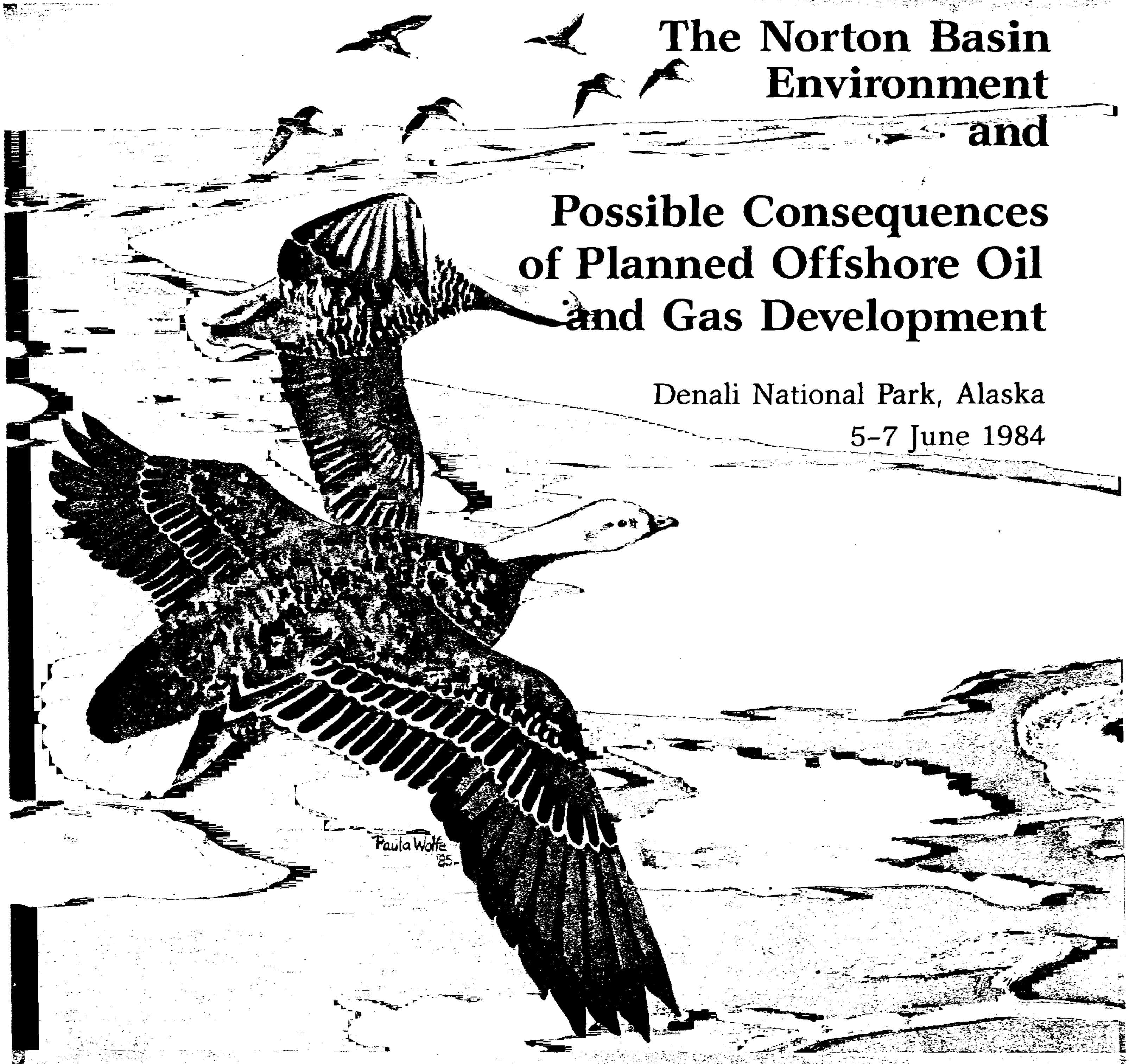
Outer Continental Shelf Environmental Assessment Program
Proceedings of a Synthesis Meeting:

The Norton Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development

Denali National Park, Alaska
5-7 June 1984



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OCS Study, MMS 85-0081

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Edited by

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for the

Outer Continental Shelf Environmental Assessment Program

NOAA/Ocean Assessments Division
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and
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Notices

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Preface

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) was established by a basic agreement between the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of the Interior, Bureau of Land Management (BLM), to conduct environmental research on Alaskan continental shelf areas identified by BLM for potential oil and gas development. Recently, through agency reorganization, the Department of the Interior's Minerals Management Service (MMS) has assumed responsibility for offshore mineral leasing, and OCSEAP now functions through NOAA's National Ocean Service in Anchorage, Alaska.

OCSEAP periodically holds interdisciplinary synthesis meetings to address environmental issues and resource use conflicts that have arisen concerning proposed offshore oil and gas lease areas. OCSEAP investigators, other scientists, OCSEAP and MMS management personnel, and representatives of the state of Alaska, the petroleum industry, and local and other interest groups attend these meetings. Synthesis reports are based on these meetings and include discussions of data presented during the meetings. Further presentations and data interpretations based on additional recent information may also be included.

This synthesis report presents and evaluates available environmental data in relation to potential petroleum development in the Norton Basin OCS Planning Area, including the areas encompassed by Sales 57 and 100. It is based on information brought together at the Norton Basin Synthesis Meeting of 5–7 June 1984 complemented by information from the literature. An earlier synthesis meeting (28–30 October 1980) focused on the Sale 57 area in Norton Sound and resulted in a synthesis report in 1982; the purpose of this report is primarily to update the information in the earlier report and to provide information on the areas west of Norton Sound that are included in the Sale 100 lease offering.

Acknowledgments

This report was prepared with contributions and assistance from scientists of the Minerals Management Service and the National Oceanic and Atmospheric Administration, other federal agencies, the state of Alaska, the petroleum industry, environmental consulting organizations, specific interest groups, and selected individuals. Appreciation is extended to synthesis workshop organizers, chairpersons, individuals who presented papers, and other individuals who submitted written or graphic material for this synthesis report. In particular, we appreciate the material submitted by Cal Lensink, Kathy Frost, William Stringer, James Payne, William Sackinger, Dick Prentki, David Liu, and the composers of Chapter 6, Lynn Robbins and Steve McNabb. Special appreciation is due Paul Becker and Toni Johnson for their tireless efforts in organizing and conducting the synthesis meeting.

The important contributions of Lloyd Lowry, Kathy Frost, Peter Connors, William Sackinger, James Payne, Steve Jewett, Doug Woodby, and members of MMS and NOAA in critically reviewing portions of the draft report are gratefully acknowledged.

This report is published as part of OCSEAP, a program of environmental studies conducted through basic agreement between the Minerals Management Service and the National Oceanic and Atmospheric Administration.

Executive Summary

The first oil and gas lease sale in the Norton Basin Outer Continental Shelf (OCS) Planning Area—Lease Sale 57—took place in 1983; the second—Lease Sale 100—is scheduled for June 1986. To assemble environmental information for use in the leasing process prior to Sale 57, which consisted of tracts within Norton Sound proper, an information synthesis meeting was held in 1980 in Anchorage, Alaska, and a synthesis report was published in 1982. In anticipation of Sale 100, which encompassed a larger area and included tracts to the west of Norton Sound, a second synthesis meeting was held 5–7 June 1984 at Denali National Park, Alaska.

The purpose of the Sale 100 Norton Basin synthesis meeting was to bring together appropriate scientists and administrators to discuss the most recent scenarios of oil and gas development in the Norton Basin, identify the hazards to such development, and characterize the biota and habitats at risk from such development. This synthesis report summarizes the information assembled and discussed at the meeting, and includes additional outside information where necessary to provide a brief, coherent synthesis of the Norton Basin environment and possible consequences of OCS petroleum development. It includes a brief description of the probable industrial activities related to Sale 100, an evaluation of the physical environment and of the behavior of pollutants that might be introduced by these activities, an evaluation of hazards to such activities, descriptions of near-shore and offshore ecosystems and their expected sensitivities to these activities, and a description of regional socioeconomic and subsistence use patterns and potential development-caused changes in these patterns. Significant points follow:

1) Lease Sale 57 (March 1983) has resulted in the drilling of two test wells in Norton Sound from jackup drilling units. Nome has been the shore base for sea and air support. Exploratory drilling began in summer 1984.

2) Activities following Sale 100 are expected to resemble those that have followed Sale 57. Initially, jackup drilling rigs are expected to be towed into the area and operated from June to October. Later, ice-strengthened drillships, artificial and caisson-retained islands, or floating mobile offshore drilling units may be used to extend exploration into the winter season. If commercial discoveries are made, hydrocarbons will be produced from bottom-founded production platforms. Oil will likely be transported by subsea pipelines to a processing and storage facility at Nome, and from there by icebreaking tankers to transshipment terminals on the Alaska Peninsula or to refineries.

3) The Minerals Management Service (MMS) made (in August 1984) a mean-case recoverable resource estimate for Sale 100 of 258 million bbl of oil. The mean-case estimate for Sale 57 was 480 million bbl. (These estimates have since been revised to 282 and 466 million bbl for Sales 100 and 57, respectively.) The MMS estimates that the chance of recoverable oil existing in Sale 100 areas is between 8 and 9%, and in Sale 57 areas, about 14%.

4) Geomorphological characteristics that might influence the transport and fate of oil include bathymetry, sediment characteristics, and coastal landforms. The Norton Basin is shallow (< 50 m deep) throughout; the seafloor sediments are sands, silts, and muds. Beaches are mostly sand or gravel. Mainland coasts are mostly smooth (occasionally wave-cut cliffs) and are indented here and there with lagoons and bays. Island coasts are frequently wave-cut cliffs.

5) Two climatic regimes—summer and winter—prevail, and dominate the hydrography. In summer (June-October), seas are free from ice, temperatures are maritime, winds and storms usually come from the south, and rain is frequent. Ocean currents are generally northward, with local anomalies such as the complex circulation patterns around St. Lawrence Island and the waters in eastern Norton Sound that are isolated from the northward flow. In winter, current reversals to the south, frequently associated with ice "breakout" in the Bering Strait, are common, and nearshore waters are more saline than in summer.

6) Tides over most of the region are of the mixed, predominantly semidiurnal type, though diurnal tides predominate locally in Norton Sound. Strong winds have more effect on water level than do tides.

7) Ice moves generally southward through the Norton Basin in winter. In addition to the ice that freezes *in situ*, ice breakout at the Bering Strait and the constant opening and refreezing of ice leads in northern Norton Sound and south of St. Lawrence Island contribute ice to the region during winter.

8) The Yukon River currently contributes most of the sediments to the Norton Basin; sediments are deposited in eastern Norton Sound, off the Yukon River delta and in coastal bays and lagoons. Strong currents prevent river sediments that bypass the delta (mostly silts) from settling elsewhere in the Norton Basin, and much of the sea floor in the Chirikov Basin and the Bering Strait has geologically old sediments.

9) Patterns of transport of spilled oil are predicted to be different between summer and winter, reflecting the influence of the different weather regimes. Models by the Rand Corporation show oil spilled in Norton Sound in summer to move northerly or northeasterly at a rate of approximately 5–10 km per day, reaching land on the south side of the Seward Peninsula or passing through the Bering Strait to the Chukchi Sea. In winter oil is predicted to move southward or southwestward about 3–5 km per day, approaching land (but probably stopped by shorefast ice) at St. Lawrence Island or locations on the south side of Norton Sound.

10) Oil spilled at sea weathers rapidly, and many weathering processes such as evaporation, dissolution, and dispersion slow to almost a steady state within several days to a few weeks. Oil stranded on beaches exposed to strong wave action may be undetectable after a year or two. In marshes, lagoons, or other low-energy environments, spilled oil may persist for many years.

11) Frequently, cleanup actions are called for when large oil spills occur at sea. Such actions are most effective when the oil slick is moving slowly and seas are calm and clear of ice. In ice-infested waters with strong currents, cleanup may be difficult or impossible, but regulations will prohibit drilling at such times until cleanup capability has been demonstrated.

12) Effects of, and concern about, discharges of drilling muds and cuttings are much less than for oil spills. Typically, drilling fluids have a short radius of influence: 200–500 m from the drill site in benthic environments and 2–4 km downstream in the water column.

13) Environmental hazards on or in the sea floor that are thought to offer substantial risks to offshore development activities include sediment scouring of the sea floor, ice gouging of the bottom, sand-wave migration, biogenic and thermogenic gases in sediments, sediment liquefaction, and faulting and seismicity. These phenomena are hazardous to structures resting on or buried in the sea floor (*e.g.*, drilling platforms, subsea pipes). Most are localized in occurrence, but some (*e.g.*, gas in sediments, potential for sediment liquefaction) are widespread in certain parts of the Norton Basin.

14) The major offshore hazards above the sea floor are moving sea ice, icing of superstructures of vessels, and effects of wind and waves on structures. Multiyear ice floes, though not common in the Norton Basin, are probably the greatest potential hazard to bottom-founded structures.

The greatest hazards to onshore facilities are thought to be the effects of storm surge; such effects include inundation of low-lying areas and erosion of coastal landforms.

15) The nearshore ecosystem, defined herein to extend landward from about the 10-m depth contour, is important habitat for marine mammals, birds, and fishes. Its greatest importance is probably for waterfowl, shorebirds, seabird colonies, salmon and other anadromous fishes, and a few marine fish species. The Yukon River delta stands out as more important than other coastal areas for most species.

16) Three marine mammal species—spotted seal, ringed seal, and belukha whale—find important habitats in the nearshore environment. Spotted seals and belukha whales concentrate in summer at selected river deltas, bays, and lagoons to feed on fish; they leave the nearshore area in winter. Ringed seals breed, bear their young, and feed in the nearshore fast-ice habitat in winter and spring; most follow the ice out of the area in summer.

17) Birds are common in the nearshore zone (and offshore) only during the open-water season, with the exception of the oldsquaws and eiders that winter around St. Lawrence Island. Waterfowl, shorebirds, and cranes in this area are a major national resource; large numbers stage, nest, and rear broods of young in wetlands of coastal areas. Most species of these groups tend to concentrate nearer the coast during staging, brood-rearing, or molting than they do during nesting. In comparison, loons, gulls, and terns are less important in terms of human interest, numbers, or unique populations.

18) Seabirds nest in tremendous numbers in coastal cliff colonies; over 4 million populate the Norton Basin area in summer. The plankton-feeding species, and the largest numbers of individuals, nest on islands near relatively deep, plankton-rich oceanic waters. Fish-eating species are dominant in the smaller mainland colonies around Norton Sound, and tend to feed nearer their colonies than do the planktivorous species.

19) The fish community of the nearshore zone consists of anadromous species (mainly salmon, but also others such as ciscoes, whitefishes, and char) and a few common marine species (herring, sand lance, smelt, and capelin). Five species of salmon spawn in streams that empty into Norton Sound; they leave the streams as juveniles, tarry briefly in coastal areas before moving on to the deep sea, then return to the streams as adults. Most other anadromous species do not enter the marine environment; they feed in river deltas and other estuarine areas throughout the summer, and some overwinter in the larger deltas. Herring, capelin, and sand lance move from the marine environment to spawn and feed in nearshore waters during the open-water season.

20) Food webs in the nearshore zone have three major energy sources: terrestrial plants (foods of geese and some ducks), estuarine invertebrates (prey of anadromous fishes), and marine invertebrates (major prey for many water birds, juvenile salmon, and marine fishes).

21) Important habitats in the nearshore zone occur mainly in and near river deltas, bays, and lagoons; they are used mainly in summer. The Yukon River delta overshadows all other areas in importance as habitat. Seabird colonies on coastal cliffs of islands and the mainland support generally larger numbers of individuals than do other habitats. A few habitats—open-water areas surrounding St. Lawrence Island and deep river deltas and bays that support overwintering fishes—are important in winter.

22) The nearshore animals most susceptible to adverse impact from OCS development are the waterfowl that concentrate in habitats at the edge of the sea: brant, cackling Canada geese, emperor geese, and some diving ducks. Some seabirds are susceptible in the nearshore zone, though most feed offshore and are thus more susceptible to impact there. The OCS activity of greatest potential threat to most biota in the nearshore environment is major oil spills.

23) The offshore ecosystem, located seaward of approximately the 10-m depth contour, is dominated by marine mammals, seabirds, demersal fishes, and benthic invertebrates. It is a summer feeding area for many species, a spring and fall migration pathway for others, and an overwintering area for some (mainly fishes and a few mammals). Its use by mammals and birds is strongly tied to the annual patterns of ice formation, ablation, and movement.

24) Seven species of marine mammals are common in the offshore environment: ringed and bearded seals, walrus, polar bear, and belukha, gray, and bowhead whales. The ringed and bearded seals, walrus, and polar bear are ice-associated species and occur mainly (but not entirely) in winter (seals and polar bear), and in spring and fall as migrants following the ice edge (walrus). The whales migrate through in spring and fall as open water is available (belukha, bowhead) or stay as summer inhabitants (gray whale). Less common are ribbon seal, Steller sea lion, and minke, killer, humpback, fin, and sei whales; most of these are summer visitors.

25) Some marine mammals in the offshore zone feed on marine fishes (ringed seal, belukha whale), some eat benthic invertebrates (bearded seal, walrus, gray whale), some eat zooplankton (ringed seal, bowhead), and one consumes mainly other mammals (polar bear). It is very unlikely that the bowhead population obtains a major portion of its food sources in the Norton Basin; the extent of active feeding there is unknown, but available evidence indicates it to be slight. The gray whale population is probably more highly dependent on food obtained in the Norton Basin than is any other of the mammal populations.

26) Several million seabirds feed in the offshore region during the open-water period. The most numerous are least, crested, and parakeet auklets, short-tailed shearwater, thick-billed and common murres, black-legged kittiwake, and horned and tufted puffins.

27) The most numerous seabirds—auklets, short-tailed shearwater, thick-billed murre—are planktivorous and feed in the western Norton Basin where the ocean currents enhance plankton production and availability. Those that feed largely on fish—common murre, puffins, pelagic cormorant—are fewer and feed more widely in eastern areas (*i.e.*, Norton Sound).

28) The offshore fish community is low in biomass compared to similar communities farther south in the Bering Sea. It contains a mixture of Arctic and North Pacific forms, and is dominated by demersal or semidemersal species. Pelagic species make up a relatively small portion of the biomass.

29) Saffron cod and probably Arctic cod are the most numerous of the demersal or semidemersal species; starry flounder, shorthorn sculpin, plaice, and yellowfin sole are also common. As one would expect, epifauna and infauna are dominant in the diets of these fishes.

30) Of the pelagic species, salmon are the most conspicuous, appearing in Norton Sound mostly as migrants between natal streams at the coast and deeper oceanic environments to the south. Herring and rainbow smelt are common year-round residents. Foods of pelagic fishes are largely zooplankton or other fishes.

31) Perhaps the largest standing stocks per unit area of benthic invertebrates in the Bering Sea are found in the Norton Basin—in western Norton Sound and the Chirikov Basin. A few species (*e.g.*, red and blue king crabs) are commercially harvested, and many others (*e.g.*, bivalves, shrimps) are important foods for vertebrates. But the most abundant, the echinoderms, are largely a trophic dead end in terms of human interests; small proportions are consumed by vertebrate predators.

32) Zooplankton production appears to be highest in the western parts of the Norton Basin, and lowest in Norton Sound. Influxes of nutrients from the North Pacific and increased vertical mixing of the water column apparently enhance production in the west. Much of Norton Sound receives relatively low levels of this ocean nutrient input, and its waters are vertically stable.

33) The food webs of the offshore ecosystem appear to be based largely on phytoplankton production. Much of the phytoplankton apparently settles to benthic environments as detritus, for pelagic secondary production is low in comparison with that on the bottom, despite the relatively low temperatures at the bottom in many places.

34) Important offshore habitats are concentrated mostly in the St. Lawrence Island–Chirikov Basin–Bering Strait region, and not in Norton Sound. Three characteristics of this region probably account for the concentration: it is a migratory pathway for many mammals, it has generally warmer bottom waters in summer than does Norton Sound, and its nutrient input and consequent secondary production are relatively high.

35) The greatest threat to offshore biota from OCS development appears to be the potential for large oil spills. Seabirds are the most susceptible of the offshore vertebrates to adverse impact. Concern exists about effects of development on gray and bowhead whales, but existing evidence does not suggest these species to be nearly as susceptible to adverse effect as are birds. Other mammals, fishes, and invertebrates appear relatively secure (as populations) from significant impact.

36) People living in the Norton Basin region acquire a large portion of their food and their cash income from mammals, fish, and birds harvested for subsistence. The Yukon River delta residents rely primarily on fish, mainly salmon and other anadromous species, and secondarily on marine fish and marine mammals. Communities elsewhere at the perimeter of Norton Sound and the Seward Peninsula harvest a broad array of species—fish and shellfish, seals and other sea mammals, caribou, birds—but salmon is still probably their key subsistence item. St. Lawrence Islanders depend primarily on marine mammals such as walrus, seals, and bowhead whale; secondarily on marine and anadromous fishes; and to some extent on birds. Harvesting activities are essential elements of the social and cultural lives of Norton Basin people.

37) Recent socioeconomic studies suggest that direct economic effects of OCS activities on Norton Basin communities (*e.g.*, local increases in support or supply industries, employment, or inflation) are likely to be small. The main potential for economic change may be through the participation of individual residents in the OCS work force. If large-scale economic changes occur, impacts on subsistence and sociocultural systems are likely to be more substantial than currently predicted.

38) Attitudes about OCS development vary among communities. St. Lawrence Island native corporations do not appear to be interested in having OCS industrial activities come to the island. Most Norton Sound residents and institutions appear opposed to development, fearing environmental and social disruption. Nome residents show less opposition than most, viewing development as inevitable and perhaps even beneficial in some aspects.

39) Environmental change brought about by OCS development could affect subsistence harvest levels by causing changes in populations of subsistence species and in the subsistence activity patterns of native communities. Some animal populations will not be changed by OCS development; others might, but the extent of change cannot yet be predicted. Changes in subsistence activities might also occur but, again, the extent of change cannot yet be predicted.

40) A socioeconomic-sociocultural path model has been developed for the Norton Basin region to help predict socioeconomic consequences of OCS development. The model is based on existing data about apparent trends in economic, cultural, and social characteristics of communities in the region. It has not been validated, so the reliability of its predictions is not known. The model predicts that changes in economic, sociocultural, and subsistence systems caused by OCS-induced economic changes are possible. However, changes in subsistence systems are difficult to predict, since the model focuses on key economic variables and omits ecological variables.

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Introduction

by Joe C. Truett

With major contributions from Richard Prentki

1.1 THE PROPOSED ACTION

Exploration for oil and gas on the outer continental shelf of Alaska has accelerated in recent years. Early industry interest and OCS leasing programs were in Cook Inlet and the Gulf of Alaska. More recently, interest shifted to the Beaufort Sea; areas southwest of the Beaufort are now receiving attention.

The Norton Basin OCS Planning Area, in the northern Bering Sea, is an area in which industry has shown considerable interest in exploring for oil and gas. The first lease sale in the area, Sale 57, was in 1983; the second, Sale 100, is scheduled for June 1986. This report is based on the proceedings of a synthesis meeting that focused on this region and its resources in view of Sale 100. It updates the synthesis meeting (28–30 October 1980) and synthesis report (Zimmerman 1982) held prior to Sale 57, and expands the area of consideration beyond Norton Sound to include the St. Lawrence Island–Chirikov Basin area (Fig. 1.1).

The following description of the proposed action is being used by the Minerals Management Service (MMS 1984) as a basis from which to assess the environmental hazards to lease exploration and development, and effects that exploration for oil and gas in the Norton Basin may have on the environment. It includes estimates of recoverable oil, descriptions of actions that have already taken place as a consequence of Sale 57, and projections of exploration and development modes for Sale 100.

The timing of events and level of activities given in these MMS scenarios are based on the assumption that the amount of economically recoverable oil is approximated by the mean-case resource estimates for both Sales 100 and 57 (Tables 1.1 and 1.2). The mean-case resource estimate as of August 1984 for Sale 100 was 258 million barrels (bbl) of oil and that for Sale 57 was 480 million bbl. The marginal probability for the Sale 100 area was 0.086 (implying that the chance of recoverable oil existing in the area is less than 10%), while for Sale 57 it was 0.14. By November 1984, the resource estimates had been revised to 282 million bbl for Sale 100 and 466 million bbl for Sale 57, and may soon be revised again (letter from C. Cowles, MMS, November 1984), but the following scenarios are based on the August 1984 estimates.

1.1.1 Lease History (Sale 57)

Sale 57 was the first lease sale in the Norton Basin OCS Planning Area. The sale was held 15 March 1983, but litigation delayed issuance of the leases until 1 June 1983. Of the 418 tracts—totaling 963,072 hectares (ha)—which were offered, only 59 tracts—totaling 135,936 ha—were leased.

Two continental offshore stratigraphic test (COST) wells have been drilled in Norton Sound; both wells were drilled from jackup drilling units. For each well most of the major materials needed for drilling were stored on a barge anchored near the drilling unit. Nome was the shore base for sea and air support. The seagoing supply boats operated out of the existing port facilities at Nome. Two helicopters were used to transport personnel and light equipment and supplies between the drilling units and Nome. Kenai and Dutch Harbor were occasional sources of nonroutine equipment and materials.

Exploration plans for Sale 57 leases had been submitted by Exxon Company USA (Exxon) and ARCO

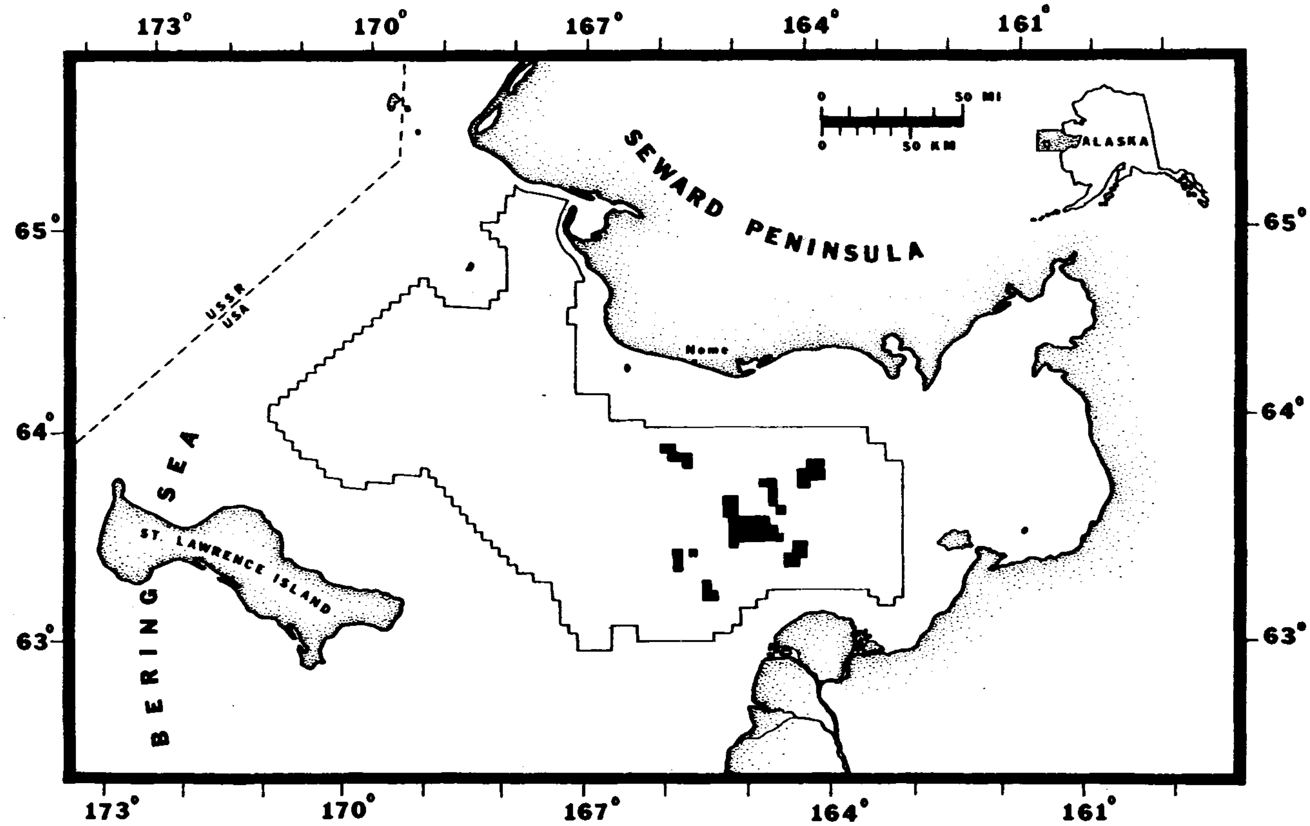


FIGURE 1.1—Norton Basin Outer Continental Shelf Planning Area, Alaska, showing tracts leased in Sale 57 (shaded) and the limits of Lease Sale 100.

Alaska, Inc. (ARCO) at the time of the synthesis meeting. These plans indicated that exploratory drilling would begin in Norton Sound during the summer of 1984. Each plan showed a number of potential well sites and indicated that the wells would be drilled from jackup units.

Following the synthesis meeting, two wells were drilled by Exxon and one by ARCO, all in the western part of Norton Sound. Lease locations, water depths, and drilling schedules for these wells were as follows:

Leasing Organization	Lease Number and Block	Water Depth (m)	Well Spudded	Well Completed
Exxon	7-0414, Block 267	15	6-19-84	7-23-84
Exxon	7-0430, Block 448	10	7-25-84	9-17-84
ARCO	7-0436, Block 949	20	6-25-84	8-19-84

1.1.2 Lease Sale 100 Scenarios

For drilling exploration wells during the first few years of the lease, jackup rigs are considered to be the primary units. These units, along with the support barges, can be towed into the operating area from about mid-June to mid-October. Drilling and testing of the wells may take from 45 to 85 days depending on the depth to be drilled and the amount of testing required. Prior to freeze-up and the encroachment of sea ice, the jackup units and barges will be towed out of the area. If the initial exploratory drilling is encouraging, other types of drilling units may be used to drill wells in the area: ice-strengthened ship- or circular-shaped drillships; artificial and caisson-retained islands; or mobile offshore drilling units.

Ice-strengthened drillships (with assistance from icebreaking work/supply boats and icebreakers) have been used to drill exploratory wells in the Canadian Beaufort Sea from late spring to early fall. These drillships are capable of operating in waters 15 to 303 m deep. The conical drilling unit (CDU), a new circular-shaped floating drilling unit, is designed to withstand moving ice about 1.2 m thick; this unit is also assisted by icebreakers or icebreaking work/supply boats. The CDU is designed to operate in waters 40 to 60 m deep.

Artificial islands and caisson-retained islands are bottom-founded drilling units that have the capability of withstanding the ice forces and permitting year-round drilling. Artificial islands are man-made structures composed of granular fill material (sand and gravel) and have been used in water as deep as 19 m in the Beaufort Sea. Caisson-retained islands consist of prefabricated concrete or steel caissons that are floated into position, joined, and lowered onto a berm composed of dredged material. The caissons form a retaining wall that constrains the fill material supporting the drilling rig. Two caisson-retained islands have been used in the Canadian Beaufort Sea in water depths of 13 and 21 m. When drilling and testing are complete, the caissons can be refloated and towed to another site.

Mobile offshore drilling units that are capable of resisting the forces of sea ice may also be used in the Norton Basin OCS Planning Area. Each unit consists of a floating structure that supports the drilling rig, and rests on the sea floor or on a man-made subsea berm during drilling operations. These units are outfitted with the drilling rig, auxiliary equipment, accommodations, and supplies before being towed to the drill site.

