portion is overlain by floating fast ice where the accentuated sub-ice currents could provide an additional mechanism for winnowing of fine-grained sediment from the outer margin of the sub-ice platform (of Barnes and Reimnitz 1973).

The delta front is a term used here to describe the relatively steep (typically greater than 1:500) margin of the delta characterized by apparently rapid deposition of sediment in water depths of 2-10 m. Maximum rates of progradation probably occur adjacent to the major distributaries (and associated sub-ice channels), presumably during the summer months. The morphology of the delta front is more complex along the northwestern part of the delta (Fig. 6B), where it includes a series of large (3-5 m high) shoals which appear to be migrating laterally into Norton Sound. This northeasterly movement is perpendicular to the dominant direction of summer sediment transport, perhaps representing either a secondary bifurcation of the Alaska Coastal Water or the effect of superimposed storm- or tide-induced currents. The outer margin of the delta front (in 5-10 m water depths) is an area of intense ice gouging during the winter months (Thor et al. 1977), which may result in significant resuspension and reworking of the sediment.

The sediment characteristics of the delta front are poorly known, but the western margin probably consists of parallel laminated poorly sorted silty sand and sandy silt, presumably fining offshore. The shoals on the northwestern side of the delta probably consist of better sorted, sandy sediment.

The prodelta is characterized by extremely gentle slopes (typically 1:2,000) marking the distal edge of the deltaic sediments which extend up to 100 km offshore. Sediment is initially deposited from suspension in this environment; however, water depths are still relatively shallow (10-20 m), hence much of the sediment is subsequently reworked. Evidence of such