If commercial discoveries are made in the Norton Basin, bottom-founded platforms will be used for production. Depending on water depth, seafloor conditions, ice conditions, and size of the petroleum reservoir, any of several types of platforms may be used. Artificial (granular fill) and caisson-retained islands may be used in the shallower parts of the basin. To accommodate the production equipment and the drilling rigs, these platforms would need to be larger than the islands used for exploratory drilling. Platform designs based on the multi- or single-leg (monocone) production platforms used in Cook Inlet may also be used. In Norton Sound, these types of platforms would have to be heavier and stronger than the Cook Inlet platforms to resist greater ice forces. Large concrete or steel "islands" (larger versions of the mobile offshore drilling units) or large monopod-monocone structures might also be used in the planning area. Construction and outfitting of these types of platforms would occur in ice-free harbors. After staging, the platforms would be moved to the production site where installation would be completed during the open-water season.

The transportation scenario for Sale 57 envisions that the produced oil will be transported via pipelines to a processing and storage facility at Cape Nome, which is located about 20 km east of Nome. This facility would occupy approximately 40 to 50 ha. To protect the subsea line from the keels of drifting ice masses, the pipeline would be laid in a trench cut into the sea floor and covered with fill material.

Icebreaking tankers would carry the oil from Cape Nome to a transshipment terminal on the south side of the Alaska Peninsula or to refineries. Because of the shallow nearshore depths in the vicinity of Cape Nome, an ice-resistant tanker-loading facility would have to be constructed; the tankers might also be loaded from an offshore processing and storage facility. Such a facility would require the same strength, structural integrity, and size as the production platforms in the area.

1.2 NATURAL HAZARDS TO OCS STRUCTURES AND ACTIVITIES

Potential hazards to the exploration and development of the Norton Basin include geologic hazards associated with the sea floor, hazards generated by moving water and sea ice, and hazards to coastal facilities (Zimmerman 1982). Hazards on or beneath the sea floor include the presence of permafrost, scouring by ice and currents, faulting and seismicity, liquefaction of sediments, movement of sand waves, and gas charging of sediments. Above the sea floor, moving ice, wind and waves, and icing of structures may pose problems. At the shore, erosion and storm surge may be hazardous to coastal facilities.

1.3 ENVIRONMENTAL IMPLICATIONS OF THE PROPOSED ACTION

The Norton Basin is an area of major importance to many animal species in which humans have intense interest. Marine mammals and birds are particularly diverse and abundant. Following are summaries of the region's biota and human use of the biota, from Starr *et al.* (1981).

During spring and fall, large numbers of marine mammals funnel through the Norton Basin, en route to summering areas in the Chukchi Sea and the Arctic Ocean to the north, or to wintering areas in the central and southern Bering Sea to the south. It has been estimated that 200,000 to 250,000 walruses, 200,000 to 250,000 spotted seals, 1,000,000 to 5,500,000 ringed seals, 300,000 bearded seals, 9,500 belukha whales, 1,700 to 2,900 bowhead whales, and 16,500 to 19,000 gray whales are present in western and northern Alaska waters; a large majority of these either migrate through or reproduce, overwinter, or feed in the Norton Basin annually.

Twenty-four seabird colonies scattered throughout this region support an estimated 4.3 million birds. The seabird populations on St. Lawrence Island and Little Diomede Island (2.7 and 1.2 million birds, respectively) are the largest and third largest in the Bering Sea. Large percentages of some seabird species nest wholly within the Norton Basin region. Colonies located on St. Lawrence Island support 62% of the crested auklet population in the eastern Bering Sea, and the entire eastern Bering Sea population of least auklets breeds on St. Lawrence and Little Diomede islands.

Norton Sound is heavily used by waterfowl, shorebirds, and passerine birds migrating between southern wintering grounds and northern breeding grounds.

TABLE 1.1—Mean case estimated schedule of exploration, development and production of petroleum for OCS Lease Sale 100, Alaska.

Sale Year	Calendar Year	Exploration Wells	Delineation Wells: Oil	Delineation Wells: Gas	Exploration and Delineation Drilling Rigs	Production Platforms and Equipment: Oil	Production Platforms and Equipment: Gas	Production and Service Wells: Oil	Production and Service Wells: Gas	Production and Service Wells: Rigs	Miles of Trunk Pipeline: Oil	Miles of Trunk Pipeline: Gas	Number of Shore Bases	Production: Oil Mbbl[1]	Production: Gas Bcf[2]
0	1985														
1	1986	1			1										
2	1987	1	1		2										
3	1988	1	1		2										
4	1989	1	1	1	3	0.3									
5	1990	1	1	2	3			4		2					
6	1991	1		1	2	2		6		2	60		0.20		
7	1992							6		2	60		0.25		
8	1993						2	4	6	2	70	80	0.25		
9	1994						2		6	2		80	0.25	6	
10	1995								2	2		70		22	
11	1996													22	49
12	1997													22	62
13	1998													22	62
14	1999													22	62
15	2000													21	62
16	2001													19	62
17	2002													17	62
18	2003													15	62
19	2004													12	62
20	2005													11	62
21	2006													9	62
22	2007													8	62
23	2008													8	62
24	2009													7	62
25	2010													6	62
26	2011													5	62
27	2012													4	62
28	2013													0	62
29	2014														62
30	2015														50
31	2016														39
32	2017														26
33	2018														14
34	2019														0
35	2020														
TOTAL		6	4	4	13	2.3	4	20	14	12	190	230	0.95	258	1,294

SOURCE: MMS 1984.

NOTE: This schedule is cumulative with Sale 57.

[1]Mbbl, millions of barrels.

[2]Bcf, billions of cubic feet.

TABLE 1.2—Mean case estimated schedule of development and production of petroleum for OCS Lease Sale 57, Alaska.

Sale Year	Calendar Year	Exploration and Delineation Wells		Platforms and Equipment	Production and Service Wells		Miles of Pipeline	Miles of Shore Terminals	Production	
		No.	Rigs		No.	Rigs			Oil Mbbl[1]	Gas Bcf[2]
0	1983									
1	1984	6	2							
2	1985	11	4							
3	1986	13	5	1						
4	1987	11	4	2						
5	1988	4	2	3	15	2	93	0.7		
6	1989			3	45	5	93	0.9	25	25
7	1990				89	10		0.3	78	78
8	1991				14	2		0.1	100	123
9	1992				9	1			78	142
10	1993								51	135
11	1994								35	119
12	1995								26	108
13	1996								19	103
14	1997								14	97
15	1998								11	95
16	1999								9	91
17	2000								7	90
18	2001								6	89
19	2002								4	87
20	2003								4	87
21	2004								3	86
22	2005								3	85
23	2006								2	83
24	2007								2	70
25	2008								2	52
26	2009								1	37
27	2010									28
28	2011									21
29	2012									17
30	2013									13
31	2014									11
32	2015									9
33	2016									7
34	2017									6
35	2018									5
36	2019									4
37	2020									4
38	2021									3
TOTAL		45	17	9	172	20	186	2.0	480	2,010

[1]Mbbl, millions of barrels.

[2]Bcf, billions of cubic feet.

The Yukon–Kuskokwim Delta (the Kuskokwim part of which is outside our area of interest) is one of the most productive waterfowl habitats in the world; it is estimated that 3 million waterfowl and over 100 million shorebirds use the area during summer. More than half of the continental population of black brant and 80% of the world's population of emperor geese nest in this area.

The Norton Basin, and especially the Yukon River delta, is important in terms of number of fish produced. The delta is a major migratory route for 2 to 5 million spawning salmon each year, is a principal rearing area for outmigrating juvenile salmon, and provides important habitat for sheefish, ciscoes, and other whitefishes. All of these fishes are major subsistence items for local residents of this region.

The Norton Basin supports a rapidly developing commercial herring and king crab fishery, as well as a nearshore set-net fishery for salmon. These fisheries harvest an average of 1,020 metric tons of king crab, 1,173 metric tons of herring, and 900,000 salmon annually. Dollar value estimates for 1979 Norton Basin commercial fisheries products were $2,721,805 for king crab, $777,608 for herring and herring roe on kelp, $876,547 for salmon caught in Norton Sound proper, and $7,619,500 for all salmon harvested from the Yukon River system.

There are about 18,000 native residents in this area, the majority residing in more than 26 small villages scattered along the coast and near the deltas of major river systems. Most of these people rely on subsistence harvests of fish and game for an important portion of their livelihood. Because a variety of animal species such as whales, walrus, seals, salmon, marine fishes, shellfishes, terrestrial mammals, seabirds, and waterfowl are available, the Norton Basin probably supports the largest and most diverse subsistence harvest of any similar-sized area in the state of Alaska.

Potential consequences of OCS oil and gas exploration and development in Norton Sound on these resources and their human users include (1) effects of pollutants (particularly oil) on valuable biological resources and their food chains; (2) effects of increased industrial activity (*e.g.*, boat and air traffic, drilling activities, presence of people) on birds and mammals; (3) effects on biota of changed patterns of resource harvests by people; and (4) effects on local people of industry-caused changes in socioeconomic traditions and in abundance or distribution of animals traditionally harvested.

1.3.1 Releases of Oil

Accidental oil spills cause perhaps the greatest environmental concern relative to OCS development in the Norton Basin. Chronic releases of relatively small amounts of oil are of less concern, but may have adverse local effects.

Oil spilled in marine areas where seabirds concentrate to feed or in bird nesting and feeding areas in the Yukon River delta probably pose the greatest threat to large numbers of animals. Oil may also be a major hazard to salmon juveniles residing in river estuaries, or to waterfowl congregating to molt in nearshore waters. Oil effects on bird, mammal, or fish food chains will probably be less of a problem than will the effects of oil on the animals themselves.

Probabilities of Oil Spills

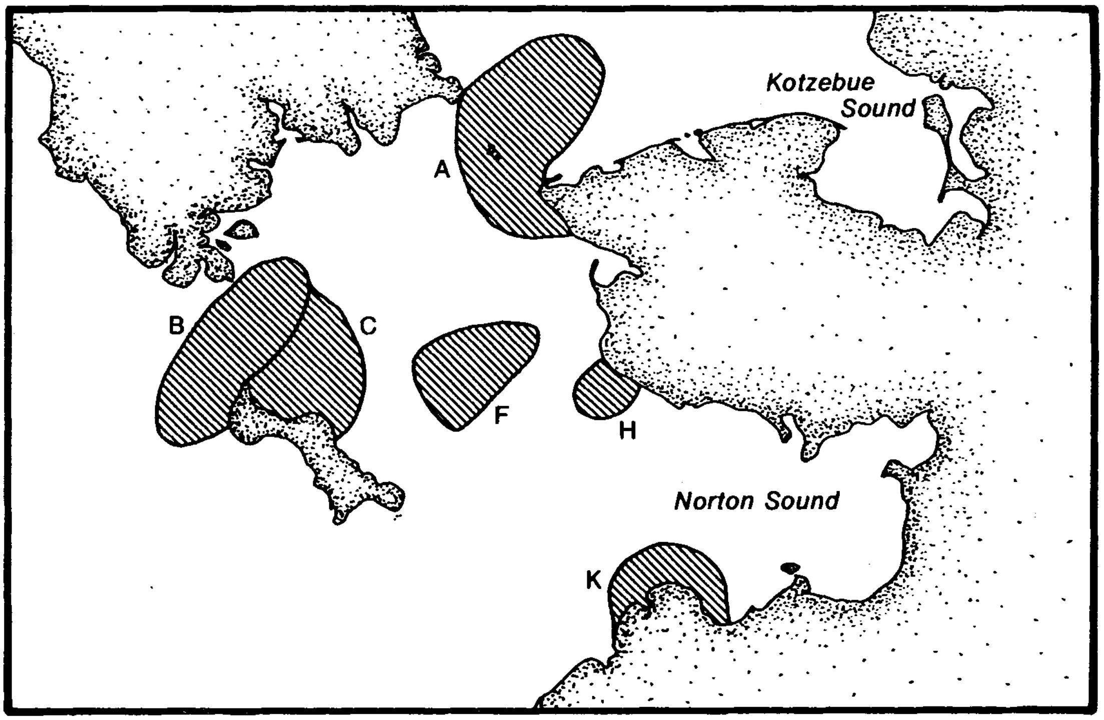
For each oil and gas lease sale, MMS develops projections for the number of major oil spills that could occur over the life of the field during discovery, production, and transportation of the unrisked mean oil resource. *Unrisked* means that commercial quantities of oil are assumed to be discovered, regardless of how unlikely this occurrence may be. For Sale 100, the marginal probability of this assumption being correct is only 8.6%. The oil spill projections are calculated as the product of the estimated oil resource times the historical rate of oil spillage per production volume from the federal offshore area and from international tankering. The calculations take into account statistically significant, decreasing trends in spillage from platforms and tankers that have occurred over the past decade (Lanfear and Amstutz 1983). (No such trend has been observed for pipelines.)

For Sale 100, MMS projects a 57% chance that one or more spills of at least 1,000 bbl will occur either within the Norton Basin or along a tanker route through the Bering Sea. However, the most likely number of such spills is zero. For proposed Sale 100 plus existing Sale 57 leases, MMS projects an 84% chance of one or more spills. For these two sales together, MMS projects a 13% chance of one or more spills of at least 100,000 bbl.

Conditional Probabilities of Oil-Spill Contact

The Rand Corporation has computed trajectories for hypothetical oil spills in the Norton Basin. Examples of these trajectories and their modeled derivation are discussed elsewhere in this synthesis report (Section 2.2.1). Probable contacts of these trajectories with land and primary biological resource areas are as follows.

If a spill occurred somewhere within the Norton Basin, the spill probably would not reach land within 3 or 10 days, but would within 30 days (Fig. 1.2). Within 30 days much of the initial toxicity of the spill will have been lost through evaporation plus dispersion and possible cleanup actions (see Section 2.2.3). St. Lawrence Island and the shoreline from Golovnin



	Percent Chance of Contact		
	3 days	10 days	30 days
LAND	9	18	62
Yukon Delta	0.2	0.7	2
Eastern Norton Sound	0	0	3
Golovnin Bay to Cape Woolley	8	9	18
Cape Woolley to Bering Strait	0.2	2	8
St. Lawrence Island	0.9	5	19
King Island	0	0.1	0.1
Diomede Islands	0	0.1	0.3
BIOLOGICAL RESOURCE AREAS			
Bering Strait Offshore (A)	0.3	2	4
Yukon Delta Offshore During Open-Water Season (K)	4	4	4
Winter Whale and Walrus Migration Corridor (B)	0.1	4	12
Chirikov Basin Gray Whale Feeding Area During Open-Water Season (F)	6	7	8
Sledge Island Offshore During Open-Water Season (H)	0.4	2	5
St. Lawrence Offshore Bird Feeding Areas Open-Water Season (B & C)	0.2	0.2	0.2

FIGURE 1.2—Biological resource areas in the Norton Basin (above) and probabilities that an oil spill occurring within the proposed Sale 100 lease area would contact land or a biological resource area (below) (provided by Minerals Management Service, Anchorage, Alaska).

Bay to Cape Woolley—particularly the Cape Nome area, site of a hypothetical tanker terminal—are most at risk with an 18–19% chance of contact. Shorelines of the Yukon River delta, King Island, and the Diomede Islands have a one-in-fifty or less chance of oil-spill contact.

The conditional probabilities of spill contact with individual offshore biological resource areas (Fig. 1.2) are low and range from near-zero to slightly greater than 10% through 30 days. If a spill occurred in the Norton Basin, there is only a 4% chance that the Yukon delta offshore would be contacted by the slick in summer. The gray whale feeding area in the Chirikov Basin has an 8% chance of summer contact with such an oil spill within 30 days. The winter whale and walrus migration corridor west of St. Lawrence Island has a 12% chance of oil-spill contact through 30 days. Conditional contact probabilities for additional areas are given in Figure 1.2.

Note that these "conditional" probabilities are *conditioned* on the assumption that a spill has occurred, and refer to habitat contact only. The probabilities should not be taken to mean that the biological resource itself has a contact probability equal to that of its habitat, nor should oil contact with the resource be necessarily equated with death or destruction of that biological resource.

1.3.2 Releases of Drilling Muds and Cuttings

Drilling muds and cuttings are less likely to have significant adverse effects than are oil spills. Though more certain to occur during the exploration phase than oil spills, releases of these substances will be quickly diluted to low levels with distance from release, and the constituents are generally relatively benign in moderate to low concentrations (Ayers *et al.* 1980; Northern Technical Services 1981). Caustic soda, lignosulfonates, and some bacteriacides are considered the main toxic components of drilling muds (Hameedi 1982). Drill cuttings, consisting of chipped and pulverized sediment and rocks, are normally not toxic, though they may smother organisms in the immediate proximity of their release.

1.3.3 Increased Levels of Human and Industrial Activity

Petroleum exploration and development will cause increased numbers of people to occupy the area, and boat and aircraft traffic and other sources of disturbance may increase. Disturbance to migrating whales and to birds is a concern, particularly if such activities occur at a time and a place such that these animals could be displaced from potentially critical habitat. Increased levels of OCS-related activity near belukha calving areas, walrus haulouts, seabird nesting cliffs, or waterfowl nesting areas may have adverse effects.

1.3.4 Impacts on Resources Caused by Changes in Human Life-styles

Invariably, when exploration and development activities occur in areas remote from human population centers, significant changes in the life-styles of residents may be expected. These changes, such as increased per capita income and increased mobility of hunters and fishermen, frequently cause changes in resource use patterns. For example, increased cash income and mobility generate the potential for greater efficiency in harvesting mammals, birds, and fishes. On the other hand, increased income may cause a decreased desire in hunters to harvest resources, or may cause hunters to change their patterns of harvest.

1.3.5 Effects on Subsistence Economies

An important concern of residents of the region is that OCS development may cause changes in subsistence life-styles by affecting the distribution or abundance of fish and wildlife harvested for subsistence. OCS development would undoubtedly affect the social and economic patterns of traditional life-styles in the region by generating increases in cash and employment available to local communities. It has been the pattern elsewhere in Alaska that altered life-styles caused by industrial development result in loss of community traditions, increases in crime, and dissatisfaction with current employment patterns (Braund and Burnham 1984).

1.4 THE SYNTHESIS MEETING

On 5–7 June 1984, OCSEAP principal investigators, other scientists, representatives of resource management agencies and native corporations, and other interested parties met in Anchorage, Alaska for the Norton Basin Synthesis Meeting. The meeting provided a forum for presentations of results of research conducted in the Norton Basin planning area since the Norton Sound Synthesis Meeting, which was held 28–30 October 1980. Interdisciplinary workshops were convened during the meeting to assess the state of knowledge of nearshore and offshore ecosystems and the potential effects of OCS development on these systems. A human resources workshop addressed existing socioeconomic patterns in the Norton Basin region and changes in these patterns that could be expected in the event of large-scale OCS development.

New information presented at the meeting included:

1. Scenarios of OCS development.
2. Socioeconomic patterns and trends.
3. Sea-ice movement and the effects of ice on OCS structures.

4. Status of knowledge of the Yukon River delta ecosystem.
5. The Chirikov Basin as a feeding area for gray whales.
6. Transport and weathering of spilled oil.

This report has been developed primarily on the basis of information presented, or identified as important, at the synthesis meeting. Outside information has been used to supplement that provided at the meeting.

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2

Physical Environment and Pollutant Behavior

by Joe C. Truett

With major contributions from S.-K. Liu and James R. Payne

Oil spills are considered one of the greatest potential threats of outer continental shelf oil and gas lease development to biological resources. To make the best predictions about the possible ecological consequences of oil spills in the Norton Basin, one must evaluate hypothetical scenarios of the transport and fate of spilled oil. This in turn requires a background knowledge of the physical features and processes characteristic of the region.

This chapter first summarizes the kinds of information about the Norton Basin physical environment that affect oil transport and fate—its geomorphology, meteorology, hydrography, sea ice characteristics, and sediment-transport mechanisms. It then presents scenarios of the transport and fate of oil and other pollutants (*i.e.*, drilling fluids).

2.1 THE PHYSICAL ENVIRONMENT

2.1.1 Geomorphology

Geomorphological features in the Norton Basin OCS Planning Area that influence transport and fate of oil and other pollutants include bathymetry, seafloor sediment characteristics, and coastal landforms.

The continental shelf is relatively shallow throughout the Norton Basin (Fig. 2.1). The deepest portion, with water depths to approximately 50 m, lies within and to the south of the Bering Strait; depths lessen to the southeast toward and into Norton Sound. A shallow (< 10 m) deltaic fan platform created by sediment deposition from the Yukon River extends seaward in the southwest corner of Norton Sound for a few tens of kilometers. Norton Sound itself has an average depth of about 18 m (Cacchione and Drake 1979).

Channels in an otherwise relatively flat bottom exist in Norton Sound just south of Nome, in the Bering Strait, and just east of St. Lawrence Island (Hanley *et al.* 1980; Starr *et al.* 1981). The Norton Basin continental shelf is a mosaic of relict and modern surface sediments, mostly sands, silts, and muds. Holocene transgressive sand and post-transgressive muds predominate in surface sediments of deeper portions of the Norton Basin; modern Yukon River deposits of silt and sand predominate in Norton Sound (Nelson *et al.* 1981) (Fig. 2.2). Currents apparently have inhibited deposition of Yukon River sand and silt over the relict deposits in the Chirikov Basin (McManus *et al.* 1974). In some places, thin gravel lag layers, formed during the Holocene shoreline transgression, cover subsea glacial moraines. Bioturbation by infauna has so extensively changed some of the older deposits, that no near-surface physical structures remain in the sediments (Nelson *et al.* 1981).

Coasts bordering the Norton Basin planning area are extremely varied from place to place in their morphology. The shoreline is generally smooth, interrupted intermittently by bays and isolated headlands (Fig. 1.1). From Cape Prince of Wales on the Bering Strait and throughout Norton Sound the coast consists mainly of narrow beaches with the terrain rising steeply behind them; wave-cut cliffs abut the sound locally in the north and east. Extensive flat coastal lowlands are found along the entire east coast of Norton Bay and along the Yukon River delta. Sand and gravel spits are common along these mainland coasts, and frequently act as protective barriers for shallow lagoons (Sears and Zimmerman 1977; Starr *et al.* 1981).

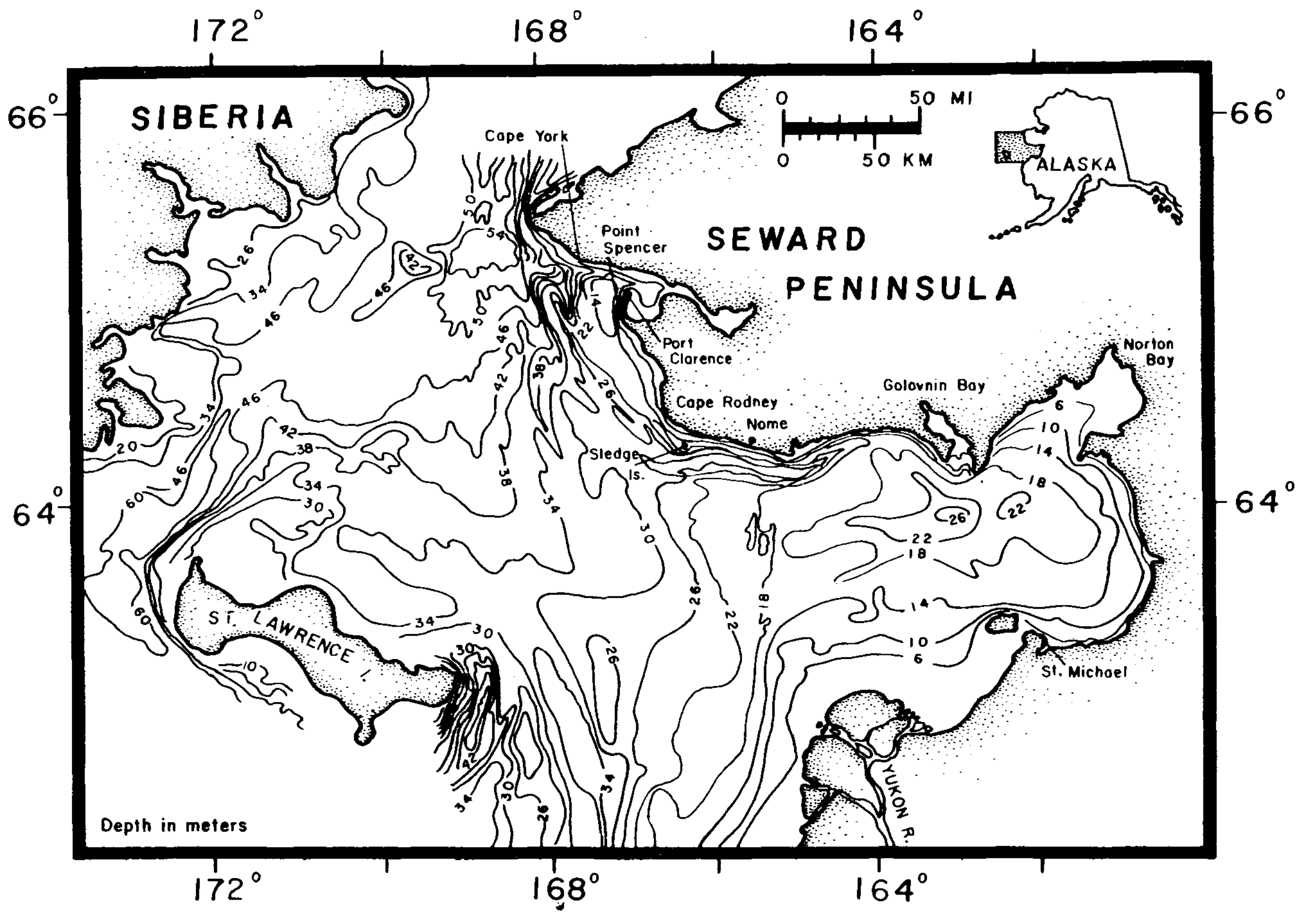

FIGURE 2.1—Bathymetry of the Norton Basin OCS Planning Area, Alaska (from Nelson *et al.* 1981).

Several islands are found in the Norton Basin planning area (Fig. 1.1). Most, except those of the Yukon and other river deltas, are rolling uplands, bordered by steep, rocky, wave-cut cliffs. St. Lawrence Island, the largest, is a lake-dotted bedrock plain, most of it less than 30 m above sea level (Starr *et al.* 1981).

The beaches and intertidal zones are variable in substrate composition (Fig. 2.3). Those fronting the Yukon River delta, and for some distance east of the delta, are mainly mud. Sand or gravel predominate in beaches from eastern Norton Sound all the way around to the Bering Strait, though boulders or bedrock appear along some stretches (Sears and Zimmerman 1977).

2.1.2 Climate and Meteorology

The Norton Basin planning area has two very different regimes of climate—summer and winter. The summer season, June through October, coincides with the time that seas are essentially free of ice. During the winter season, November through May, sea-ice cover is complete or nearly so (McNutt 1981; Starr *et al.* 1981).

The seasonal presence or absence of the ice pack is extremely important for the climate. It introduces a continental-type influence in winter; this allows cold arctic and continental air to establish itself over the ice-covered sea with wide ranges in daily and seasonal temperature. In summer, the open seas cause a maritime climate to prevail, with a more uniform daily temperature regime and enhanced precipitation (Overland 1981).

In winter, polar air masses usually predominate for extended periods. Temperatures average from −15° to −12°C. Winds prevail from the north and northeast, frequently reaching high speeds; velocities exceeding 70 knots (110 km/h) have been recorded during most months. Snowfall during this period may range from 130 to 180 cm (Overland 1981; Starr *et al.* 1981). Summer temperatures are maritime; they are generally as much as 12°C above freezing, but drop below freezing late in the season. Winds are from variable directions, but tend to be southerly; storms moving through from the northern Pacific can cause extended periods of cloudiness and rain. Precipitation in this period ranges from about 40 to 50 cm annually (Overland 1981; Starr *et al.* 1981).

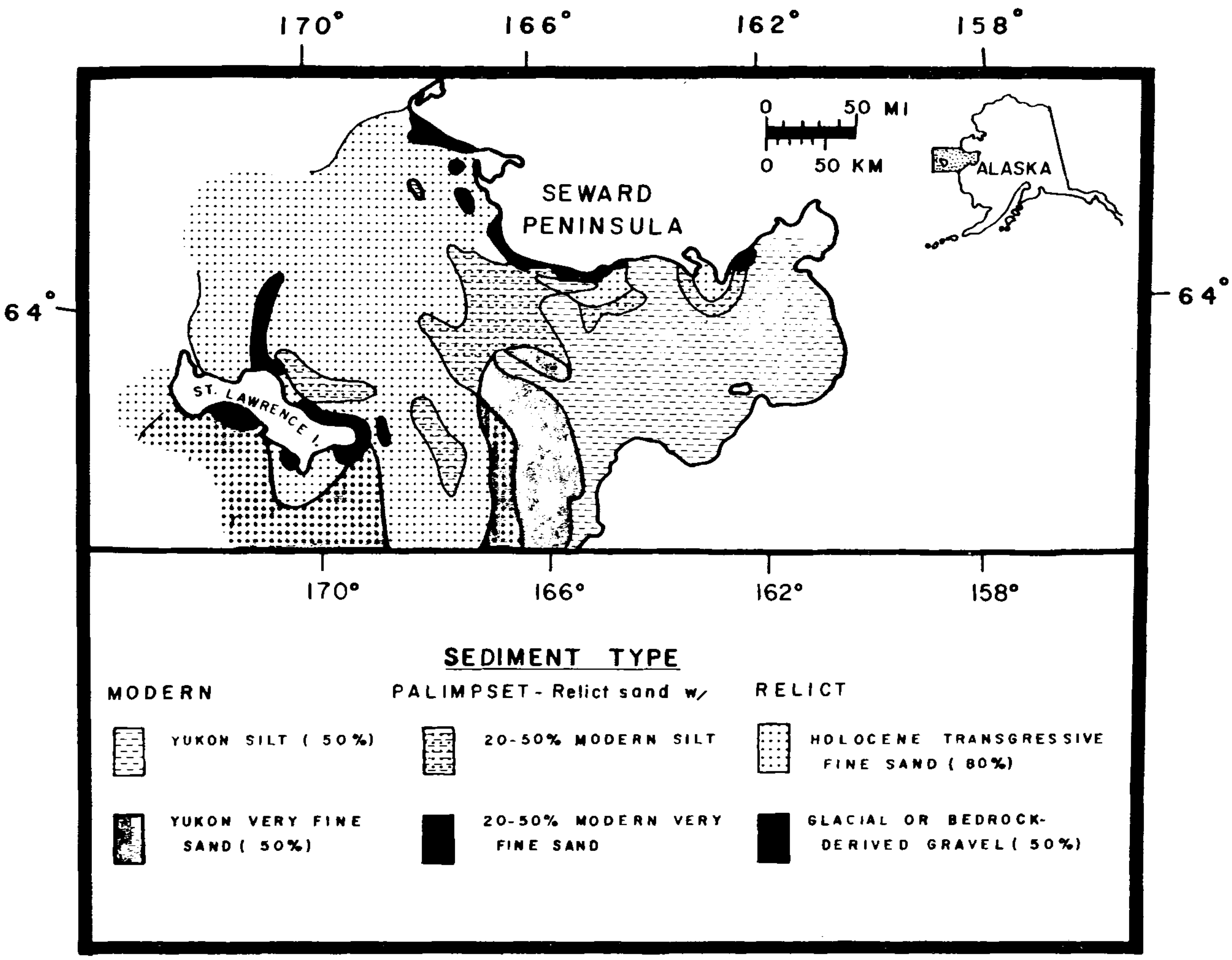

FIGURE 2.2—Surface sediment distribution in the Norton Basin (from Nelson *et al.* 1981).

2.1.3 Hydrography and Circulation

Like the climate, summer and winter have two distinctly different patterns of hydrography and circulation in the Norton Basin area. Not surprisingly, these correspond in time to the two seasons of meteorological activity. Zimmerman (1982) noted that an autumn transitional period occurs from November through early December and that a spring transitional period occurs May through early June. These transitional periods have, as would be expected, highly variable patterns of circulation and transport as the summer pattern changes to the winter pattern in fall, and vice versa in spring. The presence of ice in winter and its absence in summer, plus the difference in meteorological conditions between summer and winter, both influence the seasonal differences in circulation.

In summer, two major interrelated factors dominate the regional hydrography: the persistence of distinctive water masses and the general circulation patterns of the water. Three water masses with relatively distinct characteristics persist throughout summer; from east to west these have been designated Alaskan Coastal water, Bering Shelf water, and Anadyr water (Coachman *et al.* 1975) (Fig. 2.4). In certain regions (Fig. 2.4) there appears to be significant mixing between water masses, but in general the lateral mixing appears to be small. These masses differ slightly among themselves in temperature and salinity: the Anadyr water is somewhat warmer and more saline than the Bering Shelf water, and the Alaskan Coastal water is warmer and less saline than either of the others. All these water masses flow generally northward through the planning area and exit through the Bering Strait (Fig. 2.5). This general flow pattern persists throughout the water column; it is driven mainly by a difference in sea level between the northern Bering Sea and the Chukchi Sea (Coachman *et al.* 1975), but tends to be reinforced somewhat in summer by the prevailing southerly winds.

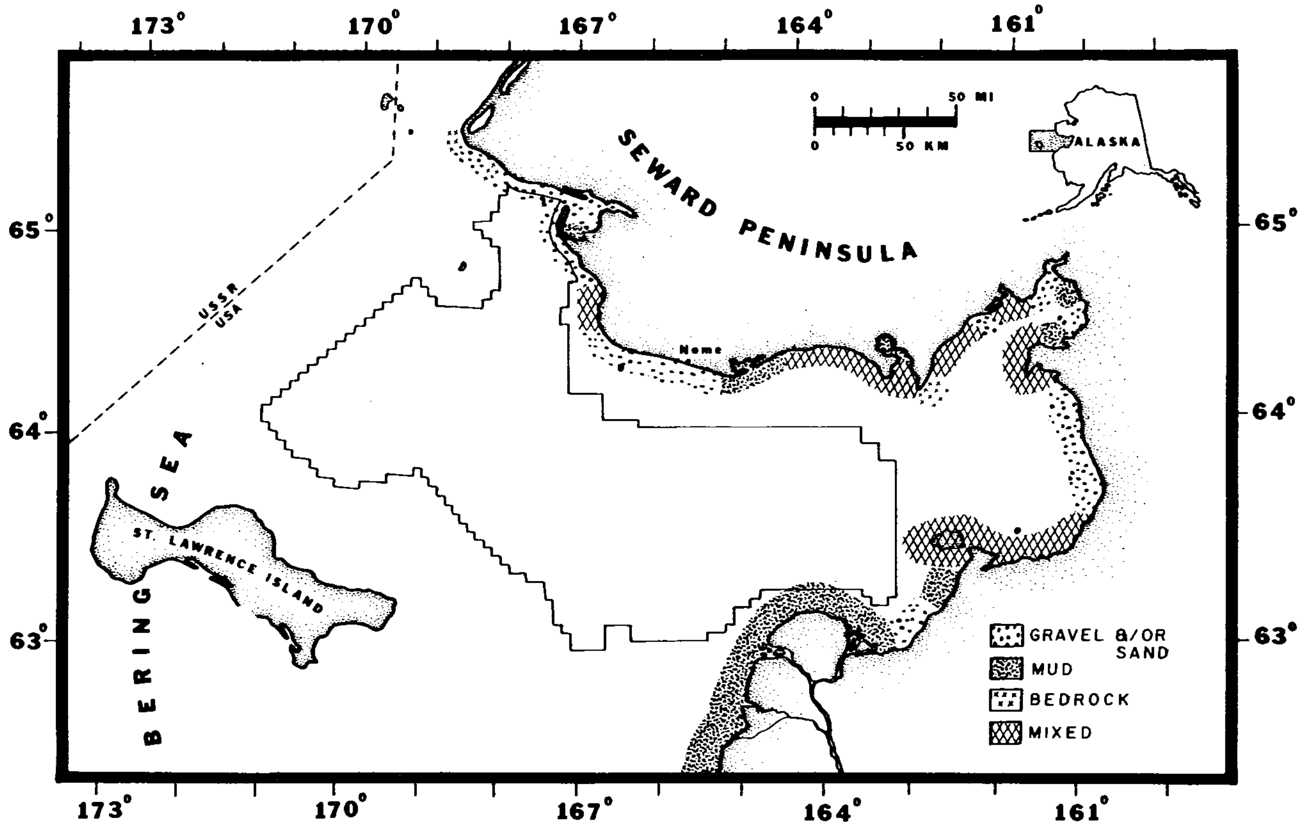

FIGURE 2.3—Substrate composition of mainland beaches in the intertidal zone of the Norton Basin (after Sears and Zimmerman 1977).

Local variations in the general northward movement coincide with the presence of large islands and embayments. In the regions north and south of St. Lawrence Island, currents are complex, but have not yet been thoroughly described; limited evidence shows a cyclonic eddy occurring off the northeast coast of the island (Takenouti and Hood 1974). In western Norton Sound a cyclonic flow pattern exists (Coachman *et al.* 1975) (Fig. 2.5), and in eastern Norton Sound waters appear to be somewhat isolated from the effects of the general Norton Basin flow pattern (Schumacher *et al.* 1978; Muench *et al.* 1981). Flow through the Chirikov Basin and Bering Strait is accelerated as the northward-moving water is constricted by the adjacent landforms.

The regional circulation pattern appears to be generally the same in winter as it is in summer. Salo *et al.* (1983) found the vector-mean current in winter to be in general northward and parallel to the local trend in bathymetry. In the Chirikov Basin and Bering Strait the flow was more directionally stable than in more southerly areas, probably because of the constriction of flow by geography in the region. Current reversals to the south, promoted by strong northerly winds, appear to be common. Reversals generally occur 2–4 times per month (Table 2.1) and last less than 5 days (K. Aagaard, Univ. Washington, unpubl. data). The southward flow created by these reversals tends to extend to the south around the end of St. Lawrence Island, but to not enter very far into Norton Sound (Starr *et al.* 1981, quoting L. Coachman pers. comm.).

Whether the Anadyr, Bering Shelf, and Alaskan Coastal water masses remain distinct from each other in winter is not known. In Norton Sound at least, lowered river inputs of fresh water and exclusion of salts from water freezing at the surface tend to mask the low-salinity signature of the Alaskan Coastal Water (Drake *et al.* 1979).

2.1.4 Tides and Storm Surges

Lunar tides and wind-generated sea level changes in nearshore areas occur in both summer and winter, but available data have been collected mostly in summer. Changes in sea level, and currents generated by tides and storm surges, are of interest in terms of oil transport and fate.

Tides are of the mixed, predominantly semidiurnal (two low and two high tides per day) type over most of the Bering Sea shelf, including St. Lawrence Island and the southwestern coast of the Seward Peninsula. Along the Yukon delta and in inner Norton Sound,

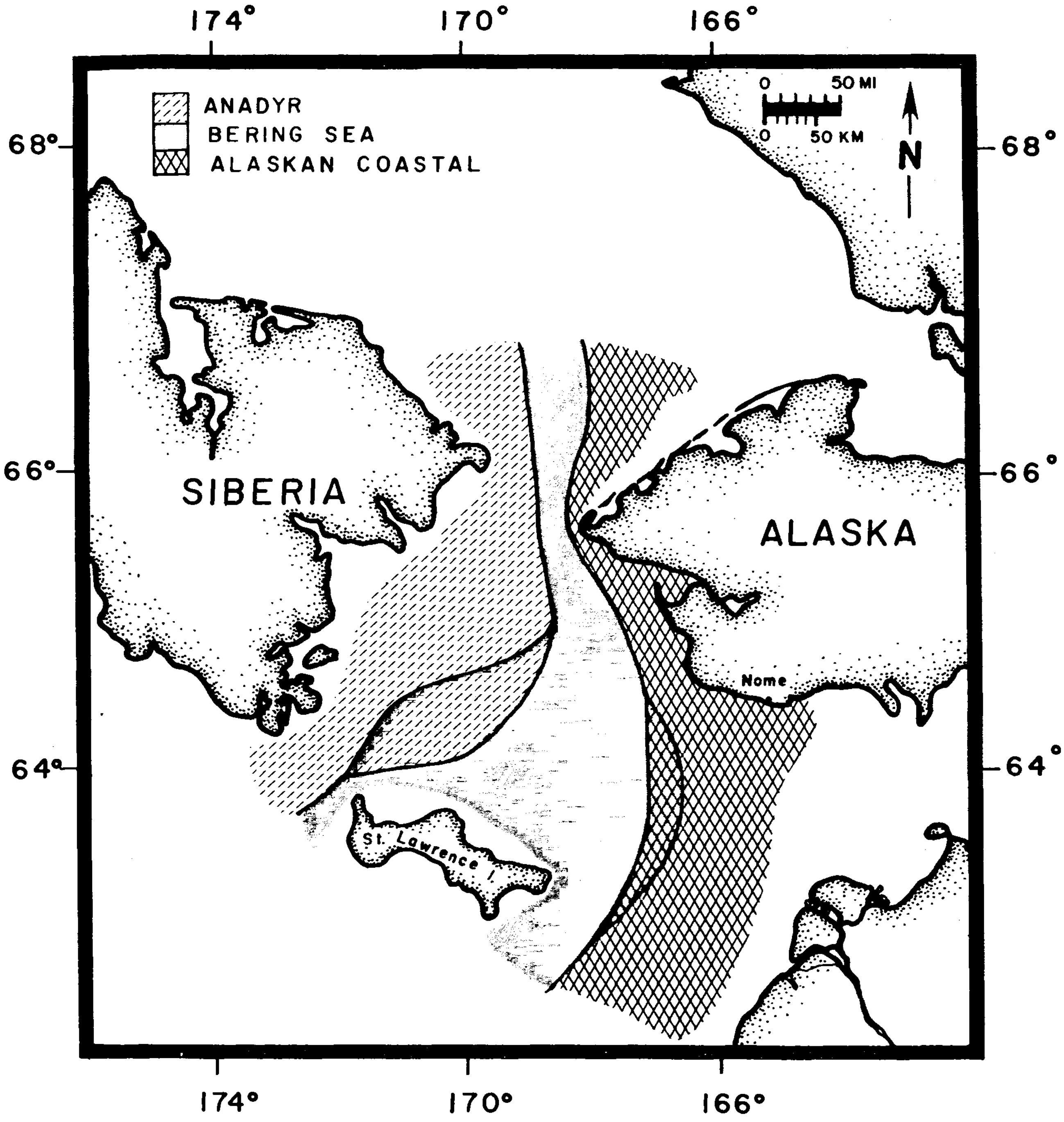

FIGURE 2.4—Approximate locations of major water masses in the Norton Basin in summer (from Coachman *et al.* 1975).

diurnal tides (one high and one low tide per day) predominate (Starr *et al.* 1981). Figure 2.6 illustrates modeled cotidal charts for the semidiurnal and diurnal tidal components.

The day-to-day change in sea level at the coast is a function of two variables, the tide and the wind. The influence of each on water levels at mainland coasts of the Norton Basin area is described by Starr *et al.* (1981) as follows:

The diurnal tidal range in Norton Sound varies from 1.2 m at Apoon Pass on the Yukon delta, to 0.4 m at Port Clarence. Winds, however, have a greater influence on water levels than the tide. At Nome, offshore winds can cause water levels from 0.6 to 0.9 m below mean lower low water for days at a time. Water levels of up to 4.3 m above mean lower low water have been recorded during storms. In Port Clarence, moderate to strong south or southwest winds of several days' duration will raise

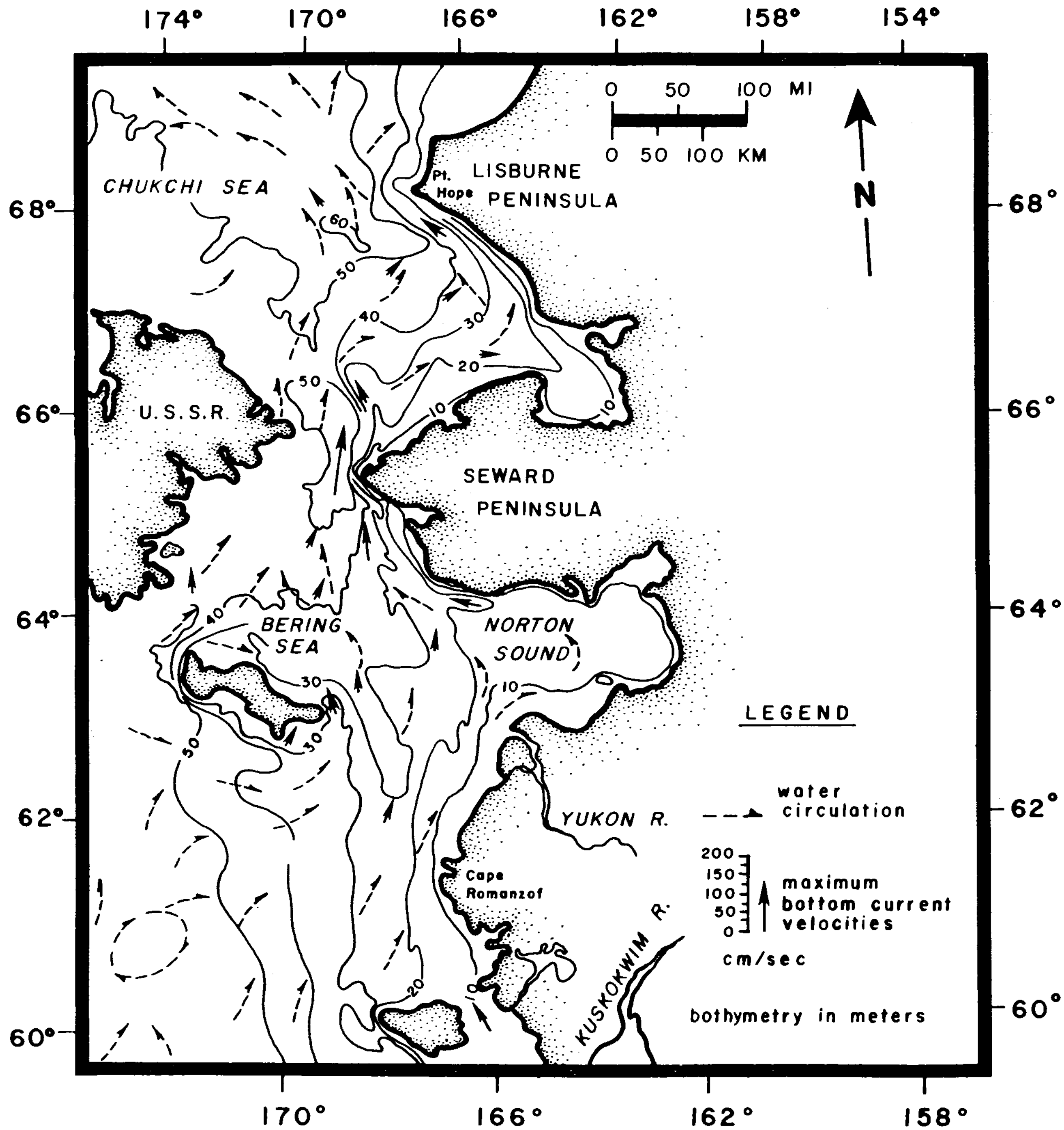

FIGURE 2.5—Offshore water circulation and maximum bottom current velocities from available measurements in the northern Bering Sea (from Nelson *et al.* 1981).

the height of the tide without changing the range. Continued northerly winds produce a lowered level, although to a lesser extent. Extensive flooding of low coastal areas can occur during wind-caused high tides. Winds of sufficient strength to cause flooding are most likely to occur in the fall. Spring storms of sufficient strength to cause flooding are rare (USCP 1977).

Currents induced by tides and winds are strongly affected by nearshore bathymetry; their direction and speed vary from area to area along the coast and near the islands, as described by Starr *et al.* (1981):

> Offshore, the area north of St. Lawrence Island appears to be a region of extreme complexity of tidal currents with areas of convergence and divergence

and abrupt variations in velocity as a result of the meeting of the Arctic and Pacific tides (Pearson *et al.* 1981). Diurnal tide currents dominate in Norton Sound. These currents are oriented east-west, with speeds of 0.7 to 1.1 km/h (Muench 1980). Nearshore currents have been documented in USCP (1977). In the Yukon delta channels, tidal currents varying from 0.9 to 2.7 km/h have been observed. In St. Michael Bay the current velocity is about 1.5 km/h and the current flows southeast on the flood and north on the ebb. In Golovnin Bay, near Carolyn Island, the tidal current velocity is about 0.9 km/h. The flood current is north; ebb current is south. Three km offshore of Nome, tidal currents average 1.8 km/h at maximum strength with flood currents flowing east and ebb currents flowing northwest. Between Sledge Island and the mainland tide rips have been observed during storms. Northwest currents in this area average 1.8 km/h at maximum strength; southeast currents average 0.9 km/h. There are no perceptible south or east currents above Cape Rodney. General current flow in this region is north and west. Along the outside coast west of Point Spencer and south of Cape York, there is a general westerly current of 2–4 km/h. This velocity is appreciably affected by direction, force, and duration of the wind. Current observations in the entrance to Port Clarence indicate that velocities seldom exceed 0.9 km/h for 3–5 km north of Point Spencer, while 2 km east of the point, velocities up to 1.8 km/h have been observed (USCP 1977).

2.1.5 Sea Ice

Sea ice forms in the Norton Basin each winter and melts completely each summer. The annual growth of the ice and its characteristics during winter have been aptly described by Starr *et al.* (1981):

> In the fall, northerly winds cool the waters of Norton Sound and the northern Bering Sea north of St. Lawrence until the water column is isothermal and at freezing temperatures. Continued cooling produces ice formation (Pease 1981). Freeze-up begins in the shallow coastal bays and lagoons as early as September in some years and as late as November in others (USCP 1977). In Norton Sound, ice formation begins along the northern shore with first ice typically forming in Norton Bay (Muench *et al.* 1981).
>
> During the winter, ice cover is essentially complete. Under northeast winds that predominate at this time of year, persistent polynyas form in the pack ice along the south side of the east-west-trending coasts of St. Lawrence Island and Seward

TABLE 2.1—Approximate statistics on southward flow in the Bering Strait, September–March, 1976–77.

Month	No. of Events	Duration (days)	Mean Duration (days)	Daily Mean Maximum Transport ($\times 10^6$ m^3 s^{-1})	Daily Mean Velocity on Day of Maximum Transport (Areal Mean Across Strait) (cm s^{-1})
September	3	1+5+1	2.3	0.9	24
		= 7		1.3	34
				0.5	13
October	2	3+8	5.5	1.4	37
		= 11		4.5	118
November	4	3+2+2+2	3.3	0.8	21
		= 10		1.9	50
				0.7	18
				1.0	26
December	3	4+3+2	3.0	1.9	50
		= 9		1.2	31
				1.1	29
January	3	1+3+5	3.0	0.3	8
		= 9		1.1	29
				1.0	26
February	2	4+4	4.0	1.8	47
		= 8		1.4	37
March	2	4+2	3.0	1.5	39
		= 6		0.4	10
Sept.–Mar.	19	60	3.2	1.35	34

SOURCE: Provided by K. Aagaard.

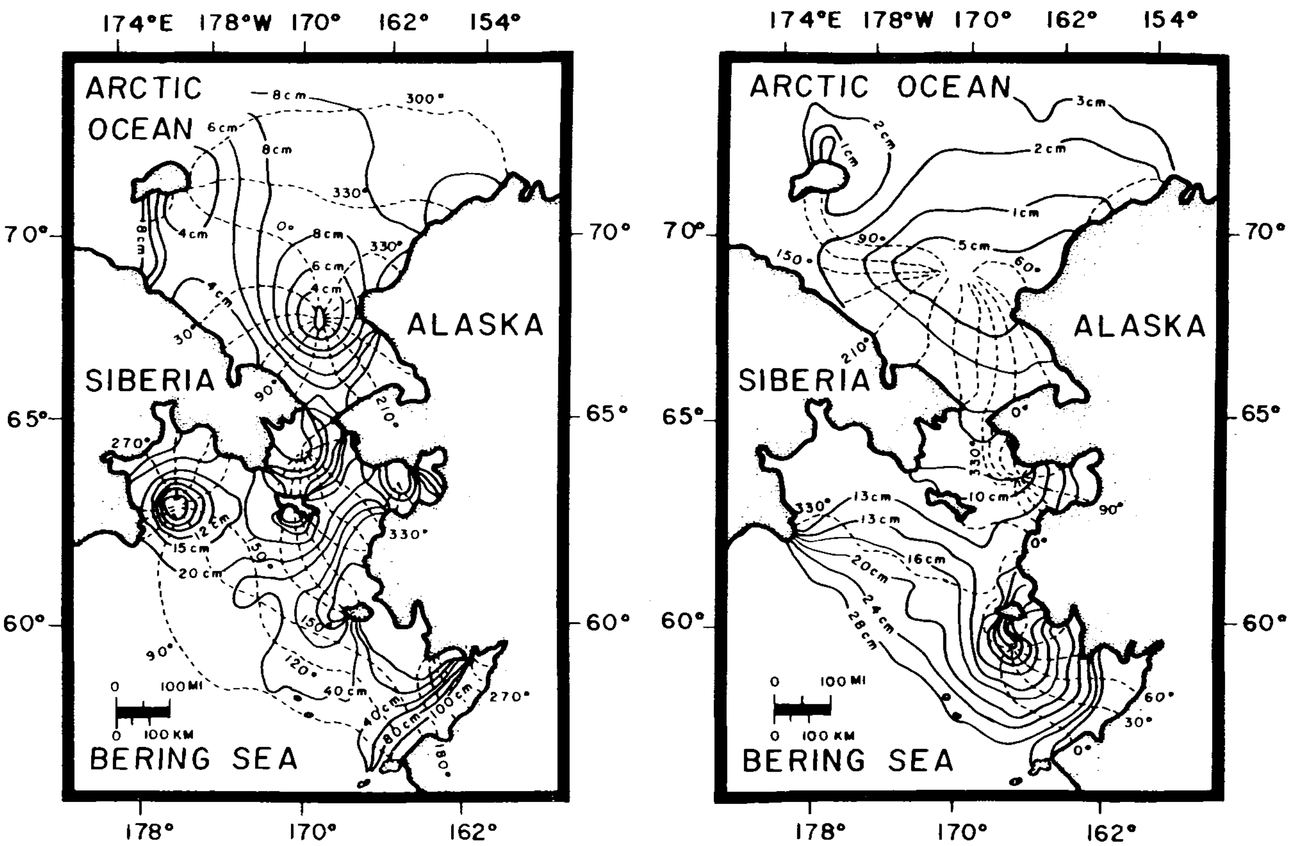

FIGURE 2.6—Computed cotidal charts for the semidiurnal (left) and diurnal (right) tidal components using the Rand Corporation three-dimensional model of the Bering and Chukchi seas (from Liu and Leendertse 1984).

Peninsula. A polynya also forms in eastern Norton Sound during more easterly winds (Pease 1981). These polynyas are areas of continual ice formation, as grease ice formed in the upper layer of the water thickens until it forms a surface layer that can support ice growth underneath. This thickening ice forms pancakes, and eventually, larger floes that are carried downwind (McNutt 1981).

Under continuing north winds, ice piles up against the shorefast ice off the Yukon delta and in a wedge along the north coast of St. Lawrence Island. At St. Lawrence Island, shear zones exist to either side of the wedge of thick ice. Floes are broken off at these shear zones and under northeast wind conditions are carried south-southwest towards the ice edge (McNutt 1981). Ice pileup along the Yukon delta shorefast ice front creates areas of pressure ridging along the shear zone.

In nearshore regions, shorefast ice develops. Shorefast ice is composed of both bottomfast and floating fast ice and is contiguous with the shore. In the shallow waters off the Yukon delta, the shorefast ice zone extends up to 40 km offshore (Ray and Dupré 1979). Throughout the northern Bering Sea, the edge of the shorefast ice is generally found inside of the 20-m isobath. Exceptions to this occur where coastal configurations protect the ice from tidal and current action.

Stringer (1980) and Stringer *et al.* (1980) provide detailed descriptions of the extent and nature of shorefast ice along the mainland coasts of the Norton Basin planning area. In general, the fast ice seems to reach its maximum seaward extent by February and to maintain that approximate location until mid-May or later. Though there is moderate variability among years and great variability among locations in maximum seaward extent of the fast ice, it is generally contained well within the 20-m depth contour. As would be expected, the fast ice extends farthest offshore in the southern parts of Norton Sound, where nearshore water depths are shallower (Fig. 2.7).

Because pack ice tends to move southward or southwestward out of the Chirikov Basin and Norton Sound in winter under the influence of northerly and northeasterly winds, areas along the southern coast of the Seward Peninsula (and sometimes in eastern Norton Sound) open and refreeze frequently (Fig. 2.8). For this reason, Norton Sound has sometimes been called an "ice factory," contributing new ice

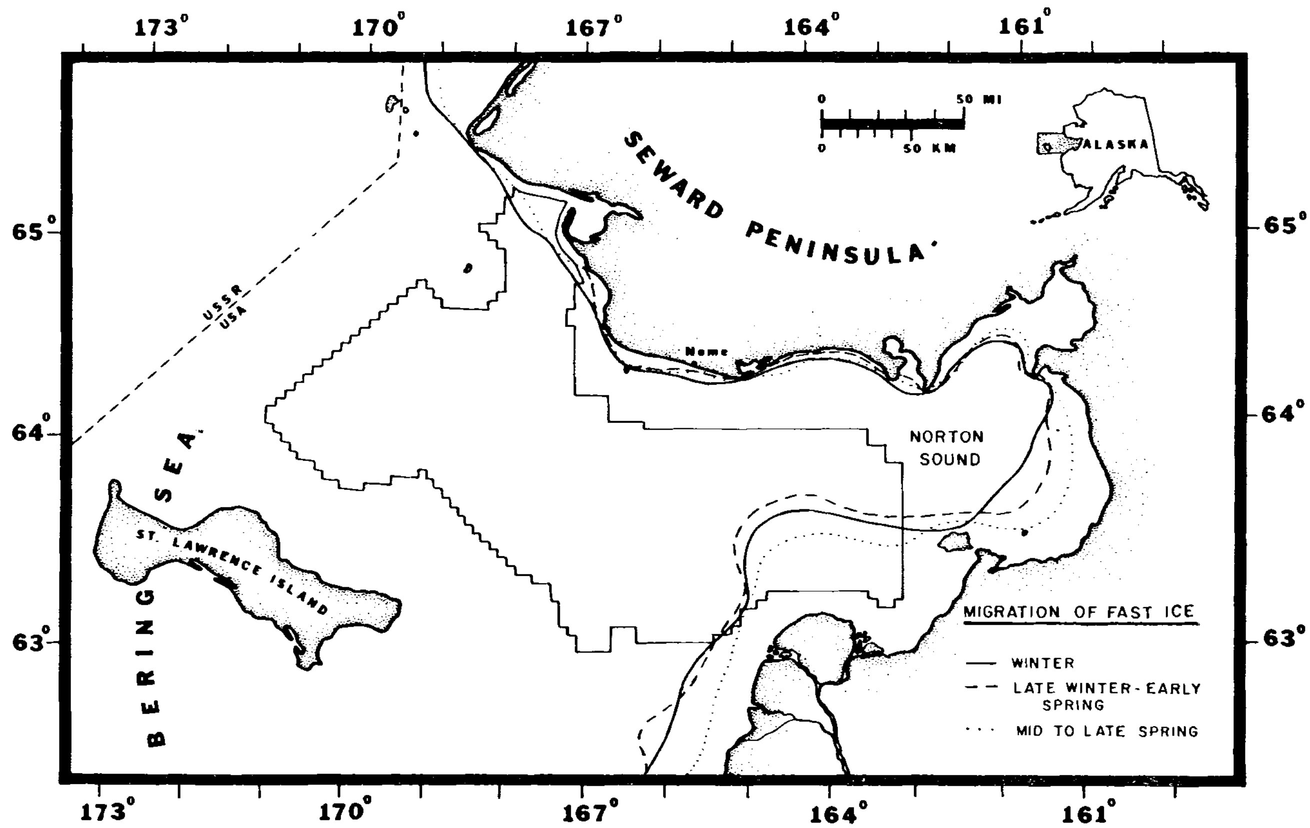

FIGURE 2.7—Average (1973–76) fast ice edges along mainland coasts of the Norton Basin from winter to late spring (from Stringer 1980).

more or less throughout the winter to the Bering Sea ice pack. Figure 2.9 depicts ice movement out of Norton Sound and gives an idea of the general rate of movement.

Another source of additional ice to the Bering Sea is ice "breakout" that moves ice from the Chukchi Sea through Bering Strait and into the Norton Basin area. Because the Bering Strait is a geographically constricted area, ice moving southward from the Chukchi Sea under the influence of northerly winds typically forms an arch that blocks or "plugs" the strait, leaving an area of ice divergence south of the strait (Fig. 2.8). Periodically, under strong northerly winds, the arch fails and Chukchi Sea ice floes rush southward through the strait into the Norton Basin area. These breakouts appear to occur two to four times a year, usually in early to midwinter, and each breakout lasts an average of about 4 days (W. Stringer, Univ. Alaska, pers. comm.).

From May through early June in the Norton Basin, air temperatures rise and winds from the south increase in frequency and intensity. Ice leaves the area through two mechanisms: (1) melting, and (2) moving northward under the influence of southerly winds and the regional northward movement of water (see Section 2.1.3). The rate of ice melt is enhanced in the vicinities of large river deltas (*e.g.*, the Yukon) by discharge of river floodwaters. By July the area is generally clear of ice (Zimmerman 1982).

2.1.6 Sediment Transport and Deposition

Knowledge of the patterns of sediment transport in the Norton Basin may give clues about the transport pathways and depositional fates of oil, drilling muds, or other pollutants carried by the water. To provide a general picture of these patterns, we review information about sediment sources, transport mechanisms and trends, and depositional fates.

Most of the present-day sediment contributed to the Norton Basin is associated with Yukon River runoff (McManus *et al.* 1977). The Yukon River discharges about 88×10^6 metric tons of sediment annually into the Norton Basin; this is about 90% of the total riverborne sediment entering the entire Bering Sea (McManus *et al.* 1974). Samples taken from the Yukon River in summer, when the peak discharge occurs, show suspended sediments to be about 10% clay, 60–70% silt, and 20–30% very fine sand.