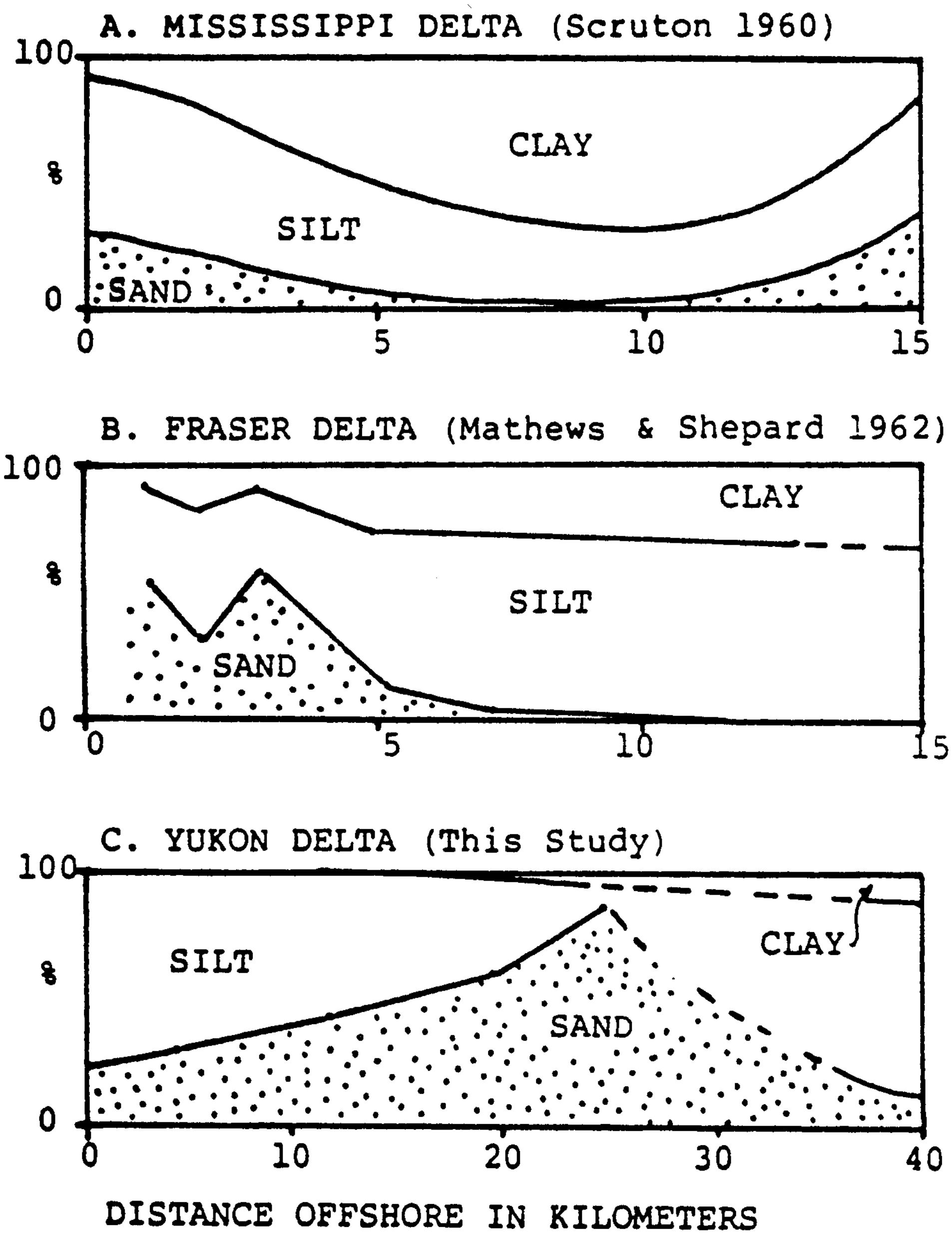


Figure 7.--Comparison of offshore trends of sediment textures off the Mississippi, Fraser, and Yukon deltas. Note the decreased amounts of clay in areas where mechanical weathering predominates.

reworking is clearly demonstrated by the unusual pattern of textural parameters described by McManus et al. (1977). The southwestern margin of the prodelta sediments (adjacent to the largest distributaries) consist of well-sorted silty sand, grading northward to moderately sorted silty sand and eastward to poorly sorted sandy silt and silt. The presence of sandy sediments in the western part of the prodelta appears to be in part the result of resuspension removal from Norton Sound by the relatively high flow velocities within the Alaska Coastal Water (McManus et al. 1977; Nelson and Creager 1977).

IMPLICATIONS

The modern Yukon Delta has several depositional environments lacking in deltas formed in more temperate climates. These depositional environments are but one indication of the extreme seasonality of coastal processes which probably characterize many high-latitude continental shelves. Table 1 is a preliminary attempt to assess the relative importance of these processes within each environment. The ability to predict the types of processes as well as the sediment characteristics and geotechnical properties which characterize each environment, should greatly aid in minimizing both the costs and environmental impacts of siting both offshore and onshore structures.

The delta also provides a modern analogue for older deltaic sediments formed under similar tectonic and climatic settings. In particular, the rates of progradation are much greater than the rates of tectonic subsistence, hence the thickness of individual progradational sequences is

Table 1.--Preliminary summary of nontectonic geological hazards of the modern Yukon Delta.

Depositional environments	Flooding	Ice scour	Sedimentation	Erosion	Permafrost	Liquefaction
Delta plain						
Active distributary	High	Moderate	High	High	None	High
Abandoned distributary	Moderate	Low	Moderate	High	Low-Mod	Mod-High
Interdistributary marsh	Moderate	Low	Low-Mod	Low	Low-Mod	Mod-Low
Coastal marsh	High	Moderate	High	Variable	Low	Low
Delta margin						
Distributary mouth bar	High	Moderate	High	Low-Mod	Low	Mod-High
Tidal flats	High	Mod-High	High	Low	Low	Variable
Sub-ice platform	N/A	Mod-Low	Variable	Variable	None	Variable
Sub-ice channels	N/A	Low	High	High	None	High
Delta front	N/A	High	Variable	Variable	None	Mod-High
Prodelta	N/A	Mod-Low	Moderate	Mod-Low	None	Low-Mod

limited by the water depths of the depositional basin (Fig. 6B). This results in the formation of a blanket-like deposit, a few tens of meters thick and thousands of square kilometers in aerial extent. The distribution of the sand-rich deposits also differs from most previously described delta models. Much of the delta plain consists of a complex pattern of radially bifurcating distributary sand; however, many of these well-sorted sands extend tens of kilometers offshore, having been deposited in sub-ice channels. These deposits represent offshore extensions of potential reservoir rocks. In addition, some of the coarsest, best sorted sands have been deposited not at the shoreline, but rather in water depths of 2-3 m at distances of up to 30 km offshore along the outer margin of the sub-ice platform. These sands should form a blanket-like deposit which may provide another potential reservoir. The textural and mineralogical composition of the sediment significantly affects the post-depositional history of the sediment. The lack of primary clays, particularly in the prodelta deposits, results in relatively little soft-sediment compaction and deformation; however, the abundant volcanic rock fragments may undergo diagenetic alteration to form an extensive matrix of secondary clays, thereby significantly reducing initially high porosities and permeabilities. In summary, the failure to recognize the unique geometry and sediment characteristics of deltaic deposits formed in the ice-dominated environment could result in serious errors in estimating the reservoir potential of older rocks.