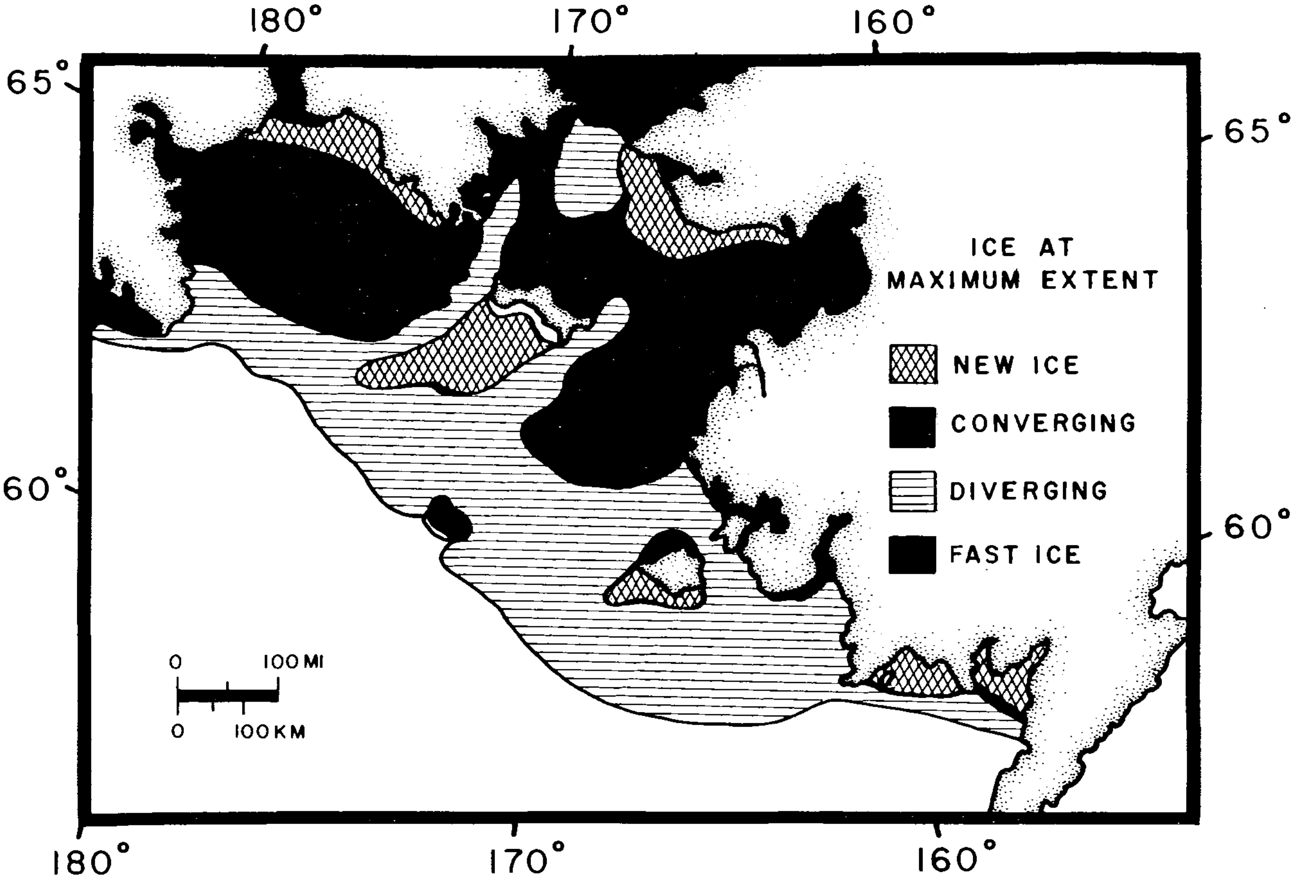

FIGURE 2.8—Schematic diagram of areas of ice generation, compaction, and divergence in the northern Bering Sea. The area of eastern Norton Sound under certain wind conditions also behaves as an ice-formation area (from McNutt 1981).

Truett *et al.* (1984) describe the general transport mechanisms and directions of this sediment once it reaches the sea. Sand and coarse silt particles are deposited mainly along the subsea channels of the delta platform, on the shallow platform itself (which may extend 20–30 km beyond the coast), on the prodelta at the outermost edges of the delta platform, or even beyond. Fines (fine silt and clay) are seldom deposited in these high-energy environments on or near the delta platform.

Some of the fine sediments are entrained in the rapidly moving Alaskan Coastal water, bypass the Chirikov Basin, and are carried through Bering Strait into the Chukchi Sea, where they are deposited. Little modern sediment appears to be deposited in the Chirikov Basin or Bering Strait regions (Fig. 2.2), presumably because of the relatively rapid bottom currents that prevail there. Other portions of these fines reach relatively quiet environments in eastern Norton Sound, and bays and lagoons along the mainland southwest of the Yukon delta. The thinness of Yukon sediments in many areas of Norton Sound suggests that they may be deposited initially in Norton Sound but may be resuspended by tide- and storm-induced currents to eventually be entrained in the Alaskan Coastal current and carried out of the Norton Basin (McManus *et al.* 1977).

In the coastal waters, coarse sediments derived from coastal erosion or from geologically old deposits are transported by longshore drift. Starr *et al.* (1981) discuss general features of longshore sediment transport near the mainland. There appears to be virtually no longshore transport along the margins of the presently active Yukon delta; the breadth and shallowness of the delta tend to reduce wave height and decrease the angle of the waves, and thereby dampen longshore currents. Between the Yukon delta and Stuart Island, longshore transport is to the east. Transport is to the north in extreme eastern Norton Sound. Transport appears to be generally eastward along the north shore of the sound, though some drift to the west may occur. Between Norton Sound and the Bering Strait, long-term drift appears to be usually northward. Many of the larger bays (*e.g.*, Norton, Golovnin, Port Clarence) appear to be sediment sinks.

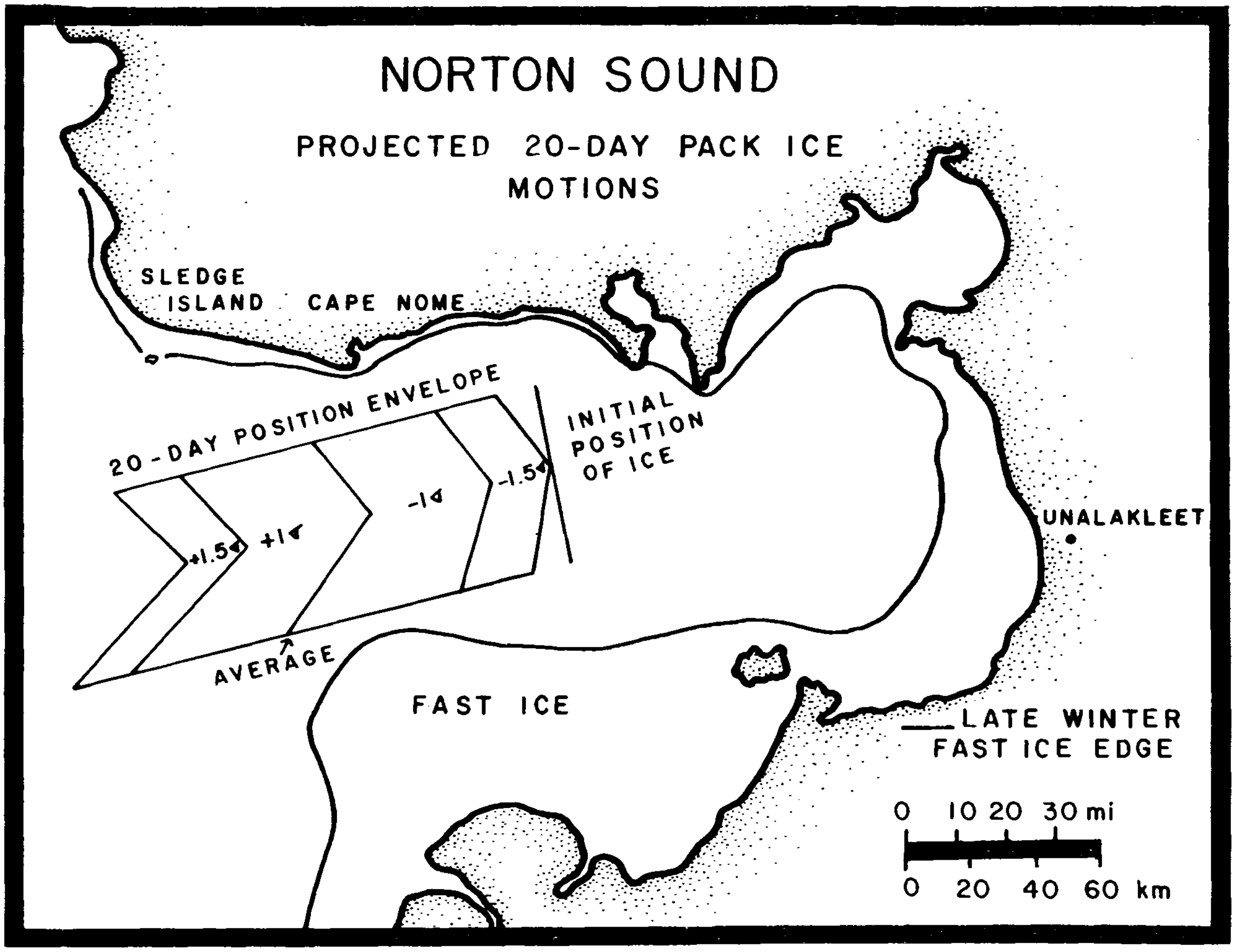

FIGURE 2.9—Net displacement of Norton Sound pack ice after drifting for 20 days. Shown is an envelope containing the 1 and 1.5 standard deviation drift envelopes and position of average drift after 20 days' drift from the initial position line extending north to south across the sound (from Stringer 1983).

2.2 TRANSPORT, FATE, AND CLEANUP OF OIL

2.2.1 Transport

The principal strategy used at the Norton Basin Synthesis Meeting for describing transport characteristics of oil that could potentially be spilled at sea was to examine the results of oil transport models developed by Rand Corporation. Information contained in this section is from publications related to these models and from S.-K. Liu, Rand Corporation (pers. comm. and unpubl. data).

The Rand modeling system that has been used to simulate oil trajectories in the Norton Basin area (and elsewhere in the Bering, Chukchi, and Beaufort seas) has a three-dimensional hydrodynamic model as one of its more important components. This model is formulated according to the equations of motion for water and ice, continuity, state, the balance of heat, salt, pollutant and turbulent energy densities, on a three-dimensional grid. The basic modeling equations and their derivations may be found in Liu and Leendertse (1978, 1984).

A weather model in addition to the hydrodynamic model is required for oil trajectory simulations. The weather model used is a stochastic model that contains a storm-track model component. It is based on synoptic weather analyses and storm-track statistics. It is described in detail by Liu and Leendertse (1984).

In addition to the hydrodynamic and weather models, the Rand modeling system includes models predicting the gravity-wave (Stokes' drift) component and dimensions of the spilled oil. These are likewise described in Liu and Leendertse (1984).

At the Norton Basin Synthesis Meeting, movement directions and physical characteristics of oil slicks from several hypothetical spills as predicted by the Rand models were presented. Computer graphics

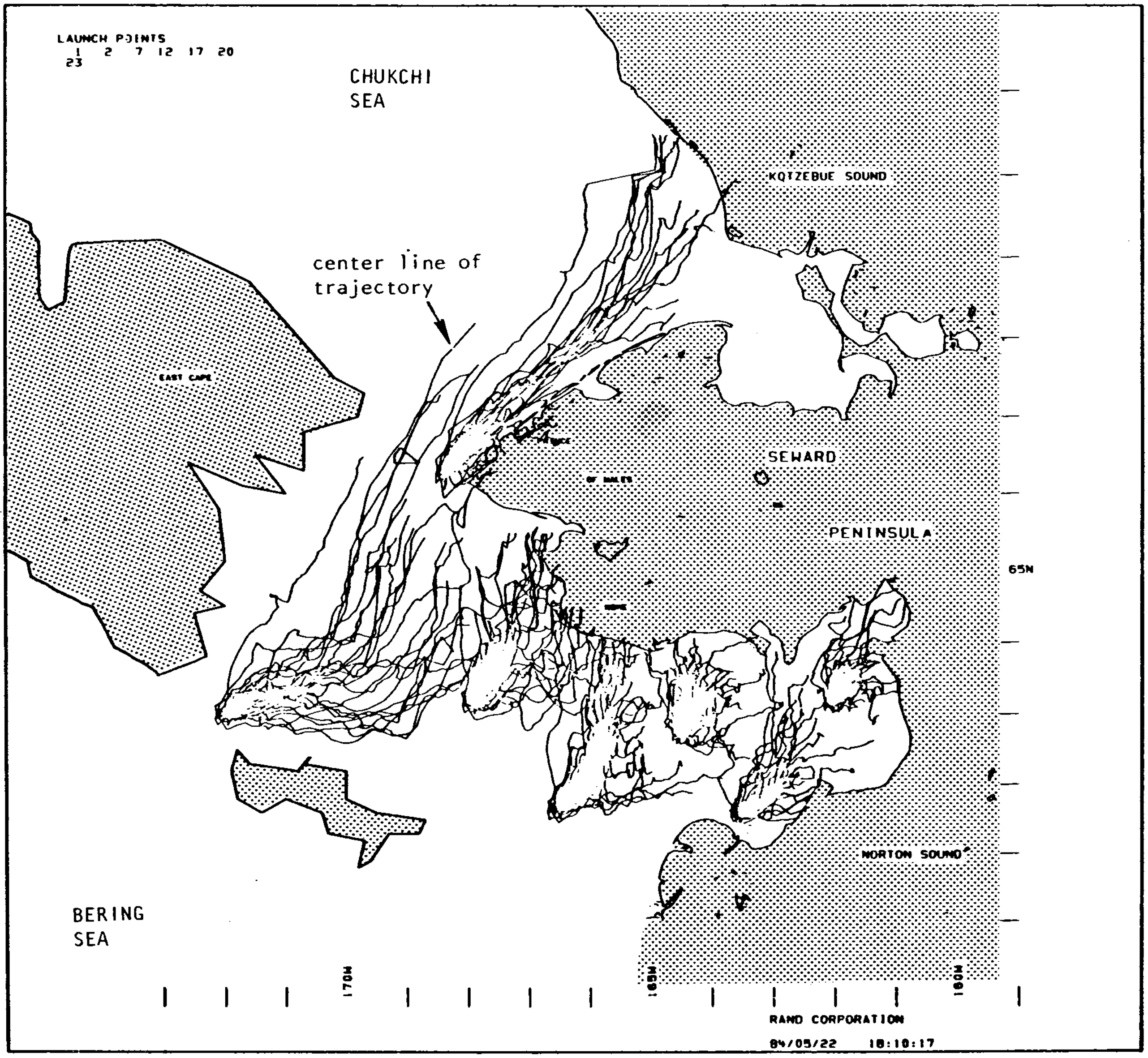

FIGURE 2.10—Thirty-day trajectories of oil from seven hypothetical launch points in the Norton Basin under 25 stochastic weather scenarios during summer oceanic conditions (provided by S.-K. Liu, Rand Corporation).

were displayed of likely patterns of dispersion of oil from several "launch points" in the Norton Basin area where oil might conceivably be spilled. Movements of slicks under typical weather conditions in summer and in winter were depicted.

Oil spill trajectory patterns in summer were considerably different from those in winter. Selected descriptions of spill trajectories and characteristics of surface envelopes modeled for spilled oil in summer and in winter follow. These analyses have strong implications for the potential effects of oil spills on biota. (Chances of oil reaching particular areas within the Norton Basin are discussed in Section 1.3.1.)

Summer

Because of the prevailing southerly winds and northward-moving ocean currents in summer, oil spills would tend to move north or northeast at this time (Fig. 2.10). Few landfalls from Norton Basin spills in summer are likely on St. Lawrence Island, in the Yukon delta area, or on the south side of Norton Sound. Landfalls might commonly occur on the south side of the Seward Peninsula.

Typical 30-day oil envelopes from hypothetical 2,000-bbl-per-day oil spills in summer are shown in Figures 2.11 and 2.12. These depictions show that the major spreading of oil on the surface follows the

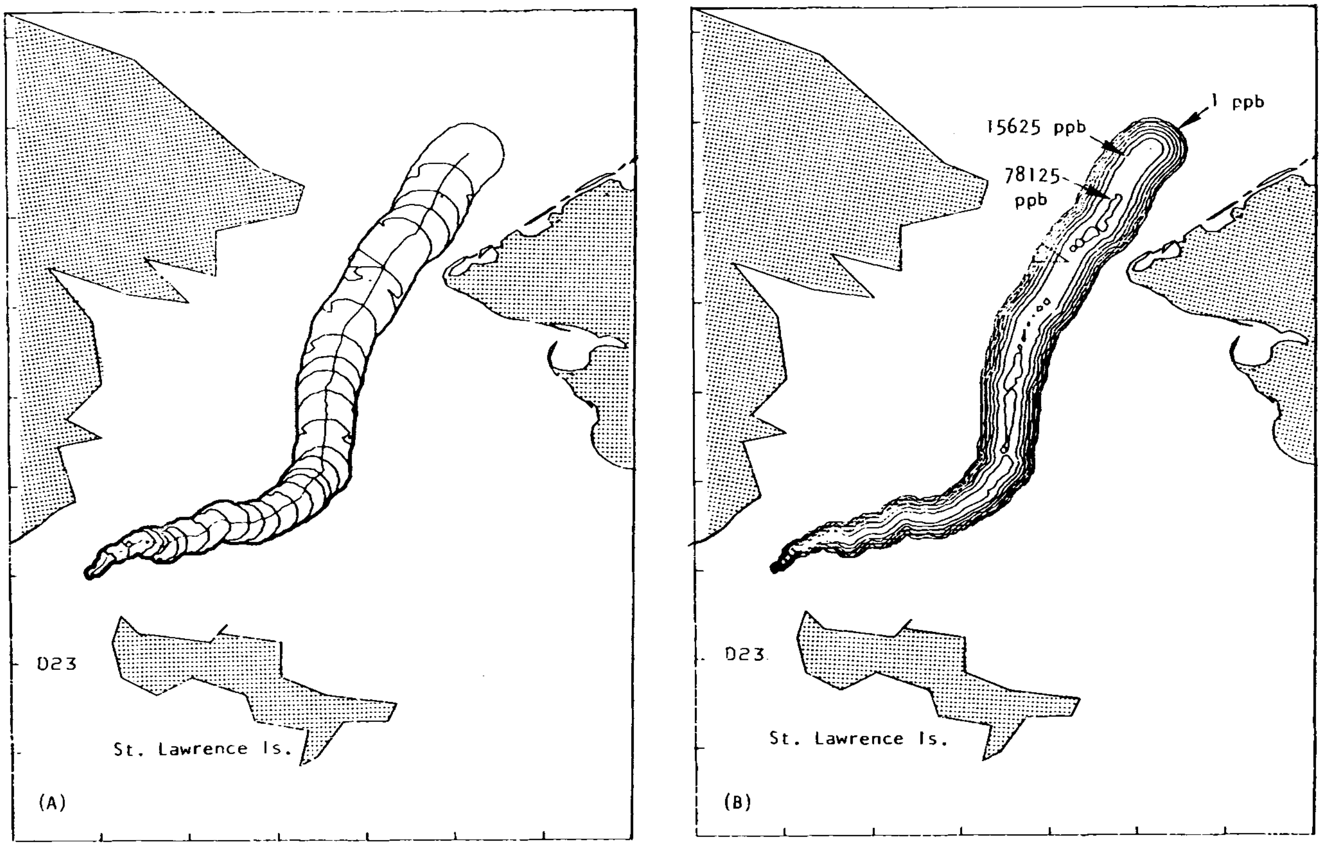

FIGURE 2.11—Daily displacement, over 30 days, of 1 ppb (in surface cm) oil envelope (A) and the distribution of surface concentration (B) from an oil spill of 2,000 bbl per day northwest of St. Lawrence Island in the summer season (provided by S.-K. Liu, Rand Corporation).

wind and current and moves at about 5-10 km per day. Lateral spreading (cross-wind or cross-current) is slow, and oil concentrations in the top few centimeters of the sea surface decrease rapidly perpendicular to the spill path.

Winter

Oil spilled in the Norton Basin in winter would tend to move west or south under the influence of the prevailing northerly and easterly winds, and travel 3-5 km per day. Figures 2.13 and 2.14 suggest that St. Lawrence Island would be in the path of many spills originating in the Norton Basin during this period, and that spilled oil might have a tendency to accumulate on the north side of the island. Launch points within Norton Sound are not illustrated, but it seems reasonable that southern shores of the sound, including the Yukon delta area, might lie in the path of oil spilled in central or eastern parts of the sound. From mid- to late winter, it is likely that shorefast ice would prevent oil from making landfall in most localities. Theoretically, oil in the water column beneath the ice could possibly be carried into river deltas, such as the Yukon, by estuarine (salt-wedge) transport acting beneath the ice. But studies completed in the Canadian Beaufort Sea and elsewhere have suggested that current speeds in excess of 15-25 cm/s are required to move fresh oil under smooth first-year ice, and if ice ridging was present, even greater impediments to under-ice movement of oil would exist (J. Payne, JRB Associates, pers. comm.).

Typical 30-day envelopes from two hypothetical 2,000-bbl-per-day oil spills in winter are shown in Figures 2.15 and 2.16. Spreading characteristics and decline in surface concentrations perpendicular to the spill pathway are similar to those of spills launched in summer (Figs. 2.11 and 2.12).

2.2.2 Fate

This section examines the likely fate (persistence and degradation) of oil once it has been spilled in an area. From an ecological impact standpoint, it is useful to evaluate the fate of oil both in the water and in coastal habitats.

When fresh crude oil or refined petroleum products are released to the marine environment they are im-

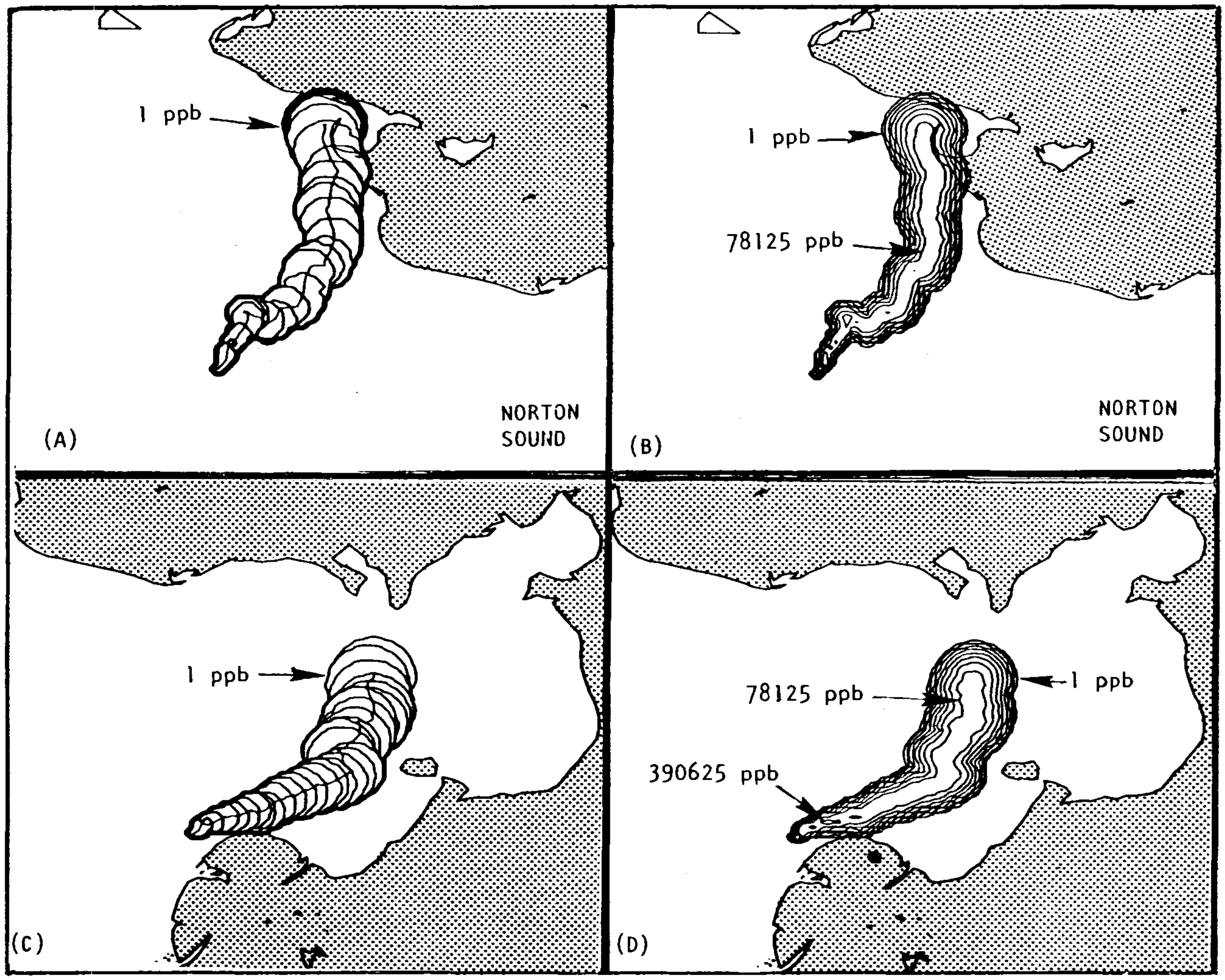

FIGURE 2.12—Daily displacement, over 30 days, of 1 ppb (in surface cm) oil envelope (A, C) and the distribution of surface concentration (B, D) from an oil spill of 2,000 bbl per day at two locations in Norton Sound in the summer season (provided by S.-K. Liu, Rand Corporation).

mediately subject to a wide variety of weathering processes that change their physical and chemical makeup, and thus change their effect on biota. The predominant weathering processes are evaporation, dispersion of whole oil droplets into the water column, dissolution of selected aromatic compounds, adsorption of dispersed and dissolved hydrocarbons onto suspended particulate matter, water-in-oil emulsification (mousse formation), microbial and photochemical oxidation, and advective removal of dispersed and dissolved components from the parent slick (Payne *et al.* 1984a). Payne *et al.* (1983, 1984a) have developed mathematical models, based on field and laboratory experiments, of weathering of Prudhoe Bay crude oil in marine water and subarctic conditions. The following discussions of oil fate in water are based primarily on their findings.

If whole crude oil were released to the Norton Basin environment, evaporation and dissolution losses would probably remove only components up to the nC-12 (and methyl-substituted naphthalene) range. Higher-molecular-weight aliphatic and aromatic components would not be subject to rapid removal and would be degraded only by the slower microbially mediated processes. If lighter-molecular-weight refined petroleum products, such as diesel oil or JP-5, were released to the environment then evaporation weathering would be the predominant removal mechanism of the majority (but not all) of the hydrocarbon components. Weathering scenarios run on the NOAA oil weathering model for JP-5 suggest that even after 200 hours (at 32°C and a 20-knot wind) approximately 20% of the overall mass of even such relatively volatile cargo might remain.

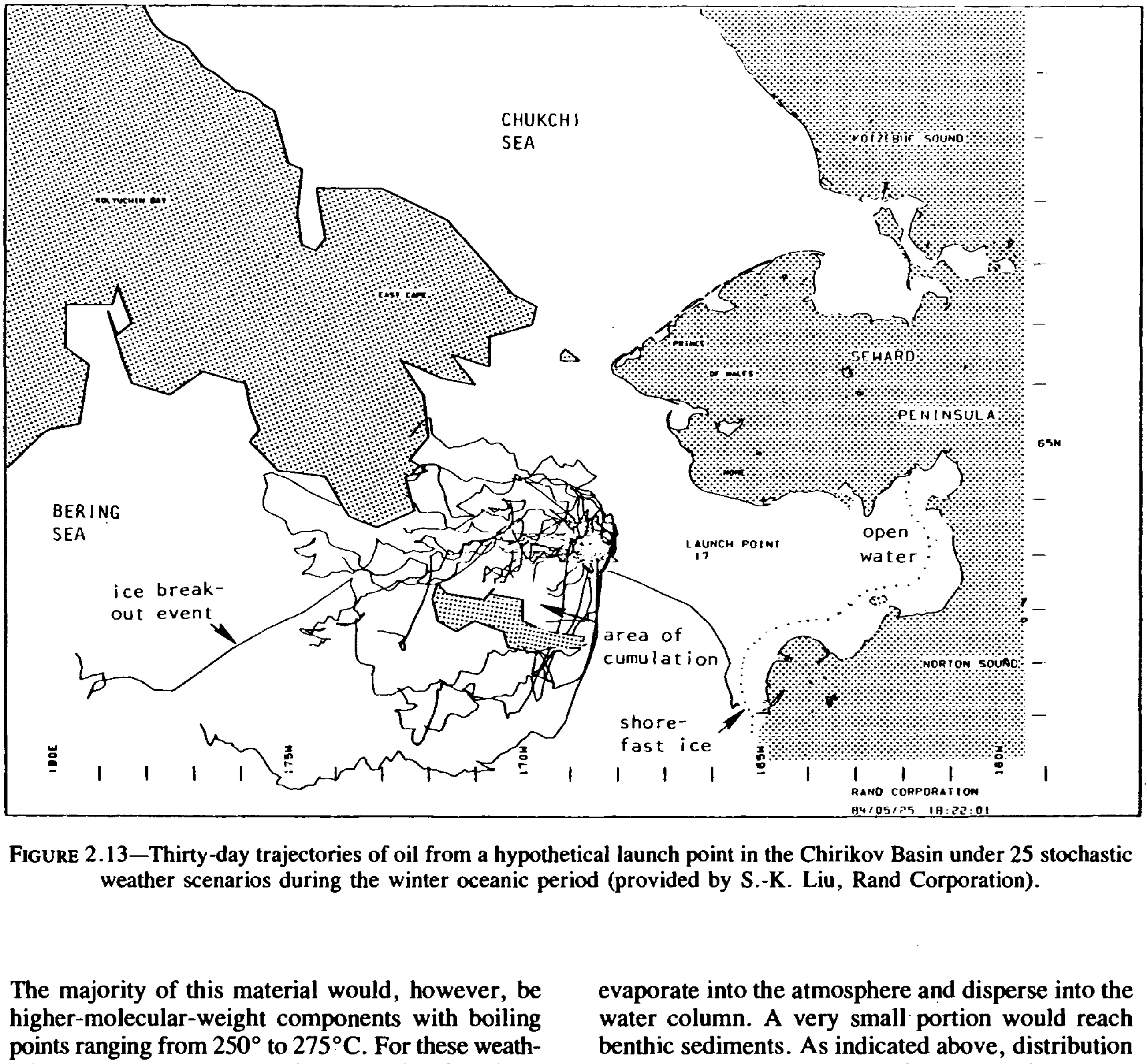

FIGURE 2.13—Thirty-day trajectories of oil from a hypothetical launch point in the Chirikov Basin under 25 stochastic weather scenarios during the winter oceanic period (provided by S.-K. Liu, Rand Corporation).

The majority of this material would, however, be higher-molecular-weight components with boiling points ranging from 250° to 275°C. For these weathering simulations a weathering scenario of 10% ice cover, 32°C water, and 20-knot wind was considered (J. Payne, JRB Associates, pers. comm.). If gasoline were released under similar conditions, oil weathering model predictions suggest that greater than 90% of the slick would be completely removed within a period of 5 to 7 hours. In contrast, weathering of a whole crude oil, such as Prudhoe Bay crude, under the conditions of a 20-knot wind and 32°C water suggests that greater than 62% of the slick would remain after the same time interval.

The rate at which spilled Prudhoe Bay crude oil would redistribute itself among atmosphere, sea surface, water column, and benthic environments over 10 days following a spill is discussed by Manen and Pelto (1984), following Payne *et al.* (1983) (Fig. 2.17). Only slightly over half the spilled oil would remain floating after 10 days; major portions would evaporate into the atmosphere and disperse into the water column. A very small portion would reach benthic sediments. As indicated above, distribution into these compartments is almost complete at the end of 10 days.