ACKNOWLEDGMENTS

This study was supported in part by the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration, under which a multiyear program responding to the needs of petroleum development on the Outer Continental Shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) office. We would like to thank John Anderson (Rice University) for the use of his automated sediment analyzer, Devin Thor (USCG, Menlo Park) for kindly providing sediment samples and bathymetric data from the sub-ice platform, and Erk Reimnitz, Hans Nelson, and Peter Barnes (USCG, Menlo Park), whose experience in Alaska has provided many insights into the deltaic processes in Norton Sound. The senior author also wishes to acknowledge the U.S. Geological Survey's Pacific-Arctic Branch of Marine Geology for providing facilities during the final preparation of the paper. Lastly, we wish to thank Dave Hopkins (USCG, Menlo Park), who conceived and initiated the study of coastal processes along the Yukon Delta.

REFERENCES

Barnes, P. W. and E. Reimnitz. 1973 . The shorefast ice cover and its influence on the currents and sediment along the coast of northern Alaska. Am. Geophys. Union, EOS Transactions 54:1108. (Abstract)

Coachman, L. K., K. Aagaard, and R. B. Tripp. 1975. Bering Strait: The Regional Physical Oceanography. Univ. Washington Press, Seattle. 172 pp.

Dionne, J. C. 1969. Tidal flat erosion by ice at La Pocatiere, St. Lawrence estuary. J. Sed. Petrol. 39:1174-1181.

Dupré, W. R. 1978. Yukon Delta Coastal Processes Study. U.S. Dep. Commer., NOAA, Environmental Assessment of the Alaskan Continental Shelf Annu. Rep. for Year Ending March 1979, 10:268-322.

Fisher, W. L., et al. 1969. Delta Systems in the Exploration for Oil and Gas: A Research Colloquium. Bureau of Economic Geology, Univ. Texas, Austin.

Galloway, W. E. 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. Pages 87-98 in M. L. Broussard (ed.), Deltas: Models for Exploration. Houston Geological Society.

Hill, D. E., and J. C. F. Tedrow. 1961. Weathering and soil formation in the arctic environment. Am. J. Sci. 259:84-101.

Lisitzin, A. P. 1972. Sedimentation in the World Ocean. SEPM Special Publ. 17. 218 pp.

Matthews, M. D. 1973. Floculation as exemplified in the turbidity maximum of Acharon Channel, Yukon River delta, Alaska. Ph.D. thesis, Northwestern Univ., 88 pp.

McManus, D. A., V. Kolla, D. M. Hopkins, and C. H. Nelson. 1977. Distribution of bottom sediments on the continental shelf, northern Bering Sea. U.S. Geol. Surv. Prof. Pap. 759-C, 31 pp.

Naidu, A. S., and T. C. Mowatt. 1975. Depositional environments and sediment characteristics of the Colville and adjacent deltas, northern Arctic Alaska. Pages 283-309 in M. L. S. Broussard (ed), Deltas: Models for Exploration. Houston Geological Society.

Nelson, C. H. and J. S. Creager. 1977. Displacement of Yukon-derived sediment from Bering Sea to Chukchi Sea during Holocene time. Geology 5:141-146.

Reimnitz, E., and P. W. Barnes. 1974. Sea ice as a geologic agent on the Beaufort Sea shelf of Alaska. Pages 301-353 in J. C. Reed and J. E. Sater (eds.), The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America, Arlington, VA.

Reimnitz, E., and K. F. Bruder. 1972. River discharge into an ice-covered ocean and related sediment dispersal, Beaufort Sea, coast of Alaska. Bull. Geol. Soc. Am. 83:861-866.

Reimnitz, E., L. J. Toimil, and P. W. Barnes. 1977. Stamukhi zone processes: implications for developing the Arctic coast. Pages 513-518 in Proceedings of the Offshore Technology Conference, May 2-5, 1977. OTC Paper 2945.

Taber, S. 1943. Perennially frozen ground in Alaska: its origin and history. Bull. Geol. Soc. Am. 54:1433-1548.

Thor, D. R., C. H. Nelson, and J. E. Evans. 1977. Preliminary assessment of ice gouging in Norton Sound, Alaska. In C. H. Nelson (ed), Faulting, Sediment Instability, Erosion and Depositional Hazards of the Norton Basin Seafloor. U.S. Dep. Commer., NOAA, Environmental Assessment of the Alaskan Continental Shelf, Annu. Rep. for Year Ending March 1977.

Toimil, L. J. 1977. Morphologic character of the "2 meter bench," Colville River delta. In P. W. Barnes and E. Reimnitz (eds.), Geologic Processes and Hazards of the Beaufort Sea Shelf and Coastal Regions. U.S. Dep. Commer., NOAA, Environmental Assessment of the Alaskan Continental Shelf, Q. Rep. October-December 1977.

Wright, L. D., and J. M. Coleman. 1973. Variations in morphology of major river deltas as functions of ocean wave and river discharge regimes. Bull. Am. Assoc. Pet. Geol. 57:370-398.