Information on the fate of petroleum on arctic coastlines is available from the Baffin Island Oil Spill (BIOS) project (Owens *et al.* 1983) and from Gundlach *et al.* (1981); the latter authors evaluate persistence of oil in coastal habitats within the Norton Basin. Results of the BIOS project (Owens *et al.* 1983) indicate that wave energy is the major factor influencing the rate of loss of spilled petroleum from arctic beaches. After one year following experimental beach spills on Baffin Island, a reduction in oil volume of at least an order of magnitude had occurred on sites exposed to intensive wave action. After two years, petroleum was not detectable on high-energy beaches and was reduced an order of magnitude even on low-energy beaches. Gundlach *et al.* (1981) predicted similar patterns of oil persistence on

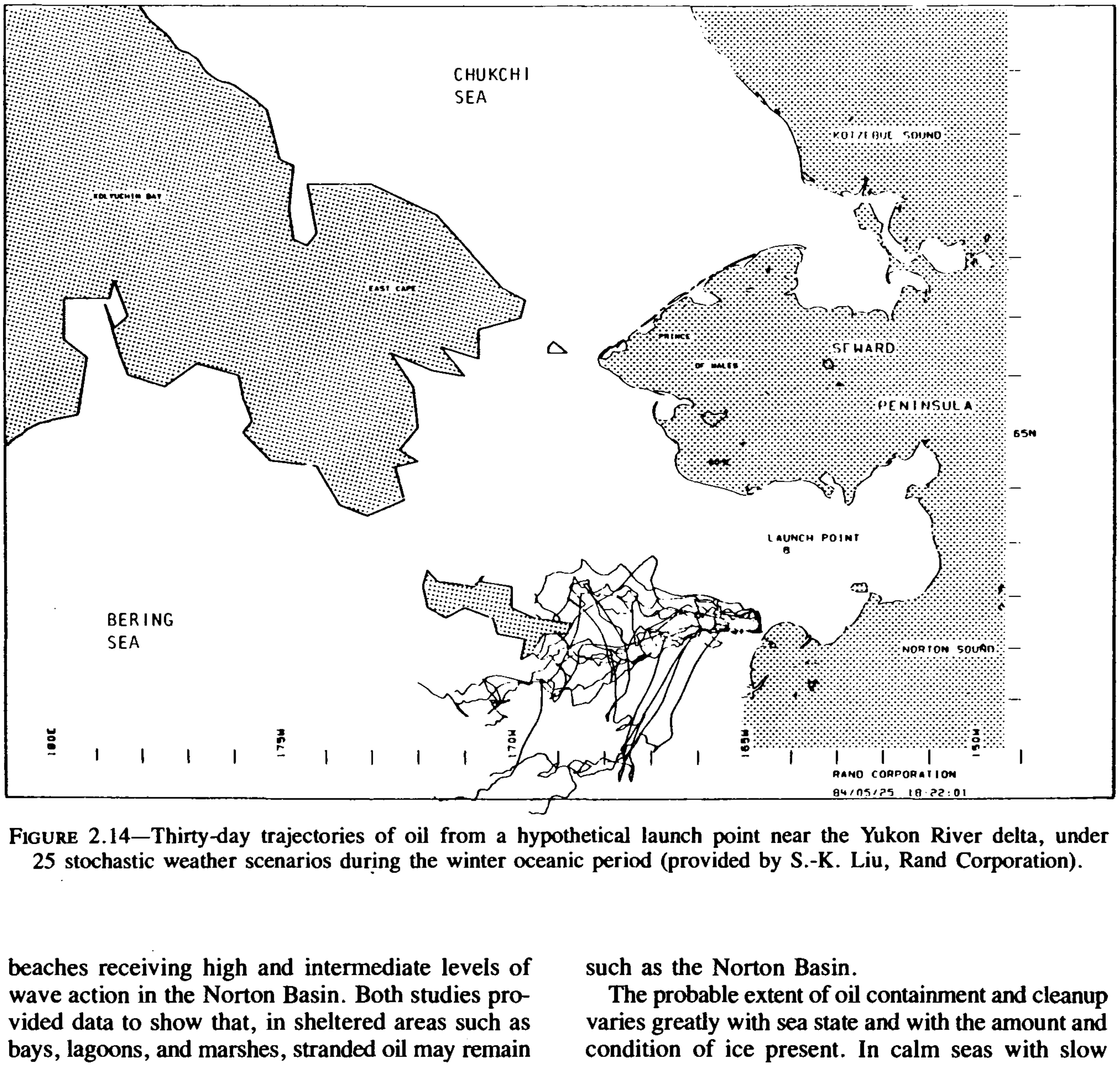

FIGURE 2.14—Thirty-day trajectories of oil from a hypothetical launch point near the Yukon River delta, under 25 stochastic weather scenarios during the winter oceanic period (provided by S.-K. Liu, Rand Corporation).

beaches receiving high and intermediate levels of wave action in the Norton Basin. Both studies provided data to show that, in sheltered areas such as bays, lagoons, and marshes, stranded oil may remain for many years before it disappears completely. Undoubtedly, many physical and chemical changes take place in beached oil long before it disappears, as found by Payne *et al.* (1983, 1984a) to occur in water.

2.2.3 Oil Spill Cleanup

As shown above, the environmental effects of spilled oil are strongly affected by the weathering that occurs within a few days to a few weeks of the spill. Oil spill cleanup is a second important way of altering and, hopefully, ameliorating the adverse effects of spills. Oil spill cleanup has been discussed extensively in other places (ADEC/ADNR 1983; Industry Task Group 1983; S. L. Ross 1983). This report will briefly summarize the applicability of state of-the-art cleanup technology in arctic areas, and point out some of the problems with cleanup in places such as the Norton Basin.

The probable extent of oil containment and cleanup varies greatly with sea state and with the amount and condition of ice present. In calm seas with slow currents and without ice, relatively high petroleum recovery rates are possible with existing technology. Rougher water presents more difficulty because of slick breakup, emulsification, and the limitations of equipment such as skimmers and booms to work under turbulent conditions. Perhaps the greatest challenge is that of spills on water containing ice, especially in rough seas. (Because ice in winter in the Norton Basin limits wind action on the water's surface, ice-infested rough seas are not common occurrences.)

Figure 2.18 illustrates a summary of containment, recovery, and disposal techniques believed by industry to be feasible, depending on surface conditions. Most of the emphasis is placed upon *in situ* burning of spilled oil, especially during heavy ice periods. Existing capabilities are more effective on

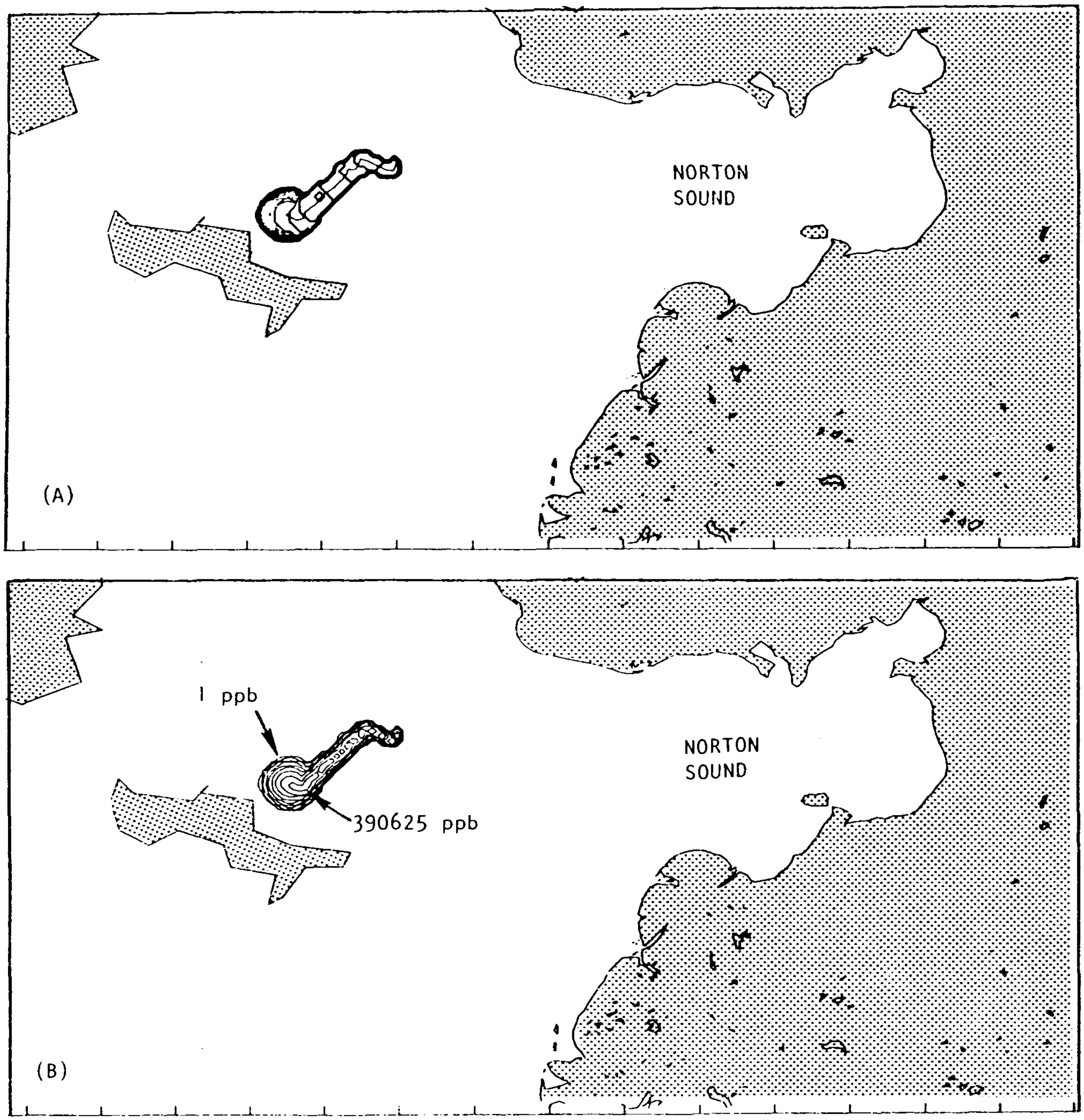

FIGURE 2.15—Daily displacement, over 30 days, of 1 ppb (in surface cm) oil envelope (A) and the distribution of surface concentration (B) from an oil spill of 2,000 bbl per day in the Chirikov Basin in winter (provided by S.-K. Liu, Rand Corporation).

landfast ice and in open water, especially if the spilled oil is ignited immediately, before significant evaporation can remove the more volatile components. Oil surfacing through brine channels in first-year ice contains sufficient dissolved gases and lower-molecular-weight components to make burning feasible. As the ice breaks up due to wave turbulence, however, water-in-oil emulsification can significantly inhibit combustion to the point that this cleanup strategy may no longer be effective (Twardus 1980; Payne *et al.* 1984b). Spills in broken ice may be difficult to handle; the greatest success is achieved when the spill is contained within a small area close to the source of the spill. When a spill is dispersed far from its

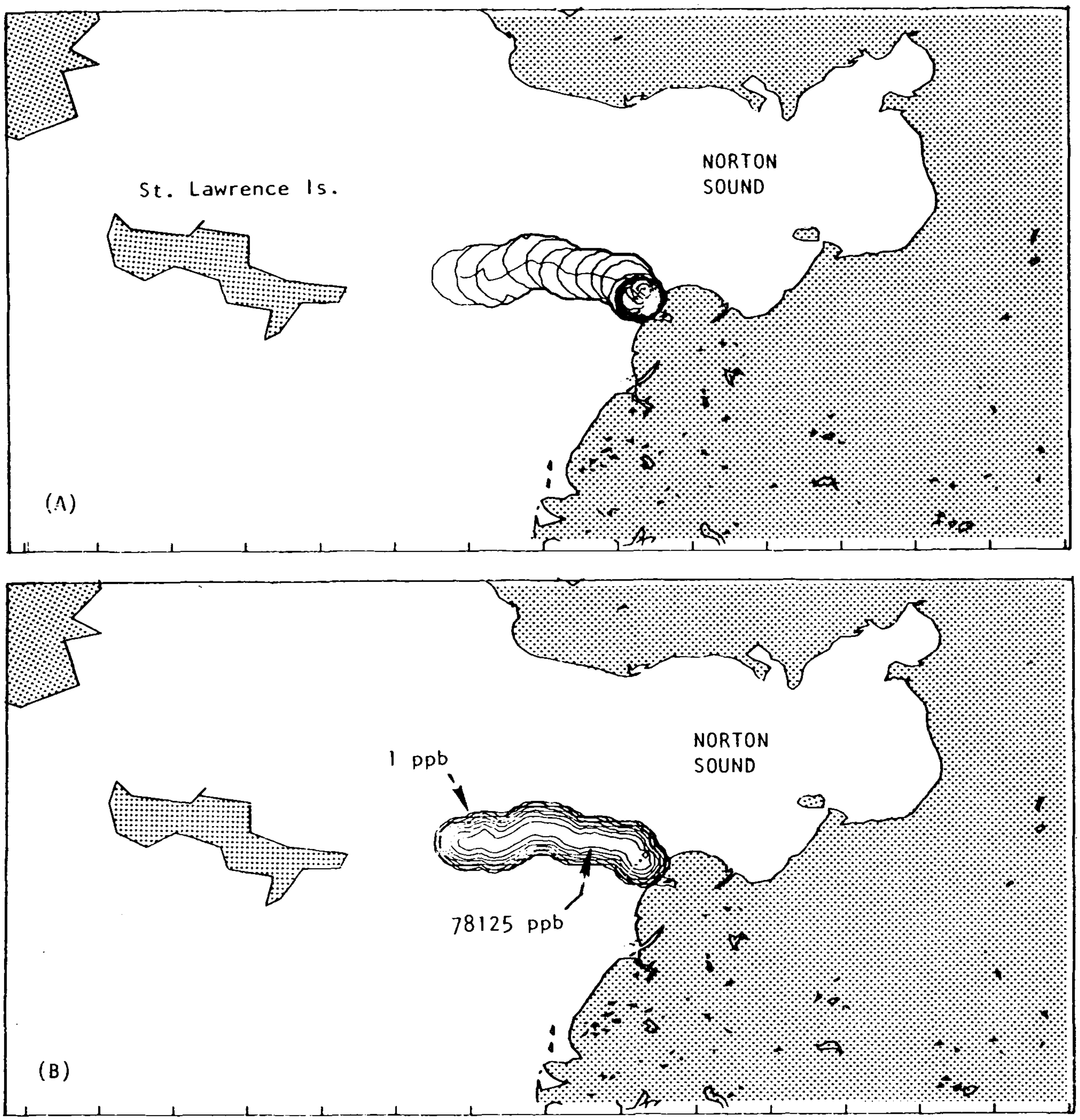

FIGURE 2.16—Daily displacement, over 30 days, of 1 ppb (in surface cm) oil envelope (A) and the distribution of surface concentration (B) from an oil spill of 2,000 bbl per day near the Yukon River delta in winter (provided by S.-K. Liu, Rand Corporation).

source or when ice is moving, containment and cleanup are most difficult (S. L. Ross 1983). In the Norton Basin planning area drilling will be prohibited below a predetermined threshold depth during broken- or pack-ice conditions until the capability to respond to an oil spill under those conditions has been demonstrated (letter from C. Cowles, MMS, November 1984).

2.3 TRANSPORT AND FATE OF DRILLING FLUIDS AND CUTTINGS

There is much less concern about the potential adverse effects of drilling mud discharges than there is about effects of oil spills, though drilling mud discharges are certain to occur, and oil spills are not. First, the distribution of normal discharges from drill-

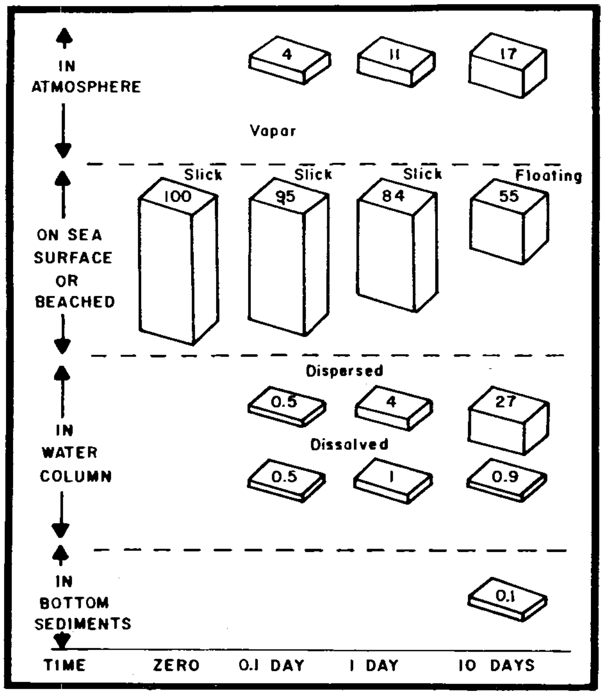

FIGURE 2.17—Speculative mass balance for Prudhoe Bay crude oil through 10 days after a spill at sea. Distribution of an initial 100 volumes of oil, assuming a wind speed of 18 km/h and a temperature of 0°C (from Manen and Pelto 1984).

ing operations is much more spatially restricted than are predicted distributions of moderate to large oil spills. Second, regulations generally prescribe biologically innocuous materials in drilling fluids, so that only slight biological effects from fluids in discharges are expected, even relatively near the discharge source. Third, the locations of releases of drilling muds and cuttings are known before they occur; their transport, deposition and effects can be thus predicted on a site-specific basis, which in itself ameliorates much concern.

Two types of drilling material discharges normally occur: the muds and cuttings released while drilling is in progress, and bulk discharges from storage tanks at the end of drilling periods (Schumacher 1982). Quantities of daily discharges of mud and cuttings range from 100 to 300 bbl. Typically, 5 to 15 bulk discharges of 50 to 200 bbl will occur per well, with a final bulk discharge of 500 to 2,000 bbl. In development and production drilling, drilling muds are recycled among wells, decreasing the average net discharge per well.

Discharges contain both particulates that settle and suspended colloidal material that spreads horizontally near the surface. The areal extent of the bottom affected by the particulates is a function of currents and water depth. The radius of impact is typically 200 to 500 m from the drill site (Meek and Ray 1980). Plume dimensions and attenuations of concentrations in the horizontally spreading plume are dependent on current velocity and rate of discharge. A typical detectable plume would be 100 to 200 m wide, 2 to 4 km long, and cover an area less than 1 km^2 (Schumacher 1982).

2.4 SUMMARY

This chapter discusses the geomorphological, meteorological, hydrographic, sea ice, and transport characteristics of the Norton Basin planning area. It depicts how spilled oil and drilling fluids might behave in the context of these physical variables, and evaluates the rates and kinds of change the spilled oil would undergo.

Geomorphological characteristics that might influence the transport and fate of oil include bathymetry, sediment characteristics, and coastal landforms. The Norton Basin is relatively shallow (<50 m) throughout; it is generally deepest in the Chirikov Basin–Bering Strait region and shallowest in Norton Sound, particularly off the Yukon River delta. Bottom sediments are composed mostly of sand, silt, and mud. Mainland coasts are generally smooth, frequently indented by bays and lagoons, and fronted by sandy to gravelly beaches. The Yukon delta has low-profile beaches dominated by silt and mud; island coasts are frequently wave-cut cliffs.

Two major climatic regimes—summer and winter—prevail. In summer, seas are ice-free, temperatures are maritime, wind and storm directions tend to be southerly, and rain is frequent. In winter, seas are ice-covered, temperatures are very cold because of dominant polar air masses, and winds tend to be northerly.

The hydrography, like the climate, has a summer and a winter phase, with short transitional periods of spring and fall. In summer, the sea is essentially ice-free and the general movement of water masses is northward under the influence of prevailing southerly winds and differences in sea level between the Bering and Chukchi seas. Local variations in this general north-moving pattern coincide with the presence of large islands and embayments. For example, currents are complex around St. Lawrence Island, and waters in eastern Norton Sound are somewhat isolated from the prevailing pattern of flow. In winter, the general regional flow pattern appears to be similar to that in summer, but with some exceptions. Current reversals to the south caused by strong northerly winds are common at this

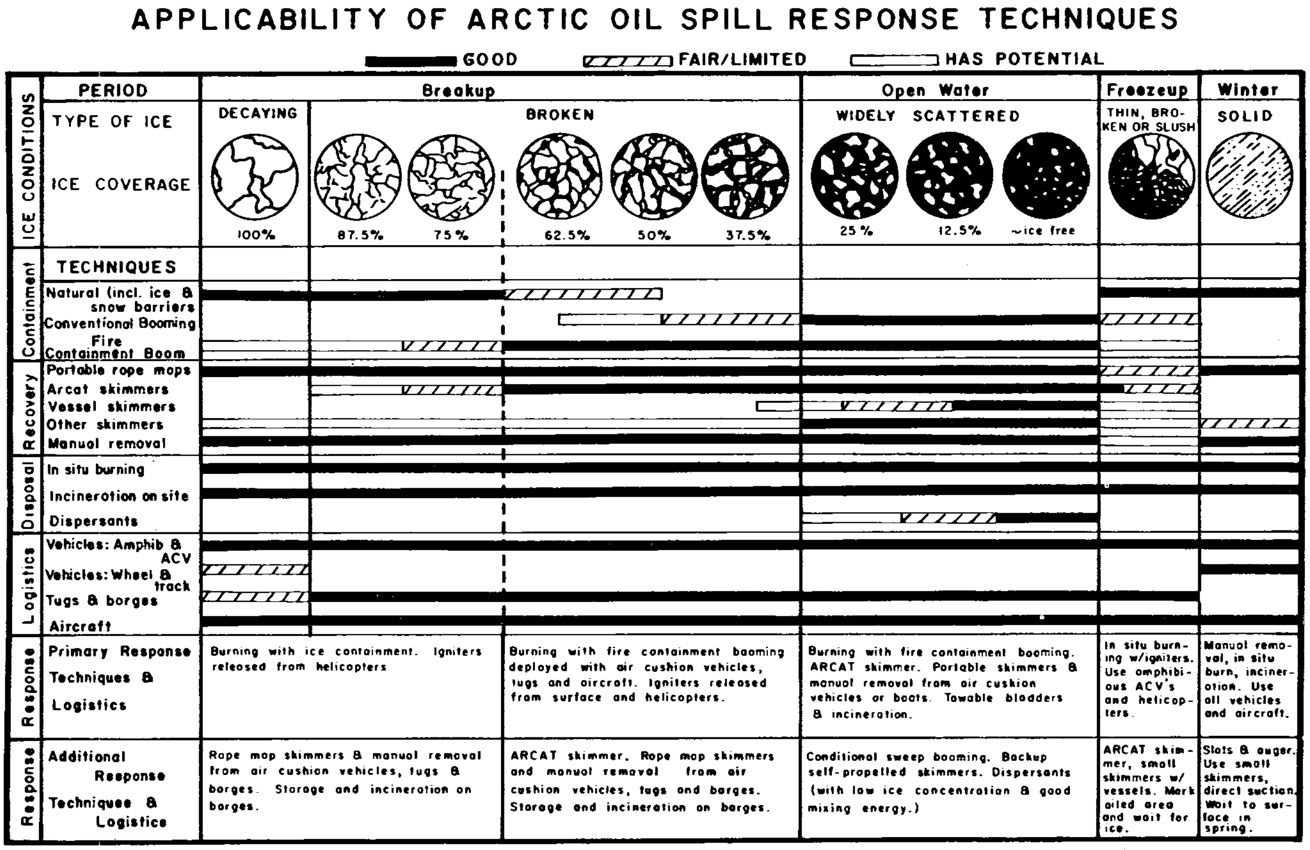

FIGURE 2.18—State-of-the-art oil spill response techniques in arctic waters (updated from ITG 1983, based on demonstrations conducted in summer 1983).

time. Lowered stream inputs and exclusion of salts from ice freezing at the surface increase the salinity of nearshore water masses.

Tides over most of the region are of the mixed, predominantly semidiurnal type; diurnal tides predominate along the Yukon delta and in inner Norton Sound. Winds tend to have a greater influence on water levels than do tides. Water level increases near 4 m have occurred in some coastal areas during storms. Currents induced by winds and tides vary considerably from place to place within the Norton Basin.

Sea ice usually begins to form in October; by late winter ice cover is essentially complete except for recurring polynyas in the vicinity (mainly south) of St. Lawrence Island and in northern and eastern parts of Norton Sound. Prevailing northerly winds augment the supply of ice to Norton Basin by two phenomena: ice breakout in Bering Strait and continuous production of new ice in Norton Sound and south of St. Lawrence Island. Ice breakout (failure of the ice "plug" in Bering Strait) causes episodic southward-moving pulses of large masses of ice into and through the Norton Basin several times each winter. In northern and eastern Norton Sound and south of St. Lawrence Island, northerly and easterly winds tend to continually reopen polynyas and allow new ice to form, then move the newly formed ice out.

Most of the present-day sediment contributions to the Norton Basin planning area come from Yukon River discharge. These river sediments (mostly sands and silts) tend to settle on the Yukon delta platform, in bays and lagoons around Norton Sound, and beyond the Norton Basin in the Chukchi Sea. Little of it, or any other modern sediment, is contributed to the sea floor in the Chirikov Basin or Bering Strait, apparently because of the strong currents in those areas. Longshore transport of sediment in nearshore waters of the Norton Basin is variable in direction. Many of the coastal bays and lagoons appear to be sediment sinks. Little longshore transport appears to occur in the Yukon delta area.

The Rand Corporation modeling system has been used to simulate trajectories and behavior of spilled oil in the Norton Basin. This system includes a three-dimensional hydrodynamic model, a weather model based on synoptic weather analyses and storm-track statistics, and models predicting the gravity-wave component and dimension of the spilled oil. Modeling results show that, in summer, oil spilled in the Norton Basin would generally move northward or northeastward. Landfalls would typically occur on the south side of the Seward Peninsula, but seldom elsewhere in the Norton Basin. In winter, spilled oil would tend to move westward or southward, approaching coasts of southern Norton Sound and St. Lawrence Island.

When oil is spilled in the oceanic environment, weathering processes that change its physical and chemical makeup begin immediately. Through a combination of evaporation, dispersion, dissolution, adsorption, emulsification, oxidation, and advection, the oil is rather quickly (within several days to a few weeks) degraded to a more or less steady-state form that has drastically different biological effects than it did in original form. Thus the environmental effects of an oil spill vary greatly with time after spill.

Once spilled oil reaches land, its persistence depends mainly on the wave energy to which the coast is exposed. Oil on coastal sites exposed to intensive wave action may disappear entirely within a year or two, but may last many years in areas such as quiet lagoons and marshes that receive little or no wave action.

Whether and to what extent spilled oil can be cleaned up, depends greatly on sea state and ice conditions. Under opportune circumstances such as calm seas, no ice, and slow rate of oil slick movement, high rates of petroleum recovery are possible with existing technology. Oil in rough or ice-infested seas with rapid surface currents may be very difficult or impossible to clean up.

Drilling fluids and cuttings discharged from well-drilling sites contain both large particulates that quickly settle and smaller particulates that spread as colloidal material on the surface. The radius of impact of settling particulates is typically 200 to 500 m from the drill site; colloidal plumes in the water column are typically detectable for only 2 to 4 km downstream of the drill site and cover an area less than 1 km^2. There is generally less concern about the transport and fate of drilling fluids and cuttings than there is about oil, because fluid and cutting releases are relatively small, predictable in time and space, and ecologically innocuous.

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3

Environmental Hazards to Petroleum Industry Development

by Joe C. Truett

With major contributions from William M. Sackinger, William J. Stringer, and Thomas L. Kozo

Section 1.1 of Chapter 1 describes the kinds of exploration and development activities that may result from OCS lease sales in the Norton Basin. The environmental hazards that are potential threats to these activities include geologic hazards on or beneath the sea floor, hazards in the marine environment above the sea floor, and hazards in coastal areas. Figure 3.1 shows some of the potentially hazardous areas in the Norton Basin.

3.1 SEA FLOOR: GEOLOGIC HAZARDS

Several types of OCS activities on or beneath the sea floor may be subject to geologic hazards there. These activities include drilling into the sea floor, anchoring of production platforms on the sea bottom, and laying subsea pipe for oil transmission. Permafrost, bottom current scour, ice gouging, faulting or seismicity, sediment liquefaction, sediment bedform migration, or gas in sediments could hinder such activities or damage production structures.

3.1.1 Permafrost

Permafrost is found in some places onshore in the Norton Sound area, but studies to date appear to indicate a low likelihood for its existence offshore (Zimmerman 1982). In any case, the potential hazards of permafrost appear negligible (Bureau of Land Management [BLM] 1982).

3.1.2 Current Scouring

Larsen *et al.* (1981) report that depressions in the sea floor caused by current scour occur mainly in two areas of Norton Sound—immediately west of the Yukon River prodelta (see also Fig. 3.2) and about 50 km southeast of Nome. These authors did not report scour depressions west or north of Norton Sound, but their identification of areas of intense current activity elsewhere (southeast of the Bering Strait and north of St. Lawrence Island) (Fig. 3.1) suggests that current scour may also occur outside Norton Sound in other parts of the Norton Basin. Current scouring is considered a moderate but not major concern to OCS development, at least in Norton Sound (BLM 1982).

3.1.3 Ice Gouging

Gouging of the sea floor by moving ice is a potential hazard to subsea pipes on or just beneath the bottom. Two types of ice gouge—single and multiple—have been recognized. Single gouges, the most common type, are cut by single-keeled pieces of thick ice; multiple gouges are formed by multikeeled, pressure-ridge ice. Gouges occur where water is 30 m or less deep, but are most common in 10- to 20-m depths. Most gouges are 0.5 m or less deep, though some are up to 1 m deep (Thor and Nelson 1981).

Areas where gouging is likely to be a problem are very localized in the Norton Basin (Fig. 3.1). The area of most intense gouging is in the shallow water offshore of the Yukon delta (Fig. 3.2), where southward-moving pack ice converges with, and shears past, a shorefast ice zone 10–30 km wide (see also Section 2.1.5). In contrast, northeastern Norton Sound is an area of ice formation and divergence, and thus has minimal ice gouging. Areas in the Chirikov Basin and near the Bering Strait are either too deep for ice gouging or escape gouging because they are areas of ice divergence (Thor and Nelson 1981). Hazard to subsea pipelines from ice gouging

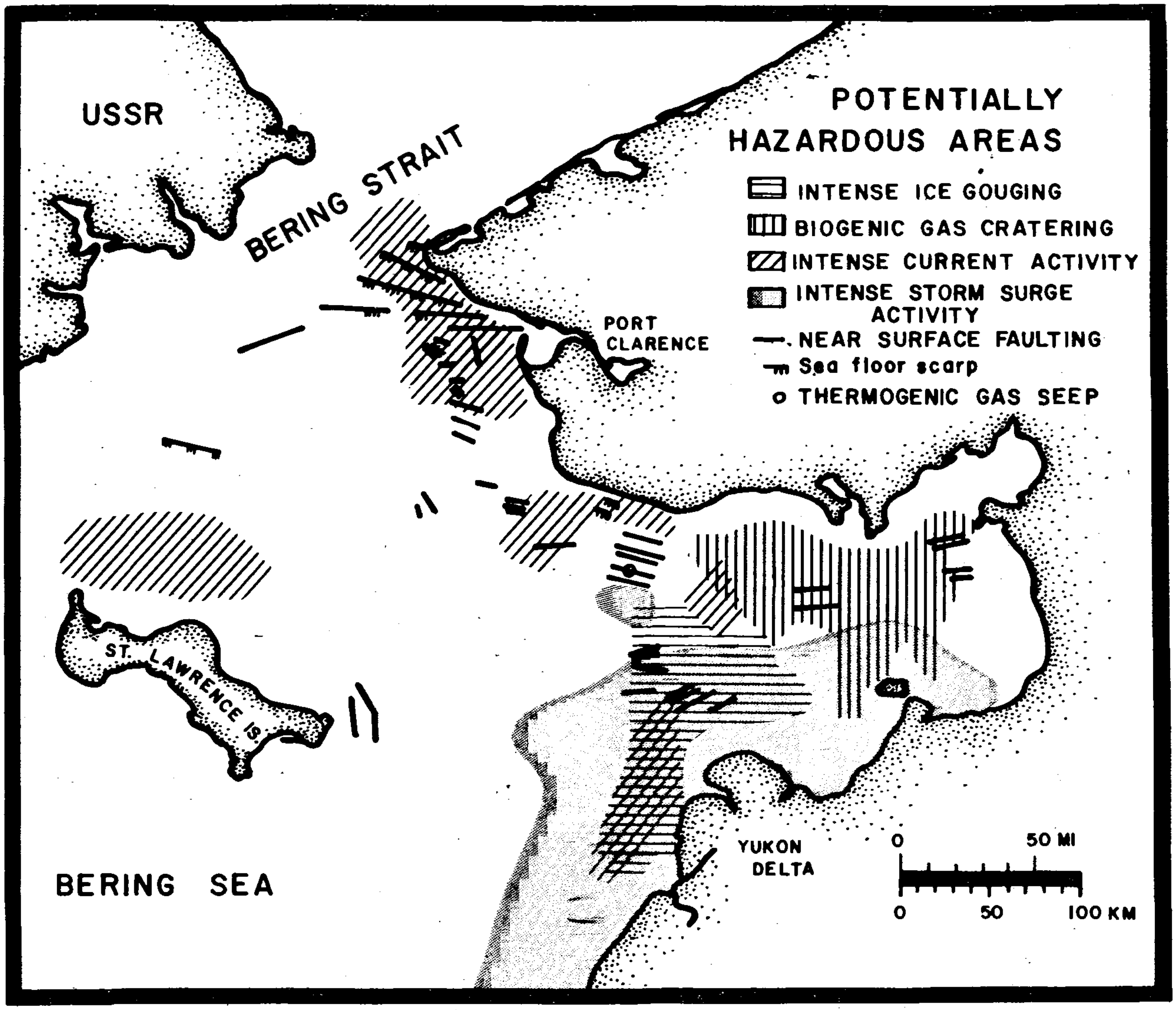

FIGURE 3.1—Potentially hazardous areas of the Norton Basin OCS Planning Area (from Larsen *et al.* 1981).

is considered minor (BLM 1982); technologies are available to trench pipelines below the 1- to 2-m depth commonly gouged by ice in Norton Sound (Zimmerman 1982).

3.1.4 Faulting and Seismicity

Many deep-seated and near-surface faults occur in the Norton Basin; most are in Norton Sound proper and along the east edge of the Chirikov Basin between northwestern Norton Sound and the Bering Strait (Fig. 3.1). Recent work (Hoose *et al.* 1981; Steffy and Hoose 1981) shows both near-surface and deep faults to be common 75–100 km offshore (north) of the Yukon River delta. Many of the faults lack surface expression in the form of scarps, suggesting that appreciable activity may not have occurred in recent times. Fault movement may have taken place rather continuously during geological subsidence of the Norton Basin, but the rate of subsidence may have decreased since the end of the Pleistocene epoch (Johnson and Holmes 1978; BLM 1982).

The maximum magnitude of earthquakes occurring in Norton Sound over the past two years is 4.2; two earthquakes with magnitudes of 6.0 and 6.5 have occurred just north of Norton Sound (on the Seward Peninsula) within the last 30 years (Biswas *et al.* 1980). Earthquake epicenters tend to cluster along mapped faults and other structural trends (*e.g.*, see Fig. 3.1) (Biswas *et al.* 1980). The fact that few earthquakes of large magnitude have been recorded in Norton Sound in historic times lends additional support to the idea that active faulting is not now a common occurrence. Nevertheless, BLM (1982) considered faulting and seismicity to be hazards

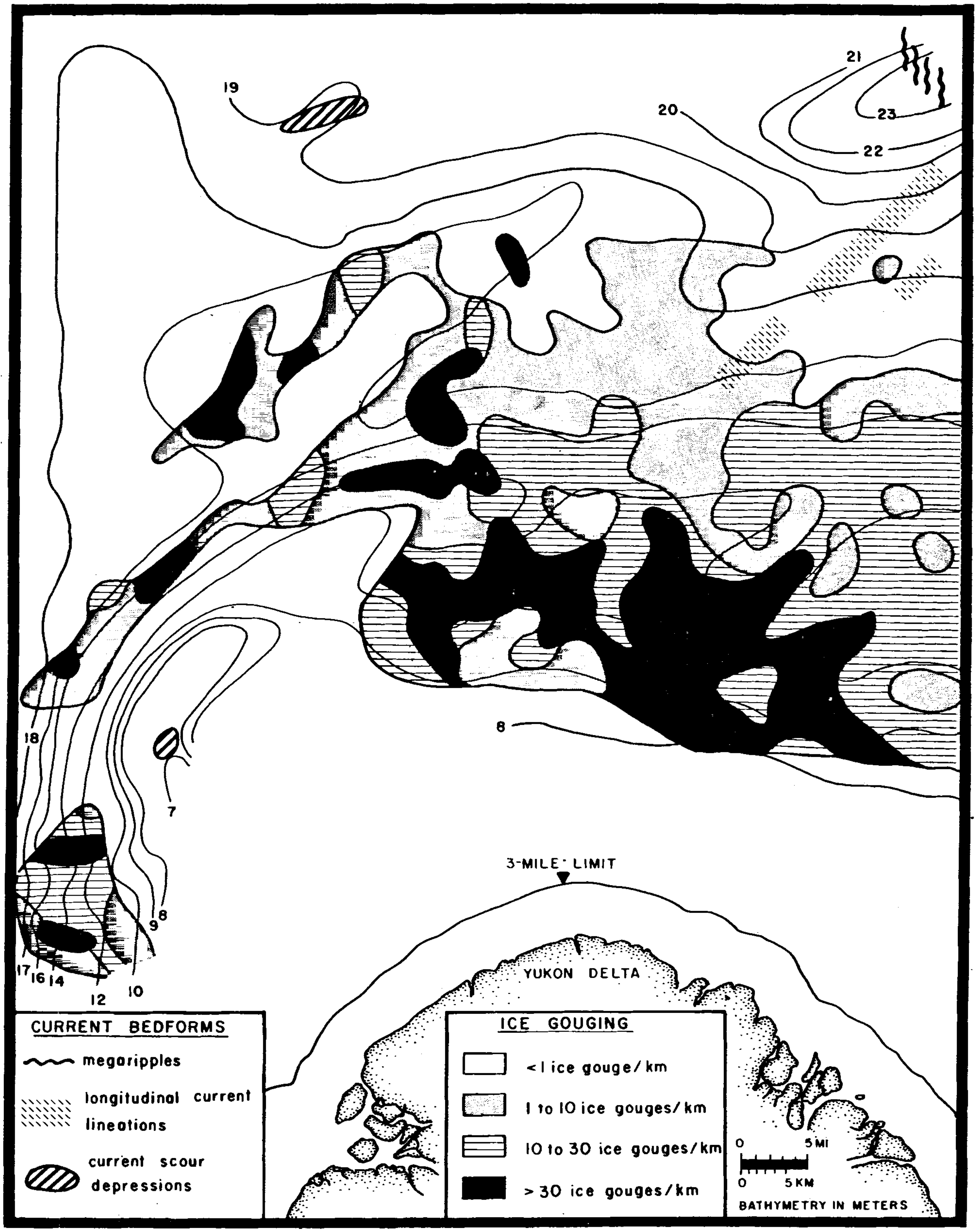

FIGURE 3.2—Ice gouge intensity and current bedforms off the Yukon River delta, Norton Sound (adapted from Steffy and Lybeck 1981).

of major concern in the Norton Sound part of the Norton Basin.

3.1.5 Sediment Liquefaction

Sediment liquefaction, which causes sediments to behave as a viscous fluid, may create hazards to structures that must be placed on or in substrates (*e.g.*, drilling platforms, subsea pipes). The liquefaction potential of Norton Sound sediment is great in central Norton Sound and in the vicinity of the western Yukon prodelta. Liquefaction may be caused by upward migration of biogenic or thermogenic gases from sediments, by earthquakes, or by wave action; it in turn may promote such hazardous phenomena as current scouring and sediment cratering (see Fig. 3.1 for distributions of some of these phenomena). Full assessment of the potential consequences of sediment liquefaction requires additional studies of *in situ* pore pressure, gas saturation, and wave cyclic loading during storms (Larsen *et al.* 1981).

3.1.6 Sediment Bedform Migration

Extensive sand-wave migration forms an unstable sea floor in the area west of Port Clarence, the only large harbor on the Alaska coast north of the Aleutians (Larsen *et al.* 1981). This is an area of intense bottom-current activity (Fig. 3.1). The development and decay of sand waves up to 2 m in height during a 1-year period have been observed in this area. Subsea pipelines could be subject to damaging stress if large free spans developed as a consequence of such bedform migration.

Current bedforms occur locally just north of the Yukon River delta as megaripples and longitudinal lineations (Fig. 3.2). Megaripples occur as a series of ripples with wavelengths of 20 to 50 m and amplitudes of less than 0.5 m; they trend normal to the prevailing westerly current. Longitudinal lineations occur as a series of furrows parallel to the prevailing current that have wavelengths of 10 to 30 m and depths of less than 0.5 m (Steffy and Lybeck 1981).

3.1.7 Gases in Sediments

Gases in sediments may create hazards of several kinds. Drilling that penetrates large gas accumulations could provide direct avenues for uncontrolled gas migration to the sea floor. Shallow subsurface gas deposits, and/or a tendency for gas cratering, may generate unstable conditions for bottom-supported structures (*e.g.*, platforms, pipes). Sediment liquefaction and current scouring may result from gases in sediments; the hazards of these phenomena have already been discussed. Several situations with thermogenic or biogenic gases in sediments occur in the Norton Basin.

A thermogenic (*i.e.*, originating from thermal processes at depth) gas seep has been discovered on the sea floor about 50 km south of Nome (Fig. 3.1) (Kvenvolden *et al.* 1979). This is in an area of near-surface faulting, suggesting that the gases migrate into the near-surface sediments along a fault zone. Seismic profiles near the fault area outline a zone of anomalous acoustic responses about 9 km in diameter at a depth of about 100 m (Nelson *et al.* 1978). This zone may present hazards if penetrated by drilling.

Larsen *et al.* (1981) reported that about 7,000 km^2 of Norton Sound and the Chirikov Basin is underlain by acoustic anomalies that may indicate shallow gas (biogenic and/or thermogenic) pockets everywhere except under the Yukon prodelta. Steffy and Hoose (1981) show shallow (within 140 m of the surface) acoustic anomalies to be abundant to at least within 25 km of land north and northwest of the Yukon delta; these authors suggest that the anomalies off the delta are caused by subsurface gas formed from buried peat. Core-penetration rates and sediment samples from 2- to 6-m vibracores confirm biogenic gas saturation of near-surface sediment at several locations in Norton Sound characterized by such acoustic anomalies (Larsen at al. 1981). Pipelines built across these potential gas pockets may be damaged by stress induced by the unequal bearing strength of gas-charged and normal sediments (Larsen *et al.* 1981).

Gas craters cover a large area of north-central Norton Sound (Fig. 3.1). These craters, which seem to form by releases of gases during peak storm periods, may be a potential hazard to offshore facilities because of the rapid lateral change in bearing strength, and the collapse of sediments that form the craters. Sediment collapse may also expose buried pipelines to ice-gouging hazards (Larsen *et al.* 1981).

The Bureau of Land Management (1982) ranks thermogenic gas hazards as a major concern in the Norton Basin. Biogenic gas in sediments, including cratering effects, is considered by BLM to be a moderate concern.

3.2 MARINE ENVIRONMENT: ICE AND WATER

Drilling, production, and shipping operations may be at risk because of hazards in the marine environment. Effects of moving sea ice on drilling and production platforms, effects of icing on structures, and effects of waves and currents on structures are evaluated in this section.

3.2.1 Ice Forces

The patterns of ice formation, distribution, and movement in the Norton Basin are discussed in Section 2.1.5. Additional aspects of ice dynamics that influence the level of ice hazard to OCS development are discussed below.

The term "ice forces" as used here refers to action of shorefast ice or floating ice that does not encounter the sea floor. (Hazards of ice gouging of the sea floor are discussed in Section 3.1.) The primary hazards of ice forces in the Norton Basin are from pack ice and to a lesser extent from shorefast ice in late fall, winter, and spring. Compression of ice by winds may result in ice ridging, and impingement of moving ice against shorefast ice creates shear zones; both these phenomena add to the normal hazards of floating ice (Zimmerman 1982).

By far the dominant form of ice in the Norton Basin is annual ice, which begins freezing about November and may reach thicknesses of 1.5 m by April. (Small floes 2 to 3 m thick may form when wave action moves one floe beneath another one.) Except for shorefast ice, this annual ice is in more or less constant motion. Floe sizes may range from zero to several kilometers in diameter, and ice coverage ranges from zero to nearly 100%. Ice ridges with keels as deep as 20 m form when wind-driven ice fields are forced against islands or shorelines in compression or shear movements (W. M. Sackinger pers. comm.).

Because of the potential threat to bottom-founded structures imposed by their interaction with multiyear ice, the possibility of this ice type being found in the Norton Basin should not be overlooked. Multiyear ice is probably not commonly found in this region, but there have been a few reports and sightings. The best documented report has been provided by Kovacs *et al.* (1982), who provide photographs of several multiyear floes grounded in the vicinity of Tin City on the Seward Peninsula just south of the Bering Strait. These authors also cite an interview with St. Lawrence Island residents at Gambell who "report seeing multiyear ice floes on occasion." The authors also mention observing multiyear sea ice south of King Island, well within the Norton Basin area. Personnel from a proprietary icebreaker cruise into the Bering Strait in December 1983 reported seeing "small pieces" of multiyear ice apparently entering the northern Bering Sea through the Bering Strait from the Chukchi Sea (W. J. Stringer pers. comm.). Few data are available on thicknesses or floe sizes of this ice. Its normal concentration in the Norton Basin appears to be low, based on these recently reported observations; whether there are infrequent occurrences of much larger amounts is not known.

Generally, the Chukchi Sea is ice-free as far north as Barrow during summer. It has therefore been assumed that multiyear ice must be transported the entire length of the Chukchi Sea in order to be introduced into the Bering Sea. The mechanism that has been invoked is the so-called "ice breakout" phenomenon (see Section 2.1; and Shapiro and Burns 1975; Sodhi 1977; Ahlnäs and Wendler 1979; Reimer 1979). It has been assumed that several such events could result in the transport of multiyear ice from the northern Chukchi Sea into the Bering Sea. However, such a transport has not been established and it is not completely clear that even first-year ice is transported from the northern Chukchi Sea through the Bering Strait by this process. In any case, one might not expect this mechanism to work every year and it would be more likely to introduce multiyear ice into the Bering Sea near the end of the winter (after several sequential "breakouts") than near the beginning of the ice season.

Stringer (1984) proposes another (but not exclusive) source for multiyear ice to be transported through the Bering Strait. Although the ice edge retreats far to the north on the Alaska side of the Chukchi Sea, on the Siberia side it is often held against the coast all summer at a location much closer to the Bering Strait. By winter, this ice becomes, by definition, second-year or multiyear ice. This ice often remains sufficiently close to the Bering Strait to be transported through rather quickly. Satellite imagery is available which shows this Siberia ice being transported through the Bering Strait in late summer. This would be a source of multiyear ice to be introduced through the Bering Strait in early winter as well as in late winter.

In summary, we see that (1) multiyear floes have been sighted in the Norton Basin, and (2) when observed, the concentration of floes was very low. Multiyear ice apparently comes through the Bering Strait from the Chukchi Sea, but at least two different mechanisms for its source in the Chukchi Sea and transport into the Norton Basin have been proposed. We know little about the ice floe sizes or thicknesses, or whether much larger amounts than reported move infrequently into the region.

The degree of hazard that moving ice offers to structures or vessels depends to a great extent on the compressive strength of the ice—the greater the compressive strength, the greater the hazard, all other things being equal. Annual ice is relatively warm ice; mean compressive strength of small samples was about 290 pounds per square inch (psi). Mean compressive strength of small samples of warm multiyear ice was 837 psi; low-strength samples ranged from 346 to 587 psi (W. M. Sackinger pers. comm.). Clearly, the multiyear ice floes, if they are as large and thick as encountered in the Chukchi Sea, offer the greatest hazard to structures.

The following types of calculations must be made to estimate the forces that moving ice will exert on various stationary structures used in OCS exploration and development, and thus to determine design criteria for structures (W. M. Sackinger pers. comm.):

1) Ice crushing force against vertical walls.
2) Force of crushing followed by flexure on sloping walls.
3) Ice-clearing forces around structures.
4) Ice rideup forces.
5) Foundation (substrate) strength in response to ice forces.
6) Extent to which ice rubble grounding buffers ice forces against structures.

3.2.2 Icing of Structures

Icing presents a hazard primarily to superstructures of work boats and service vessels, and possibly to floating drilling vessels (Zimmerman 1982). It is expected that superstructure icing that will be encountered in the Norton Basin will be similar in nature and magnitude of hazard to that which will be encountered in other areas of the Bering Sea (W. M. Sackinger pers. comm.). Present knowledge of this risk is incomplete, but additional studies are addressing the problem (MMS 1984).

3.2.3 Wind and Waves

The Bureau of Land Management (1982) estimates that wind and waves present a moderate hazard to offshore facilities. Table 3.1 shows maximum waves and winds expected for the Norton Basin region. Note that their wave-height values have repeatedly been criticized by industry as being unrealistically conservative and in error (W. M. Sackinger pers. comm.). The Norton Basin is exposed to large waves from the south and southwest in summer and fall. In shallow areas these waves are attenuated. Waves begin to break when the ratio of water depth to wave height is less than 1 (BLM 1982).

3.3 COASTAL ENVIRONMENT: STORM SURGE AND EROSION

The northern Bering Sea, including the Norton Basin area, has a history of severe storm surges. Storm surges are normally the result of storm-wind stress on surface waters to cause a rise in sea level in the coastal zone; they are sometimes augmented by a coincident rise in sea level caused by the low barometric pressure of the storm. The Bureau of Land Management (1982) considers storm surge hazard a major concern in the Norton Sound area.

Storm surges will not only flood coastal regions, but will provide a base on which waves can penetrate even farther inland. Accretion and erosion of beach materials, cutting of new inlets through barrier beaches, and shoaling of channels can occur (U.S. Army Shore Protection Manual 1977). The rise in sea level, the action of waves, and the resulting erosion can, in combination or singly, be hazardous to coastal facilities in low-lying areas.

The most recent major storm surge occurred in the Nome area on the north side of Norton Sound, 9–12 November 1974 (Fathauer 1975; BLM 1982). The total increase in sea level was estimated at 7.6 m (normal tide range is 1.2 m). Some parts of Nome were under 3 m of water; water levels more than 5 m above mean high water were seen at the eastern end of Norton Sound.

3.4 SUMMARY

Environmental hazards to petroleum development in the Norton Basin include those on or in the sea floor (permafrost, ice and current scour, faulting and seismicity, sediment liquefaction, movement of sand waves, and gas-charging of sediments), those in the marine environment (moving ice, wind and waves, and icing of structures), and those in coastal areas (coastal erosion and storm surge).

TABLE 3.1—Annual maximum winds and waves for the Norton Sound vicinity, and selected return periods.

Return Period (years)	Maximum Sustained Winds (knots)	Maximum Significant Waves (m)	Extreme Waves (m)
5	78	13.5	24.5
10	84	15.5	28.0
25	94	18.5	33.0
50	102	20.5	36.0
100	110	23.0	42.5

SOURCE: BLM 1982, following Brower *et al.* 1977.

Some of the seafloor hazards are considered to be minor concerns. Permafrost is probably sparsely distributed or nonexistent, and thus of little concern. Ice gouging of the sea floor is a common occurrence, especially in the shear zone beyond the shorefast ice edge, but technologies are available to trench subsea pipelines below the 1- to 2-m depths commonly gouged by ice.

Some seafloor hazards are of moderate concern, at least locally, or require further investigation to ascertain the levels of hazard they pose. Sediment scouring by bottom currents, potentially affecting structures on or in the sea floor, is a moderate concern in some areas. Sand-wave migration could subject subsea pipelines to damaging stress in some areas, such as Port Clarence. Biogenic gases in sediments, and the craters these gases cause when released, are widely distributed and may cause moderate hazards to offshore facilities anchored on the sea floor. Little is known of the degree of hazard that sediment liquefaction might pose to bottom-anchored structures; the liquefaction potential of Norton Sound sediments appears great and this problem needs more investigation.

The seafloor hazards of greatest concern are faulting and seismicity, and thermogenic gas hazards. Though few earthquakes of large magnitude have been recorded in the Norton Basin area in historic times, and existing faults seem not to have been recently active, the potential damage to the structures on or in the sea floor in the event of earthquakes or fault movements is considerable. Thermogenic gas seeps discovered about 80 km south of Nome in an area of near-surface faulting suggest a local hazard where drilling might penetrate large subsurface gas accumulations.

In the marine environment, the icing of structures and the effects of icing of superstructures of work boats, service vessels, and drilling vessels in the area are not well known, but are being studied. The effects of wind and waves on offshore facilities are more readily evaluated from existing data.

Undoubtedly, the marine hazard of greatest concern is that related to sea-ice forces. Drilling, production, and shipping operations may be at risk from moving ice. In the Norton Basin, multiyear ice is more hazardous than annual ice because it tends to be thicker and stronger, but it is much less common than annual ice. Multiyear ice moves into the area mainly with ice breakout events at the Bering Strait. Design criteria for structures that are to withstand moving ice must consider several aspects of the forces of moving ice against vertical or sloping structures.

Storm surge and associated coastal erosion is the major potential hazard to onshore structures and facilities. There is potential for large (7 to 8 m) storm-caused increases in sea level at the coast; under these circumstances, flooding of low-lying facilities, erosion of beach materials, cutting of new inlets, and shoaling of channels can occur. Planning and operation of onshore facilities must consider these possible consequences of storm surge.

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4

The Nearshore and Coastal Ecosystem

by Joe C. Truett and Peter C. Craig

With major contributions from Kathryn J. Frost, Calvin J. Lensink, and Peter G. Connors

In this chapter we describe the important mammals, birds, fishes, and invertebrates of the Norton Basin nearshore and coastal ecosystem. For each species discussed, information is presented on distribution and abundance, food habits, and any particularly important habitats. Where known, the apparent vulnerabilities of populations and the sensitivities of individuals to OCS-related activities (mainly oil spills) are noted. (*Vulnerability* refers to the proportions of populations that could be affected, and thus is a function of the population's distributional pattern in relation to the potential distribution of OCS activities; *sensitivity* refers to the susceptibility of individual animals to spilled oil or other activities.) Summaries of food webs, important habitats, and potential impacts of oil and gas development are presented near the end of the chapter.

The spatial limits of the nearshore and coastal ecosystem are herein defined to extend seaward generally from mainland and island coasts to about the 10-m depth contour, and landward on mainland and islands to the limits of the influence of marine water or OCS activity. In terms of animal species distribution and use, this arbitrary boundary between the nearshore environment and the offshore environment is not always relevant. This is particularly true for marine mammals, in which a distributional break between inner Norton Sound and outer Norton Sound/Chirikov Basin might be more appropriate (K. J. Frost pers. comm.). But we believe the 10-m isobath suffices as a reasonable line of demarcation for discussion purposes for most species. Animals that find important habitats in both the nearshore and the offshore environments are addressed as appropriate in *both* this chapter and Chapter 5—The Offshore Ecosystem.

Sensitivities of the various species to oil pollution and other activities related to OCS development are briefly noted, but not reviewed in detail. Recent reviews by Davis and Thomson (1984), Roseneau and Herter (1984), and Craig (1984) may be consulted for greater detail.

4.1 MARINE MAMMALS

Four marine mammals—spotted seal, ringed seal, belukha whale, and harbor porpoise—are probably the only species that, at one time or another, occur more commonly in nearshore than offshore areas. Some individuals of other species—walrus, Steller sea lion, polar bear—that are common in the Norton Basin planning area come into the nearshore zone seasonally and/or locally, and are discussed briefly in this chapter as well as in Chapter 5. Other species—bearded seal, gray whale—also venture into the deeper parts of the nearshore environment (commonly in the case of bearded seals in winter), but are treated as components of offshore areas (Chapter 5) and are not addressed here. The arctic fox, a terrestrial mammal that ventures out onto the sea ice in winter and feeds on carrion and ringed seal pups, is not addressed.

4.1.1 Spotted Seal

Spotted seals (*Phoca vitulina largha*) are present during the ice-free months throughout the nearshore zone in the Norton Basin, including Norton Sound, the southern Seward Peninsula, and St. Lawrence Island. They haul out on both rocky coastlines and sandy beaches. One to several hundred spotted seals regularly use areas near Stebbins/St. Michael, Besboro Island, Golovnin Bay, Cape Woolley, and Port

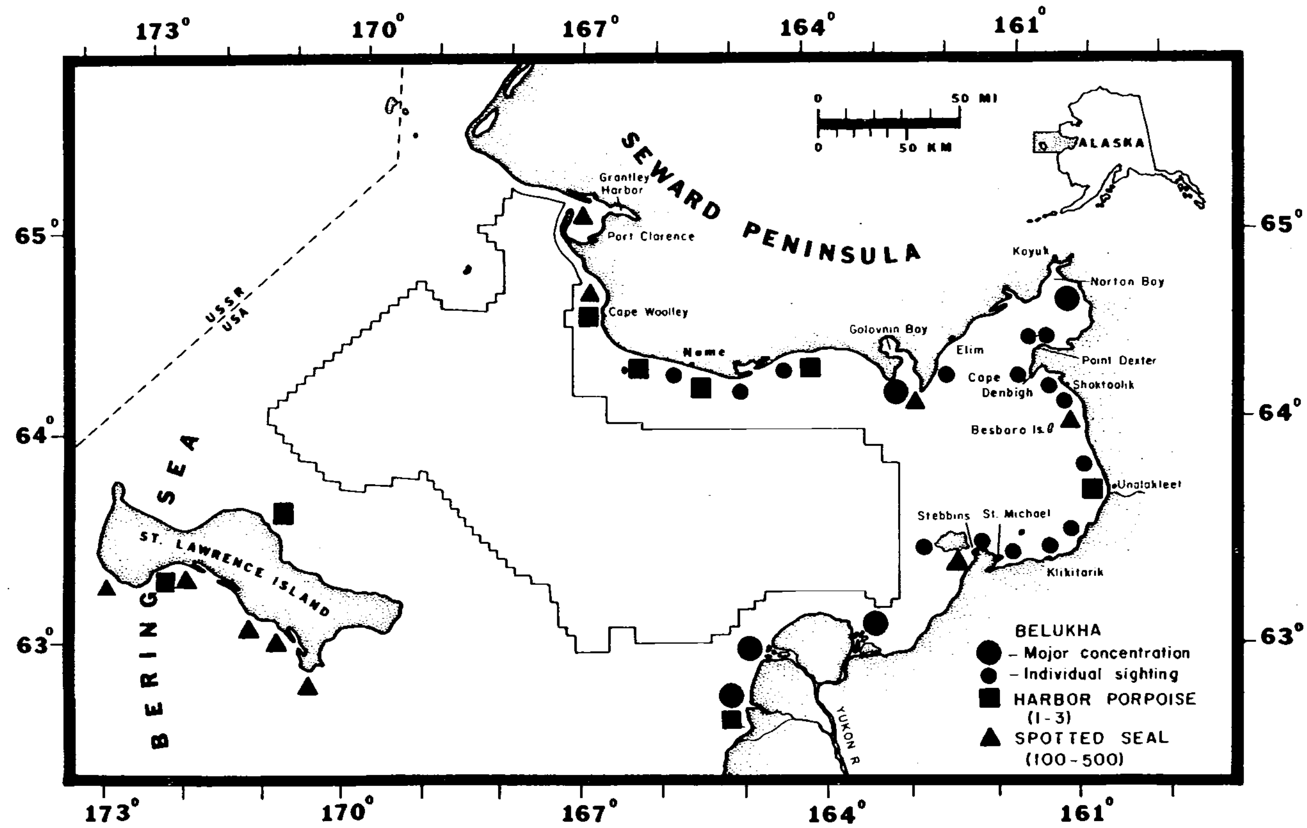

FIGURE 4.1—Sightings of belukha whales and harbor porpoises, and haulout areas of spotted seals, in nearshore areas of the Norton Basin OCS Planning Area during summer and autumn (from Frost *et al.* 1982).

Clarence (Fig. 4.1). There are three major spotted seal haulouts on the south side of St. Lawrence Island, although seals may haul out on rocks and bars at places all along the south side of the island. Along the mainland coast spotted seals are reportedly more abundant in late spring and autumn, or at least haul out in greater numbers and are more conspicuous then (Frost *et al.* 1982).

Arctic cod, saffron cod, herring, and capelin appear to be the main foods of spotted seals in spring in the Norton Basin; in fall the seals appear to eat mainly saffron cod, sand lance, smelt, and herring (Lowry *et al.* 1982). Frost *et al.* (1982) noted that the arrival of spotted seals in spring often coincided with the arrival of schools of spawning herring and salmon.

Spotted seal haulout sites and vicinities (Fig. 4.1) are presumed to be the most important habitats for these animals in the Norton Basin. The seals reappear each year at the major sites, and presumably feed nearby (Frost *et al.* 1982).

One might suspect that the seal population is relatively vulnerable to OCS activities because of the tendency of the seals to concentrate at these haulouts. Hair seals are variably sensitive to being oiled, depending on their age and physical condition and the nature and persistence of the oil (Geraci and Smith 1976; Geraci and St. Aubin 1980). Under some circumstances they could die as a result of being exposed to oil; the very young would appear to be particularly sensitive (reviewed in Davis and Thomson 1984). Oil coming ashore or activities of men or machines very near haulouts in summer may have adverse effects on seals using those sites. Spotted seals are quite sensitive to noise and human disturbance, choosing haulout sites well isolated from human activity; they may abandon traditional haulouts if OCS facilities are located nearby (K. J. Frost pers. comm.).

4.1.2 Ringed Seal

Unlike spotted seals, ringed seals (*Phoca hispida*) are primarily late fall (when ice is present), winter, and spring residents of the Norton Basin, and, except for some juveniles that remain in the Norton Basin in the open-water season, spend the summer in the Chukchi Sea or Beaufort Sea. During winter and early spring, highest densities are found in areas of landfast ice where the seals breed and give birth (Burns *et al.* 1981).

Arctic and saffron cod are probably the mainstay of the ringed seal diet in Norton Sound (Lowry *et al.*

1980, 1981). Juveniles that remain there in summer may also consume sculpins and invertebrates such as shrimps, mysids, and amphipods.

The most important habitat for ringed seals in the Norton Basin is apparently the deeper areas of landfast ice (*i.e.*, the water must be somewhat deeper than the ice thickness). Whether some segments of the coast are more important than others is not known, but one may suspect that extensive, very shallow areas, such as are found off the Yukon delta, may not provide as good a seal feeding habitat as deeper areas.

Because ringed seals are relatively widely dispersed throughout the nearshore zone, their population is probably not as vulnerable to effects of OCS activities as are populations of the more localized spotted seals. The sensitivity of individuals to being oiled is probably similar to that of spotted seals; the effects might be highly variable, depending on circumstances, but could be fatal (see Geraci and Smith 1976 and review by Davis and Thomson 1984).

4.1.3 Belukha Whale

Belukhas (*Delphinapterus leucas*) are common in the Norton Basin from spring through autumn. They are first seen near shore in May and early June and in some years as early as April. Their arrival coincides with the breakup of ice and the arrival of spawning herring and salmon. They have been sighted near Stebbins, St. Michael, Klikitarik, Unalakleet, Besboro Island, Shaktoolik, Cape Denbigh, Point Dexter, Koyuk, Elim, and throughout Norton Bay (Fig 4.1).

Two of the three main summer concentration areas of belukhas in the Bering Sea are in the Norton Basin—one in northeastern Norton Sound (Golovnin Bay to Norton Bay) and one off the mouth of the Yukon River. Belukha whales are common in Norton Bay from spring through autumn. This was historically, and is now, one of the important belukha hunting areas in Norton Sound (K. J. Frost pers. comm.). The largest documented sighting there was of 70 animals feeding on saffron cod near Rocky Point on 30 September 1981. Off the Yukon delta, the largest single sighting reported was of 100 animals in July 1981 (Frost *et al.* 1982).

Belukhas are occasionally sighted along the coast from Nome to Cape Prince of Wales. Historically, they were common in Port Clarence and Grantley Harbor. Belukhas are rarely seen around St. Lawrence Island in summer, though they are common offshore there in winter and spring. They move by the Diomede Islands on their northward migration in spring and again when they move south in autumn. They are not present around the islands during summer (Frost *et al.* 1982).

Belukhas in the Norton Basin probably eat mainly cod, salmon, and herring. In summer near the mouths of rivers they may concentrate on salmon. Observations indicate a close relationship between groups of belukhas and schools of herring and saffron cod (Seaman *et al.* 1982). Belukhas have been observed in Norton Bay in association with saffron cod (near Golovnin Bay) and salmon (Yukon delta). Saffron cod may be most important because they are available and abundant over a relatively long time period in comparison to herring and salmon (Lowry *et al.* 1982).

The tendency for belukhas to concentrate in summer in localized areas in Norton Basin makes them potentially vulnerable to the effects of OCS activities. From studies elsewhere belukhas are known to be sensitive to noises of vessels and other machines, but to be able to readily acclimate to noises that are not associated with pursuit. It appears unlikely that oil would have appreciable adverse effects (see Geraci and St. Aubin 1982 and review by Davis and Thomson 1984).

4.1.4 Harbor Porpoise

Harbor porpoises (*Phocoena phocoena*) are occasionally seen, one to four per group, in coastal waters of Norton Sound and near St. Lawrence Island, June through August (Fig. 4.1). Little is known about their distribution and abundance in the Norton Basin (though they probably occur mostly near shore), but they are fairly regularly seen when conditions permit and capable observers are present (K. J. Frost pers. comm.). Individuals caught in Norton Sound had been feeding on saffron cod (Frost *et al.* 1982). No data exist to show whether especially important habitats exist for them at specific places in the Norton Basin. Thus their vulnerability to the effects of OCS activities in the Norton Basin is not certain.

4.1.5 Offshore Species in Nearshore Habitats

Walruses (*Odobenus rosmarus*), Steller sea lions (*Eumetopias jubatus*), and polar bears (*Ursus maritimus*) are usually more a part of the offshore than of the nearshore ecosystem, and thus are addressed in Chapter 5. But each uses nearshore habitats for an important seasonal function, which is addressed here.

Walruses haul out to rest at several locations in the Norton Basin during the ice-free months; only five of these locations are regularly used by substantial numbers of animals (Fig. 4.2). These locations and the maximum numbers of walrus that have been observed at each site are: Besboro Island (200–400), King Island (5,000), Big Diomede Island (5,000–10,000), and St. Lawrence Island (east end including Punuk Islands) (15,000–60,000, depending on year). King Island was apparently not used until recently, since human habitation has ceased (Frost *et al.* 1982).

Walrus haulouts are of two types: resting areas for

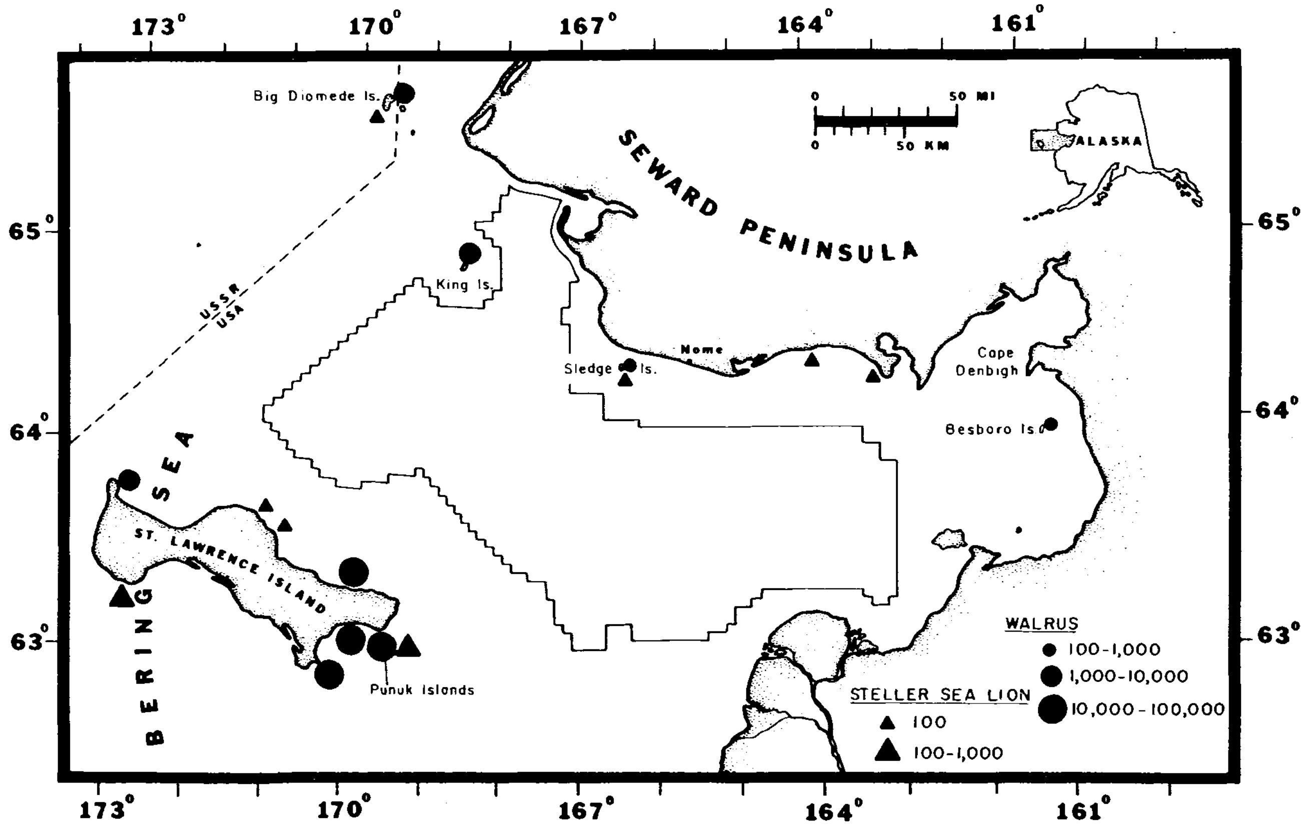

FIGURE 4.2—Major known haulouts of walruses (all seasons) and locations where Steller's sea lion haulouts have been recorded (summer) and maximum number of animals observed at haulout sites in the Norton Basin (from Frost *et al.* 1982).

mostly male walruses that are used during the summer feeding season (Besboro and King islands; occasionally Egg and Sledge islands and Cape Darby), and islands used as resting places by migrating animals along their routes of movement in autumn. Recent observations have been made of tens of thousands of migrating hauled-out walruses at several locations on St. Lawrence Island and the Punuk Islands (Frost *et al.* 1982) (Fig. 4.2).

Steller sea lions, generally males, haul out regularly but in variable numbers in the Norton Basin in summer (Fig. 4.2). Locations where sea lions have been reported to haul out are Cape Denbigh, near Nome, and Sledge Island in Norton Sound; on Big Diomede Island; and on St. Lawrence Island and the Punuk Islands (Frost *et al.* 1982). For all locations except St. Lawrence Island and the Punuk Islands, only a few individuals have been seen at irregular intervals. Several localities are used on St. Lawrence Island; up to 1,000 sea lions have been reported at Southwest Cape, 200 on the Punuk Islands, and variable (usually lower) numbers elsewhere.

Polar bears are nearing the southern limits of their distribution in the Norton Basin, and are generally found there only in winter (Cowles 1981), though occasionally a few summer on St. Lawrence Island. They use the nearshore zone for feeding and for denning and giving birth, though it is likely that most coastal denning is inland from the nearshore zone as we have defined it. Very few bears den in the Norton Basin (Cowles 1981); possible sites are in the Punuk Islands and on St. Lawrence Island (Starr *et al.* 1981) and on the Diomede Islands (Lentfer and Hensel 1980). Although the ringed seal is an important prey species for the polar bear, the nearshore fast ice (where many ringed seals breed) is apparently not an important winter and spring foraging area; most feed offshore in the moving ice (K. J. Frost pers. comm.), though little is known of the bears' winter distribution and abundance in the Norton Basin.

4.2 BIRDS

As with mammals, it is sometimes difficult to separate "nearshore" from "offshore" species of birds because some species use both nearshore and offshore habitats. However, we will follow the general pattern of others (*e.g.*, Hunt *et al.* 1981; Starr *et al.* 1981; Woodby and Divoky 1983) in treating loons, waterfowl, cranes, shorebirds, and most gulls and terns as nearshore species (this chapter), and cliff-nesting seabirds as marine or offshore species

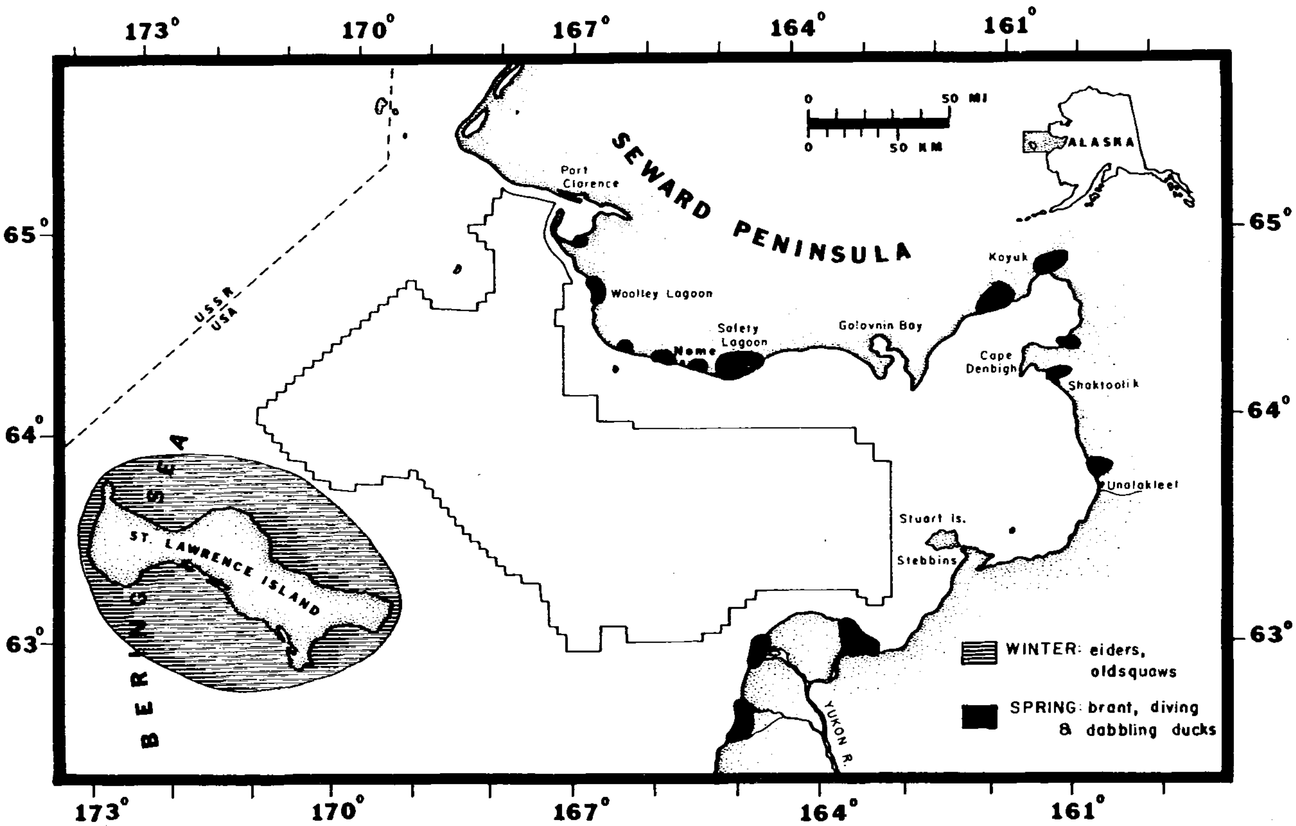

FIGURE 4.3—Winter (December-March) and spring (April-May) concentrations of waterfowl in coastal environments of the Norton Basin (after Starr *et al.* 1981; Woodby and Divoky 1983; C. J. Lensink, USFWS, Anchorage, Alaska, pers. comm.).

(Chapter 5). It is generally the case that food-web affiliations of the species in these groups in the Norton Basin follow this categorization. The offshore species nest in nearshore habitats, and, though their feeding ecology and offshore distribution are treated in depth in Chapter 5, their nesting colonies are described in this chapter.

Most birds are highly sensitive to being oiled. External oiling of birds drastically diminishes the insulative and buoyancy value of their feathers, and oil on eggs may adversely affect hatching success (reviewed in Roseneau and Herter 1984). Susceptibility to adverse effect from oil is thus primarily a function of the vulnerability of the population to being exposed to oil.

4.2.1 Loons

The red-throated loon (*Gavia stellata*) is the only common loon to use nearshore waters in the Norton Basin (Woodby and Divoky 1983). Low numbers nest in wetland habitats near the coast of Norton Sound and forage for marine and estuarine fishes in nearshore waters. They are limited in their feeding distribution in the nearshore zone by the availability of nearby wetland nesting habitat. Places where they are locally abundant (tens of birds up to a maximum of 200) include the Port Clarence area, Safety and Taylor lagoons near Nome, Fish River delta, Moses Point, Koyuk, Shaktoolik, Stebbins, and Stuart Island (Woodby and Divoky 1983). It is likely that they are more abundant on the Yukon delta than elsewhere. Because loons are localized along the coast in their feeding, their populations are relatively vulnerable to the effects of OCS activities. Further, because they dive for food, the individuals invariably come in contact with oil if a spill spreads into their feeding areas.

4.2.2 Waterfowl

The wetlands of the nearshore and coastal areas of the Norton Sound region provide nesting, feeding, and staging habitat for thousands of migrating and breeding waterfowl. Nesting takes place in the coastal lowlands, river delta flats, and salt marshes. Particularly large numbers of waterfowl use the Yukon River delta. The Akulik-Inglutalik River and other deltas are also important, but to a lesser extent than the Yukon (Starr *et al.* 1981).

Four general periods and kinds of use are recognized: overwintering aggregations; prenesting concentrations in spring; breeding, brood-rearing, and molting use in early and midsummer; and staging concentrations in late summer and early fall. Prenest-

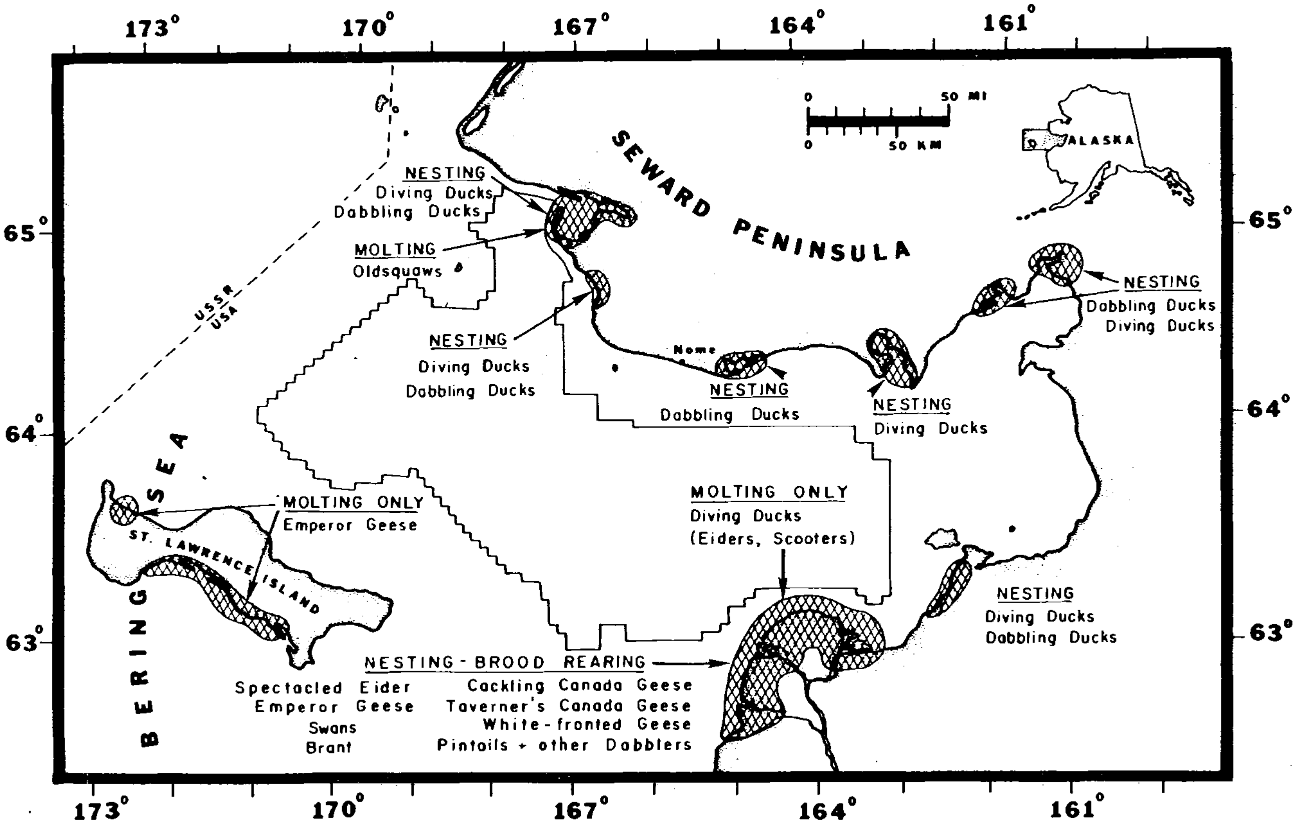

FIGURE 4.4—Summer (June–early August) concentrations of nesting/brood-rearing and molting waterfowl in nearshore and coastal environments of the Norton Basin (after Starr *et al.* 1981; Woodby and Divoky 1983; C. J. Lensink, USFWS, Anchorage, Alaska, pers. comm.). The Yukon River delta contains many times the waterfowl populations of other areas.

ing concentrations are gatherings of arriving spring migrants in specific areas before nesting begins. Birds nest, rear young, and molt in specific areas; some species have molting areas distinct from nesting and brood-rearing areas. Some species stop year after year at specific "staging" areas to feed and rest during, or prior to, southerly migration. Figures 4.3, 4.4, and 4.5 depict areas where waterfowl concentrate in winter and spring, summer, and late summer and fall, respectively.

Tundra Swan

Several thousand of the 60,000 or so tundra swans (*Cygnus columbianus*) that occur on Alaskan breeding grounds nest in wetlands adjacent to the Norton Basin. Most of these occur on the Yukon delta (Fig. 4.4); fewer than a thousand nest along the south side of the Seward Peninsula, and about 100 nest on St. Lawrence Island (Woodby and Divoky 1983; Truett *et al.* 1984). Swans arrive on the nesting areas from late April to early May (Lensink 1973). Breeding pairs remain near the nest sites for most of the summer, but nonbreeding birds gather in flocks, typically at the outer edges of river deltas. River deltas and associated wetlands are the preferred habitats for both nesting and fall staging (Truett *et al.* 1984).

Swans feed on emergent and submerged portions of water plants. The pondweed *Potamogeton* may be important to them in the Norton Basin.

Swans are relatively vulnerable to effects of OCS activities, particularly to oil in coastal waters. Large proportions of regional populations congregate in localized areas that could be affected by oil spills (*e.g.*, the Yukon delta), and the birds themselves, like other waterfowl, are relatively sensitive to oil in their habitats. Under normal weather conditions, however, most of the breeding populations may be relatively safe from oil spills because oil in marine waters would not reach their nesting sites (see Truett *et al.* 1984).

Geese

Black brant (*Branta bernicla*), cackling and Taverner's Canada geese (*B. canadensis*), white-fronted goose (*Anser albifrons*), emperor goose (*Philacte canagica*), and snow goose (*Chen caerulescens*) are the species of concern in the nearshore environment of the Norton Basin. All but the snow goose nest there;

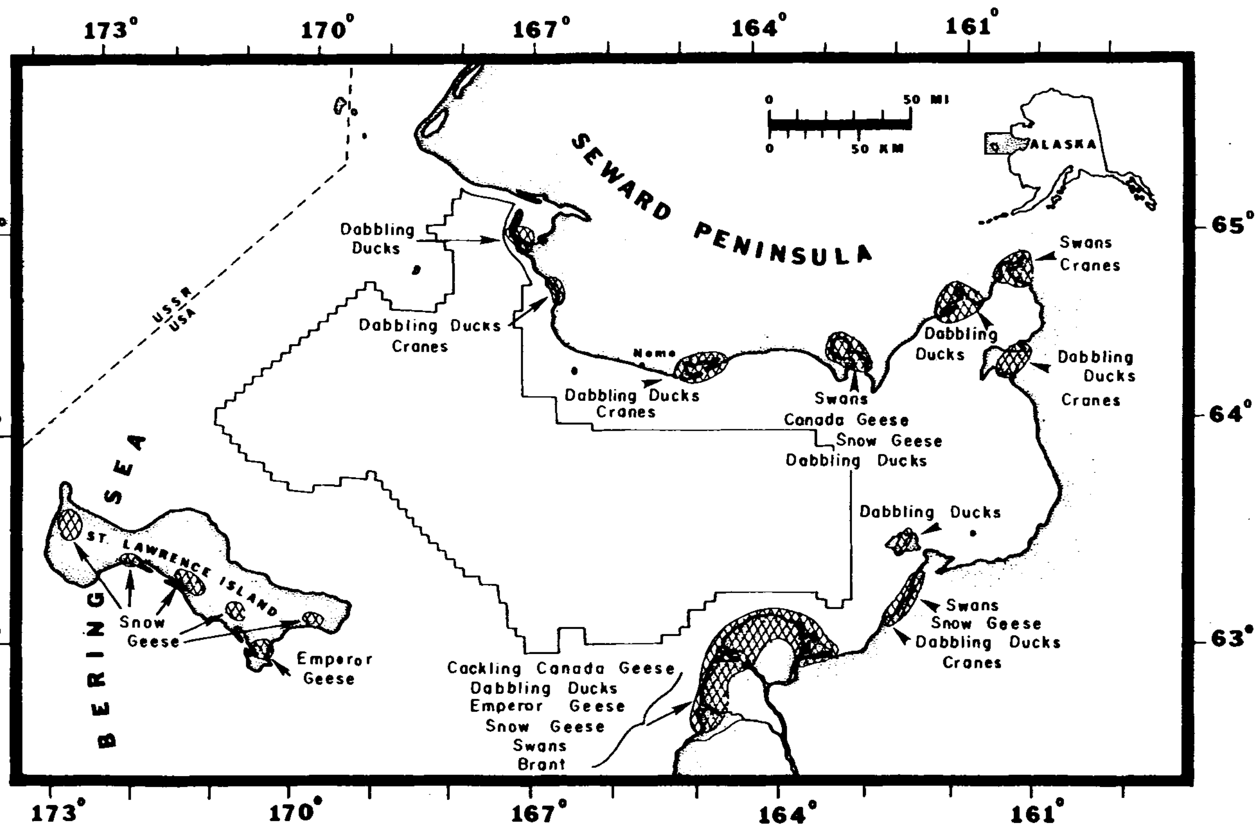

FIGURE 4.5—Late summer-early fall (late August-September) staging/feeding concentrations of postbreeding waterfowl and cranes in the coastal environments of the Norton Basin (after Starr *et al.* 1981; Woodby and Divoky 1983; C. J. Lensink, USFWS, Anchorage, Alaska, pers. comm.). NOTE: Parts of some of the staging areas, particularly in the case of snow geese and other geese, are too far inland to be vulnerable to OCS activities. Dabbling ducks are usually mostly pintails.

snow geese use the area for migration staging only.

Most of these geese find their most important nesting and staging areas just to the south of the Norton Basin, in the Yukon-Kuskokwim delta region south of Cape Romanzof (see Truett *et al.* 1984), but the north Yukon delta and other areas within the Norton Basin have moderate populations of some.

Black brant nest in the Norton Basin in appreciable numbers only in the Yukon delta area (Woodby and Divoky 1983; Truett *et al.* 1984), where they concentrate on the coastal fringe (Fig. 4.4). They are most common in other localities during spring migration (May-June) (Fig. 4.3). A few stage in coastal wetland habitats in fall. Brant consume aquatic and semiaquatic vegetation in wetland habitats. Like other waterfowl in the area, they are sensitive to being oiled. Their populations are relatively vulnerable to oil spills in coastal habitats because of their propensity to concentrate locally. Nesting brant are more vulnerable to oil spills than most geese because they nest very near the coast (see Truett *et al.* 1984).

Three races of Canada goose—lesser, cackling, and Taverner's—occur in the Norton Basin. The lesser Canada goose is an abundant migrant in the Norton Sound area, but few nest there. Woodby and Divoky (1983) found only three nests in two years' work in Norton Sound, all in the Fish River delta. In fall, almost the entire Alaska population of lesser Canada geese (about 100,000 birds) funnels through Norton Sound on its way to wintering areas farther south (Woodby and Divoky 1983) (Fig. 4.5). (The spring migration does not pass through Norton Sound.) Cackling and Taverner's Canada geese nest to some extent on the Yukon delta within the Norton Basin planning area, but the large majority of Bering Sea populations of both these subspecies nest farther south on the Yukon-Kuskokwim delta. Canada geese feed mainly on terrestrial vegetation (*e.g.*, sedges, grasses). Like other waterfowl, they concentrate in wetland habitats, especially river deltas. Because of their tendency to concentrate locally and their sensitivity to oil, they are relatively susceptible to effects of OCS activities. Nesting Canada geese are few and tend to be distributed some distance inland from the coast. Their greatest vulnerability comes in fall when migrants stage in coastal waters and river delta areas.

White-fronted geese occur in substantial numbers in the Norton Basin only on the Yukon delta, where they are widely distributed nesters. They are much more abundant as nesters outside the Norton Basin on the Yukon-Kuskokwim delta (Woodby and Divoky 1983). They are mainly terrestrial grazers in their feeding habitats, using a wide variety of coastal and inland wetlands. Because of their widespread distribution and tendency to occur far inland, they are relatively invulnerable to the effects of OCS activities.

Emperor geese are true sea geese, frequenting rocky shores and salt-washed meadows. Their nesting in the Norton Basin is concentrated on and near the Yukon delta; 1,000–2,000 also nest on St. Lawrence Island (Woodby and Divoky 1983) (Fig. 4.4). They nest very near the coast. In midsummer, a massive molt migration of nonbreeders occurs from the emperor goose breeding grounds in Siberia and on the Yukon-Kuskokwim delta to coastal habitats of St. Lawrence Island (Fig. 4.4). During spring and fall migration, emperor geese are relatively scarce in Norton Basin coastal wetlands. Emperor geese eat aquatic and semiaquatic plants, frequently feeding very near the sea. Because of this and their tendency to congregate during nesting and molting, they are highly vulnerable to potential effects of OCS activities.

Snow geese occur strictly as migrants in the Norton Basin, on their way between wintering grounds in the south and nesting grounds on Wrangel Island in the Chukchi Sea (Woodby and Divoky 1983). They are most abundant in the Norton Basin in spring. At this time, one segment of the snow goose population enters eastern Norton Sound from the interior, and another comes from the Alaska Peninsula and passes northward across the mouth of Norton Sound. The largest numbers in spring have been seen in eastern and southern Norton Sound and on the Yukon River delta. Fewer are commonly seen at these locations in fall. Because snow geese tend to feed inland from the coast, they are relatively invulnerable to the effects of OCS activities.

Dabbling Ducks

Pintails (*Anas acuta*), followed in abundance by American widgeons (*A. americana*), mallards (*A. platyrhynchos*), green-winged teals (*A. crecca*), and northern shovelers (*A. clypeata*), make up the preponderance of dabbling ducks in the Norton Basin (Woodby and Divoky 1983). Dabbling ducks use the region for both nesting and migration staging, though more stage there than nest. By far the most important area for both nesting and staging is the Yukon delta (compare Woodby and Divoky 1983; Truett *et al.* 1984). Like most of the geese, these ducks congregate for breeding and staging in the coastal wetlands, especially in and near river mouths (Figs. 4.3, 4.4, 4.5).

Dabbling ducks feed primarily on aquatic vegetation and invertebrates. Pintails in the Yukon delta area were observed to eat pondweed (*Potamogeton filiformis*), mysids, and isopods (Kirchhoff 1978). They also eat seeds of *Carex* and other wetland plants.

Because of the tendency for many dabbling ducks to occur in staging and feeding concentrations near the coast, their populations are frequently vulnerable to adverse effects of OCS activities to which they are sensitive (*e.g.*, spilled oil). They are highly vulnerable, particularly in cases where large numbers feed in marine or estuarine waters that could easily be reached by spilled oil (*e.g.*, the Yukon delta front, see Truett *et al.* 1984).

Diving Ducks

The most common diving ducks in summer in nearshore habitats of the Norton Basin are black scoter (*Melanitta nigra*) and common eider (*Somateria mollissima*); greater scaup (*Aythya marila*), oldsquaw (*Clangula hyemalis*), and red-breasted merganser (*Mergus serrator*) are also fairly common (Woodby and Divoky 1983). Many of the diving ducks nest inland over broad areas (*e.g.*, black scoters, oldsquaws); a few (*e.g.*, common eiders) nest locally in coastal habitats. Most congregate in spring and/or summer in coastal habitats to molt and/or feed. Some (eiders, oldsquaws) spend the winter in coastal waters near St. Lawrence Island (Figs. 4.3, 4.4).

In coastal waters in summer and fall, oldsquaws assemble to molt in bays and lagoons, where they feed on epifauna; greater scaup and mergansers feed mostly near river deltas on invertebrates and fish; and eiders and scoters assemble farther from shore or near rocky shores where their benthic infaunal prey is more abundant (Woodby and Divoky 1983). Most are relatively vulnerable when they concentrate in these nearshore marine waters during migration or molting, but most (except common eiders) are relatively invulnerable during nesting.

The only major place of concentration, and thus vulnerability to oil, for ducks in winter is the open water around St. Lawrence Island. Up to 50,000 eiders and 500,000 oldsquaws may spend the winter there (Fig. 4.3), shifting from place to place as the ice shifts and leads open and close (Starr *et al.* 1981 quoting Fay 1961).

4.2.3 Cranes

Sandhill cranes (*Grus canadensis*) use the Norton Basin coastal environment for migration staging in spring and fall and breeding in summer. The largest number occurs during fall migration (late August to mid-September) when cranes concentrate to feed in wetlands at the Fish River delta, Koyuk, Stebbins, and to a smaller extent at Safety Lagoon, Woolley Lagoon, and other coastal wetlands (Fig. 4.5). Spring migration occurs in late April and early May, when flocks of cranes may stop briefly at coastal wetlands all around Norton Sound. The Yukon delta is the only important crane nesting habitat in the Norton Basin; densities as high as 1.5 breeding birds/km^2 may occur on the outer fringes of the delta in early summer (Boise 1977; Jones and Kirchhoff 1978).

Cranes feed on bulbs and roots of wetland vegetation and a variety of animal foods (voles, snails and other invertebrates, and small fish). They often forage very near the sea in intertidal meadows. This intertidal foraging habitat, coupled with their tendency to concentrate at specific locations, makes them relatively vulnerable to oil. However, they are undoubtedly less sensitive to oil than are waterfowl, because they wade rather than swim in the water.

4.2.4 Shorebirds

Though many shorebirds nest in coastal wetlands of the Norton Basin, the major importance of the coastal areas is for pre- or postbreeding staging in early summer and in late summer and early fall, respectively. With a few exceptions (*e.g.*, black turnstone, *Arenaria melanocephala*), shorebirds nest in much greater abundances in inland areas not particularly susceptible to introductions of oil or to other activities associated with OCS development.

Woodby and Divoky (1983) show the peak of seasonal abundance of the most common shorebird species along Norton Sound shorelines—semipalmated and western sandpipers (*Calidris pusilla* and *C. mauri*), dunlin (*C. alpina*), and red-necked phalarope (*Phalaropus lobatus*)—to vary among species (Fig. 4.6). Semipalmated sandpipers and red-necked phalaropes are most abundant on shorelines prior to nesting; western sandpipers and dunlin are most abundant after nesting. Other authors (Gill and Handel 1981; Starr *et al.* 1981) emphasize the importance of coastal habitats in late summer, at which time postnesting birds congregate to feed in coastal lagoon and river delta areas such as Clarence Harbor, Golovnin and Safety lagoons, and wetlands of Norton Bay (Fig. 4.7). The Yukon delta coast is undoubtedly used by more individuals in late summer than is any other area in the Norton Basin.

Shorebirds gathering at these coastal habitats feed mainly on intertidal invertebrates (*e.g.*, molluscs, insects, amphipods, isopods). Because they and their prey concentrate in the same places that waterborne pollutants such as oil are likely to accumulate, shorebirds are highly vulnerable to having their feeding habitats oiled. Unlike many water birds, however, shorebirds (except perhaps phalaropes) can probably readily avoid oil in their habitats and thus may be relatively insensitive to its presence (P. G. Connors pers. comm.).

4.2.5 Gulls and Terns

Glaucous gulls (*Larus hyperboreus*) and Arctic terns (*Sterna paradisaea*) dominate this group in the Norton Basin. Woodby and Divoky (1983) found glaucous gulls to be the most common birds (except near cliff colonies) along Norton Sound shorelines.

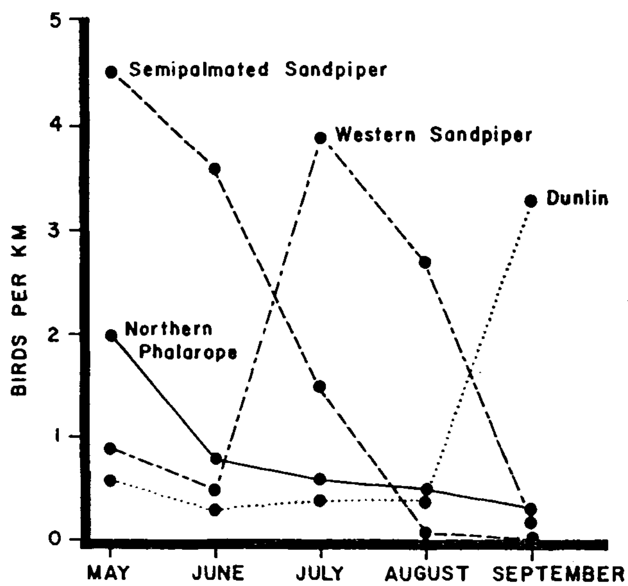

FIGURE 4.6—Seasonal abundance of the wetland shorebirds common along shoreline habitats of Norton Sound (from Woodby and Divoky 1983). (These are bird densities in 50-m wide shoreline transects; densities are often much higher in selected littoral habitats.)

This bird nests in a variety of shoreline and inland habitats—islands, peninsulas, cliffs—and forages along coastlines in all habitats. River mouths and exposed cliffs seem to have the greatest densities of glaucous gulls (Woodby and Divoky 1983). Arctic terns nest in small colonies or isolated pairs on spits, beaches, and islands, or in wetlands near lakes or ponds. Spit habitats and river mouths appear to have the greatest use by Arctic terns in Norton Sound (Woodby and Divoky 1983).

Fish are major foods of both glaucous gulls and Arctic terns; gulls eat in addition a wide variety of foods such as bird eggs and young, rodents, invertebrates, and carrion. Both gulls and terns feed in, and frequently nest near, marine and estuarine waters at the coast, and thus are probably moderately susceptible to adverse effects if oil is spilled in their feeding habitats, though gulls, in particular, may

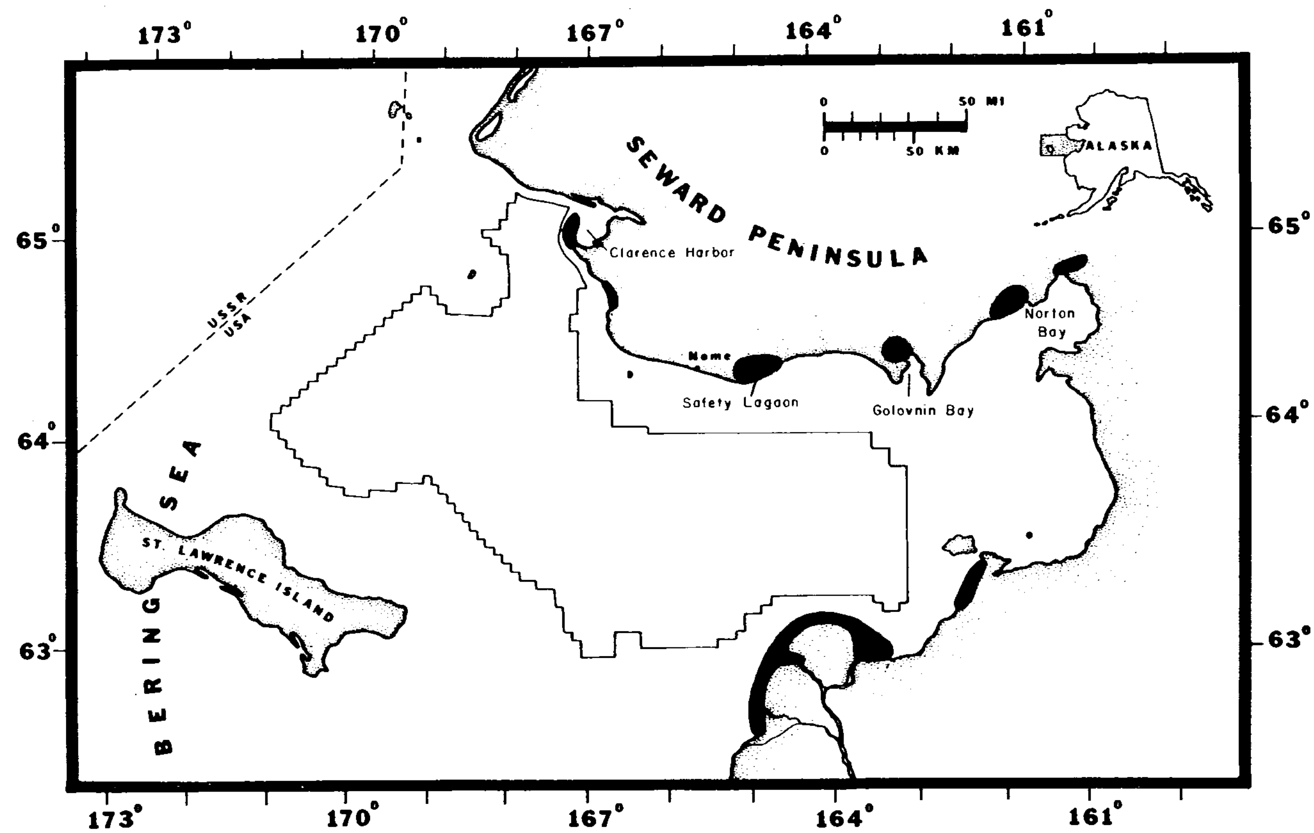

FIGURE 4.7—Late summer-early fall (August-September) concentrations of staging/feeding shorebirds in nearshore and coastal environments of the Norton Basin (after Starr *et al.* 1981; Woodby and Divoky 1983). (Black turnstones nest in these same areas.)

avoid oil. They tend not to be highly concentrated (though they sometimes nest in small groups) so the vulnerability of the populations to localized spills is probably low (Roseneau and Herter 1984).

4.2.6 Seabird Colonies

Though seabirds forage mostly in offshore environments, they nest on land, mostly at coastal locations. We discuss their distribution and abundance in nesting colonies here; their role in the offshore ecosystem is discussed in Chapter 5. The following discussions are mostly from Starr *et al.* (1981).

Hunt *et al.* (1981) estimated that a minimum of 4.3 million seabirds utilize the Norton Basin region. These authors list St. Lawrence Island and Little Diomede Island as the Bering Sea's largest and third largest colonial aggregations, with populations of 2.7 million and 1.2 million birds, respectively. Large percentages of some seabird species nest wholly within this region. The colonies on St. Lawrence Island support 62% of the crested auklet (*Aethia cristatella*) population in the eastern Bering Sea (Sowls *et al.* 1978). Least auklets (*A. pusilla*) breeding on St. Lawrence and Little Diomede islands represent 79% of the total eastern Bering Sea population (Hunt *et al.* 1981). Sizes and compositions of colonies are shown in Table 4.1.

Seabirds generally arrive on northern Bering Sea breeding grounds between late April and early June (Hunt *et al.* 1981). Timing of egg laying, hatching, and fledging is species-dependent. At Little Diomede Island, egg laying occurred from early June to late July in 1977. Fledging began in late June and continued into August (Drury and Biderman 1978).

Distribution of nesting seabirds is affected by distribution and availability of nesting habitat, but the species composition of colonies appears to be greatly influenced by the type and abundance of prey available in adjacent waters. Large numbers of plankton-feeding species such as least and crested auklets, or thick-billed murres (*Uria lomvia*) which consume considerable amounts of zooplankton as well as fish, are found only where currents carry plankton from deep oceanic waters. Coastal colonies are dominated by fish-eating species such as common murres (*U. aalge*), black-legged kittiwakes (*Rissa tridactyla*), and puffins (Hunt *et al.* 1981). Locations of colonies are shown in Figure 4.8.

TABLE 4.1—Size estimates (minimum available) and predominant inhabitants of seabird colonies in the Norton Basin area, Alaska. Colony numbers are keyed to Fig. 4.8. (Colonies consisting mainly of ducks, gulls, and/or terns, and those for which sufficient data on composition do not exist, are not included.)

Colony and Size		Predominant Inhabitants[1]								
		LeAu	CrAu	PaAu	Murr	CoMu	HoPu	ThMu	BlKi	PeCo
1. Southwest Cape	(709,000)	×	×		×					
2. Owalik Mtn.	(54,230)	×	×		×					
3. Sevoukuk Mtn.	(187,000)	×	×	×						
4. Kaghkusalik	(94,300)	×	×		×				×	
5. Savoonga	(90,000)	×	×		×					
6. Cape Myaughee	(640,500)	×	×		×					
7. Stolbi Rocks	(?)									×
8. Singikpo Cape	(64,800)	×	×		×					
18. Little Diomede I.	(807,000)	×	×	×		×	×	×		
19. Fairway Rock	(32,000)	×	×			×		×		
20. King Island	(345,971)	×	×	×		×		×		
22. Tin City	(20)									×
25. Cape Riley	(200)						×			×
28. Sledge Island	(4,769)					×	×	×	×	×
30. Topkok Head	(468)									×
31. Topkok East	(149)									×
33. Bluff	(49,322)					×	×		×	
34. Square Rock	(3,946)					×			×	
36. Rocky Point	(591)									×
37. Cape Darby	(1,386)						×			×
38. Cape Denbigh (N)	(7,250)					×		×	×	
39. Cape Denbigh (S)	(5,197)					×		×	×	
40. Besboro Island	(370)						×			
41. Egavik	(29)						×			×
42. Tolstoi	(124)									×
43. Black Point	(18)									×
44. Black Cove Island	(106)						×			
45. Unnamed Colony	(8)									×
46. Tolukowuk Bluffs	(8)									×
48. Whale & Beulah Is.	(10)						×			
52. Egg Island	(~2,000)					×				

SOURCE: Starr *et al.* 1981.

LeAu = least auklet, CrAu = crested auklet, PaAu = parakeet auklet, Murr = unidentified murres, CoMu = common murre, HoPu = horned puffin, ThMu = thick-billed murre, BlKi = black-legged kittiwake, PeCo = pelagic cormorant.

On St. Lawrence Island, seabird colonies are concentrated on the north side and west end of the island. Although nesting habitat is available at the east end of the island, fewer seabirds nest there. Those few that do nest there are fish-eating species typical of coastal colonies. The planktivorous least auklet is almost entirely absent. This difference between the communities reflects the different character of the waters at each location. The east end of the island is bathed in coastal waters strongly influenced by freshwater flow from the Yukon River (Coachman *et al.* 1975). In contrast, the west end of St. Lawrence Island is washed by currents transporting nutrients and plankton from oceanic waters (Hunt *et al.* 1981).

King Island is influenced by the oceanic currents flowing northward to the Bering Strait, even though the island lies relatively near the coast. Consequently, seabird communities on the island have both "coastal" species such as common murres and parakeet auklets (*Cyclorrhynchus psittacula*), and "oceanic" species such as least auklets and thick-billed murres. Little Diomede, the northernmost colony in the Bering Sea, is dominated by the planktivorous least and crested

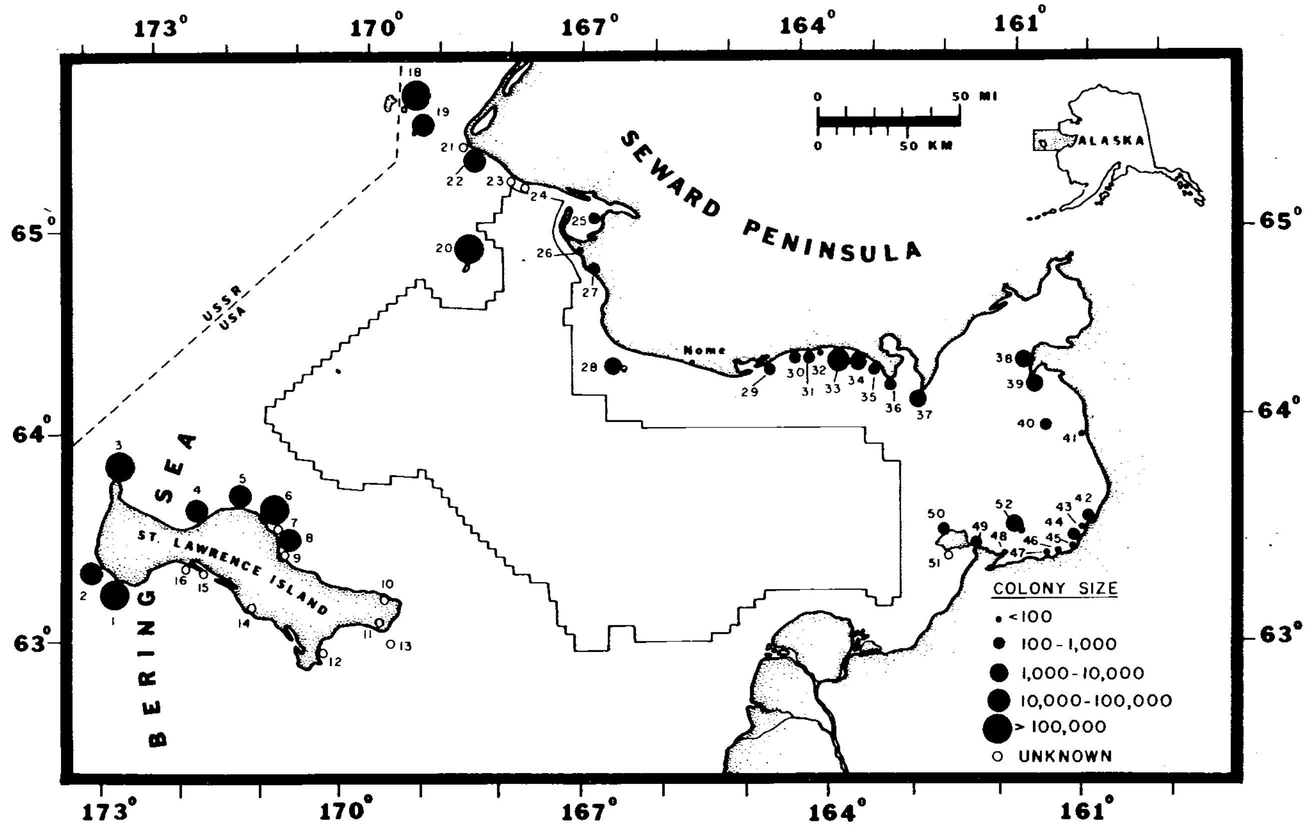

FIGURE 4.8—Seabird colonies in the Norton Basin vicinity. Where known, colony population sizes are indicated (from Starr *et al.* 1981). (See Table 4.1 for place names and colony inhabitants.)

auklets (Hunt *et al.* 1981).

The Norton Sound colonies are small and the populations of the colonies are skewed toward fish-eating species: common murre, black-legged kittiwake, and tufted puffin (*Lunda cirrhata*). Seabirds that depend upon zooplankton for a substantial part of their diet are virtually absent (Hunt *et al.* 1981).

In some ways the seabirds are highly susceptible to OCS impact at nesting cliffs. Although most feeding by seabirds of these coastal colonies takes place in the offshore environment, there is also much use of coastal waters very near the colonies by some species and at some times. Murres, black-legged kittiwakes, pelagic cormorants (*Phalacrocorax pelagicus*), and horned puffins (*Fratercula corniculata*) frequently feed very near nesting cliffs. Young murres leave their nesting cliffs by swimming. These seabirds are highly vulnerable to spilled oil at these times. Furthermore, the colonies are vulnerable to certain other OCS activities such as aircraft overflights. In terms of response, most species are highly sensitive to oil, kittiwakes probably less so than most others. Some are very sensitive to aircraft passing near (see discussions in Roseneau and Herter 1984).

4.3 FISHES

The fish community of Norton Sound and the Chirikov Basin consists of relatively few species which represent a faunistic transition between the productive waters of the northern Pacific Ocean (southern Bering Sea) and the less diverse waters of the Arctic Ocean (Chukchi and Beaufort seas) (Fig. 4.9). The fish community can be characterized by the presence of three distinct groups of fish (Wolotira 1980): (1) coldwater fishes indigenous to arctic marine waters (*e.g.*, Arctic cod, Arctic flounder), (2) subarctic boreal fishes whose distribution is centered south of the Norton Basin in the Bering Sea or Pacific Ocean (*e.g.*, salmon, herring, cod, yellowfin sole, starry flounder), and (3) northern anadromous/estuarine fishes (*e.g.*, Arctic char/Dolly Varden, whitefishes, smelts).

Fish resources in the Norton Basin are substantially less abundant than in more southerly Alaskan shelf regions. Norton Sound bottomfish account for less than 3% of the potential eastern Bering Sea bottomfish resource (see Section 5.3), and the Norton Basin and Yukon-Kuskokwim region salmon harvests are about 6% and 50%, respectively, of catches in Bristol

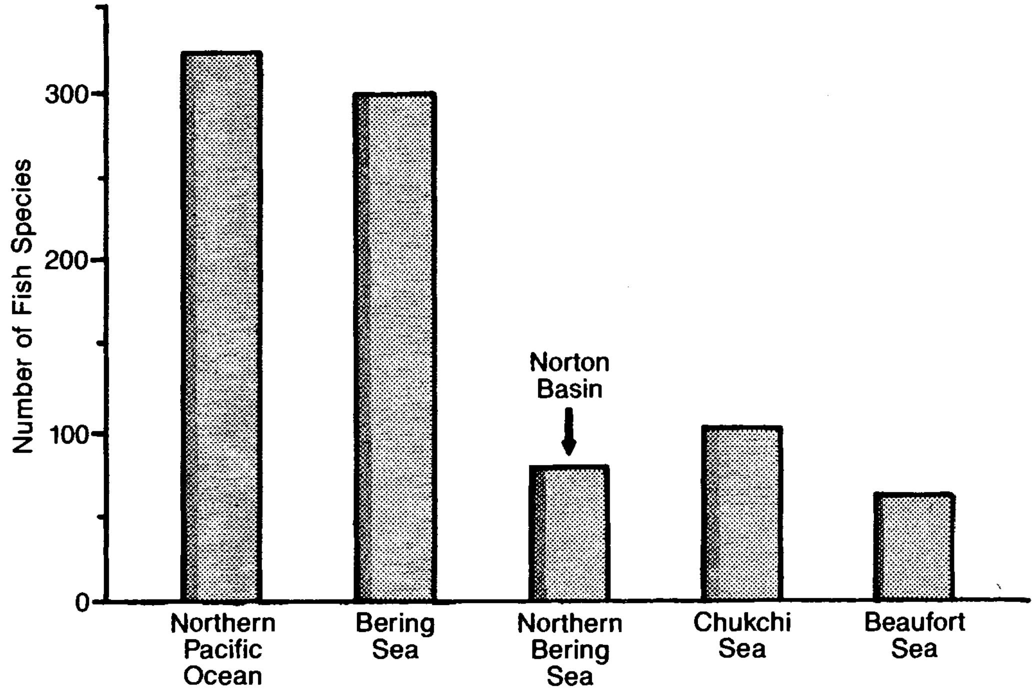

FIGURE 4.9—Number of fish species in Alaskan seas and the north Pacific Ocean. Sources: northern Pacific Ocean—Hart 1973; Bering Sea—Pereyra *et al.* 1976; northern Bering Sea—Wolotira *et al.* 1977; Chukchi Sea—Craig 1984a; Beaufort Sea—Craig 1984b.

Bay (Burns *et al.* 1982). Low seawater temperatures are believed to be the cause of the apparent paucity of commercial fish stocks in the region (Alton 1974; Burns *et al.* 1982).

The nearshore zone of the Norton Basin extends approximately 1,600 km and consists of a diverse array of aquatic habitats including large bays, lagoons, river deltas, tidal marshes, and exposed coastlines. The data base for fishes in this zone consists primarily of Barton's (1978) 1976–77 survey at Port Clarence, Golovnin Bay, eastern Norton Sound, and the Yukon delta. In addition, the Alaska Department of Fish and Game (ADF&G) annually monitors adult salmon entering the Yukon River (Geiger *et al.* 1983) and has surveyed many of the streams flowing into the Norton Basin for the presence of salmon stocks (ADF&G 1981, 1983). Other large-scale surveys by Wolotira *et al.* (1977) in offshore waters of the Norton Basin are described in Chapter 5.

Descriptions of major nearshore fishes, including information about their temporal and spatial distributions and food habits in the Norton Basin, are presented below, followed by a summation of their potential vulnerabilities to OCS development.

4.3.1 Salmon

All five species of Pacific salmon occur in the Norton Basin, but pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) are most abundant. These two species comprise 90% of annual harvests in the region (Wolotira 1980).

At least 43 streams flowing into the Norton Basin (including some on St Lawrence Island) support salmon stocks (Starr *et al.* 1981; ADF&G 1983), but the Yukon River is the major producer of salmon in this region and it supports large runs of chum, chinook, and coho, with smaller numbers of pinks and sockeye. In recent years, commercial and subsistence harvests of salmon have averaged about 300,000 fish in the Norton Basin (ADF&G 1979) and 1,420,000 in the Yukon River (Geiger *et al.* 1983). Although the magnitude of salmon resources in the Norton Basin is small in comparison to that in other Alaskan regions, Burns *et al.* (1982) emphasize that the importance of this resource to the local economy is substantial.

Wolotira (1980) summarizes the occurrence of adult salmon in nearshore waters as follows. Adult salmon are found in nearshore habitats from time of ice breakup (about mid-June) until mid-August. The timing of their occurrence varies by species; chinook salmon appear first, followed by chum, sockeye, pink, and finally coho salmon (Fig. 4.10). Commercial and subsistence salmon harvests by statistical district suggest the location of major runs (other than to the Yukon River) for each species. Most chinook and coho salmon are harvested in the Unalakleet district; sockeye catches occur almost solely in Port

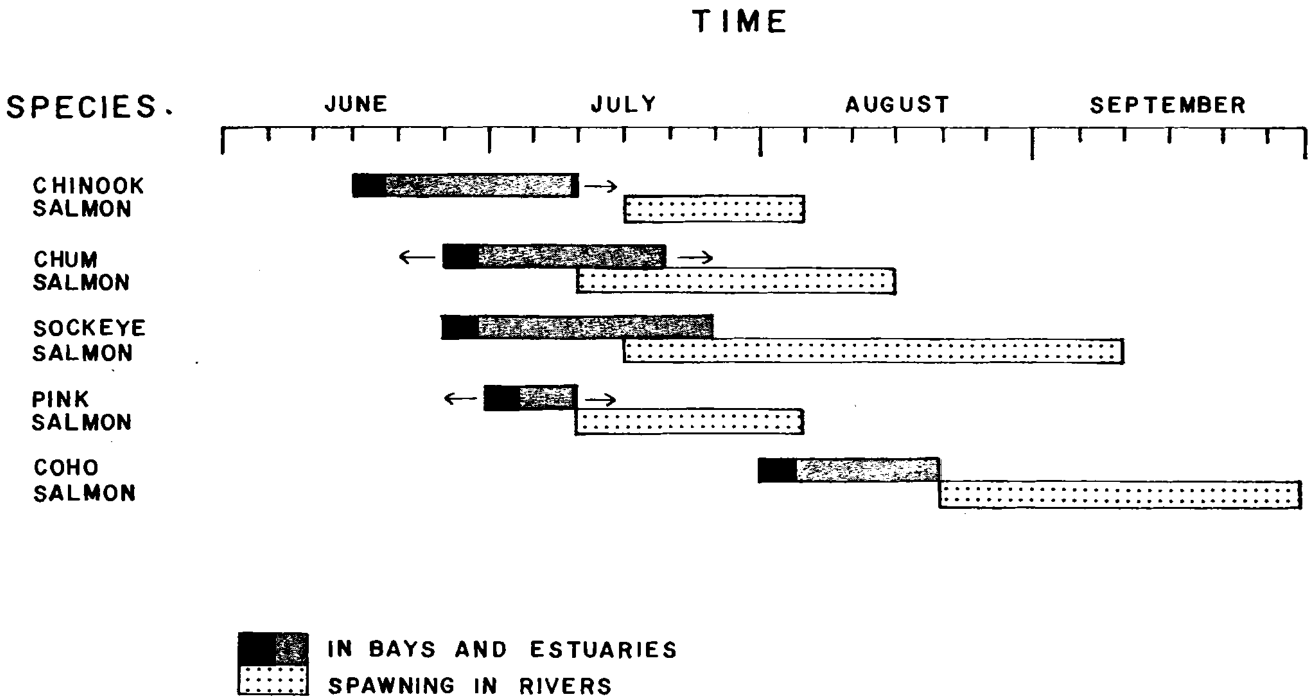

FIGURE 4.10—Timing of the occurrences of salmon species in bays and estuaries during spawning migrations in the Norton Basin (from ADF&G 1976; Wolotira 1980).

Clarence, where one of the northernmost populations of this species in North America occurs; pink salmon are harvested primarily in the Unalakleet, Golovnin Bay, and Moses Point districts; and chum salmon harvests are relatively similar throughout most of Norton Sound.

Juvenile pink and chum salmon enter nearshore waters at the onset of spring breakup (mid-June) and move offshore by mid-July (Barton 1978) or later (Straty 1981). During their nearshore residence, juvenile salmon feed primarily on plankton and fish. Although few data specific to the Norton Basin are available, major food items of pink and chum fry are generally copepods and small tunicates; coho juveniles are piscivorous, and herring larvae and sand lance are important prey; sockeye and chinook juveniles eat copepods, tunicates, other invertebrates, and fish (Manser 1969; Healey 1979; Naiman and Siebert 1979; and others). Neimark *et al.* (1979) note that chum juveniles in Norton Sound eat insects and fish. The abundance, distribution, and types of zooplankton available in coastal waters greatly influence the distribution, growth, and survival of juvenile salmon (Straty and Jaenicke 1980).

Estuaries and other nearshore areas are particularly important to juvenile salmon. These habitats provide both a rich feeding ground for newly smolted juveniles and a transition area where these fish can gradually adapt to their change from fresh to salt water. In the life cycle of salmon, it is this period of estuarine residence by young salmon that is most vulnerable to potential OCS impacts. In the estuaries, the highly concentrated juveniles, which are relatively sensitive to being oiled, are subject to both direct effects (toxicity of oil and dispersants) and indirect effects (loss of habitat or food organisms) of oil spills. As summer progresses, they become less habitat-dependent and disperse offshore and, as stronger swimmers, they can presumably vacate or avoid contaminated areas.

Utilization of the Yukon delta by juvenile salmon has been identified as an important data gap. This topic is currently under investigation by OCSEAP studies initiated in September 1984.

4.3.2 Herring

Pacific herring (*Clupea harengus pallasi*) is the most important marine pelagic species in the Norton Basin (Burns *et al.* 1982). It plays an important role in the marine food web, and is harvested in both commercial and subsistence fisheries. Major population centers for herring are to the south of Norton Sound (Fig. 4.11). The relationship of Norton Sound herring and herring to the south is unclear. Some Norton Sound herring may mix with southern stocks and others may remain year-round in Norton Sound (Barton and Wespestad 1980).

Commercial harvests of herring in Norton Sound have occurred since the early 1900's. Annual harvests

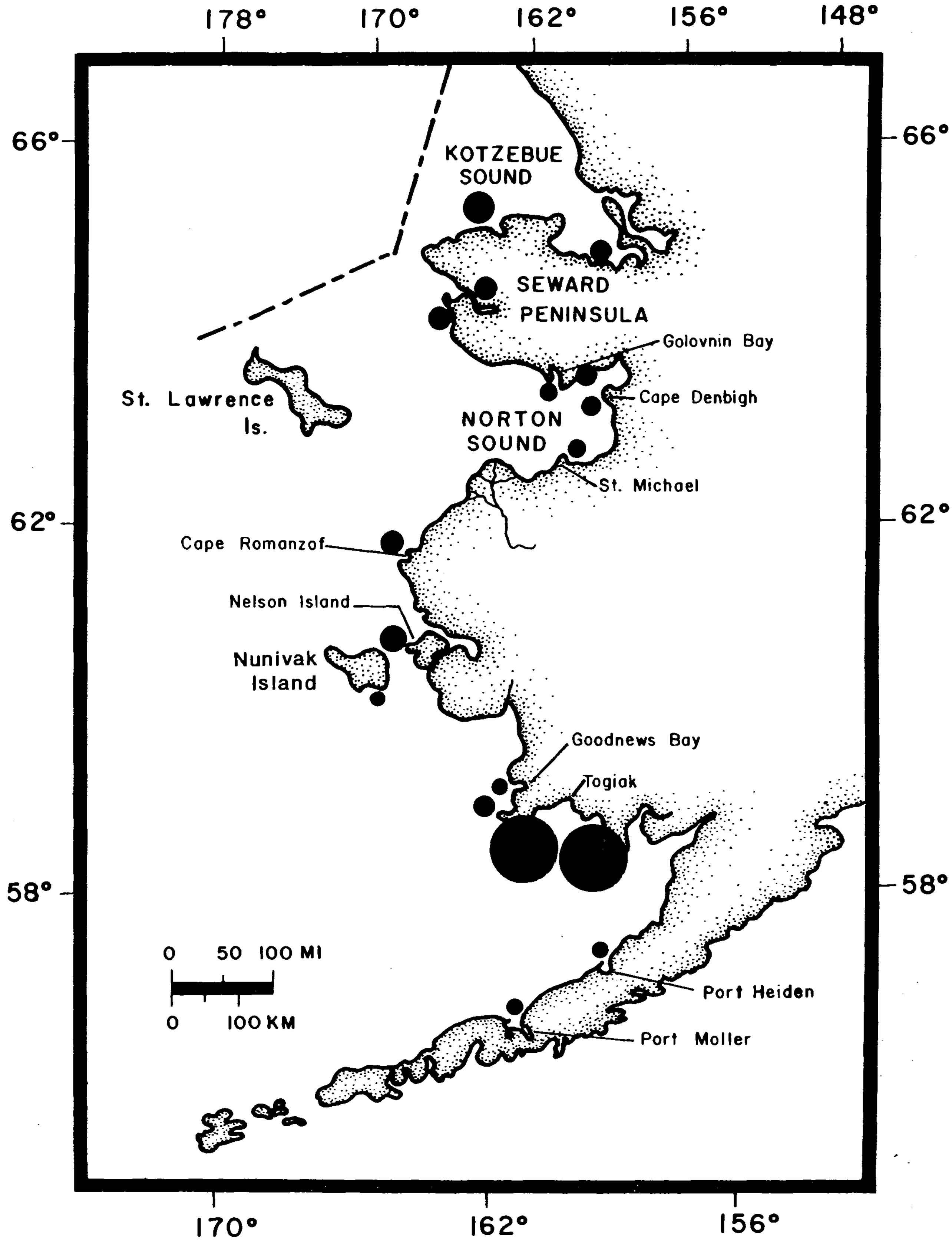

FIGURE 4.11—Distribution of herring biomass in coastal spawning areas (from Barton 1979).

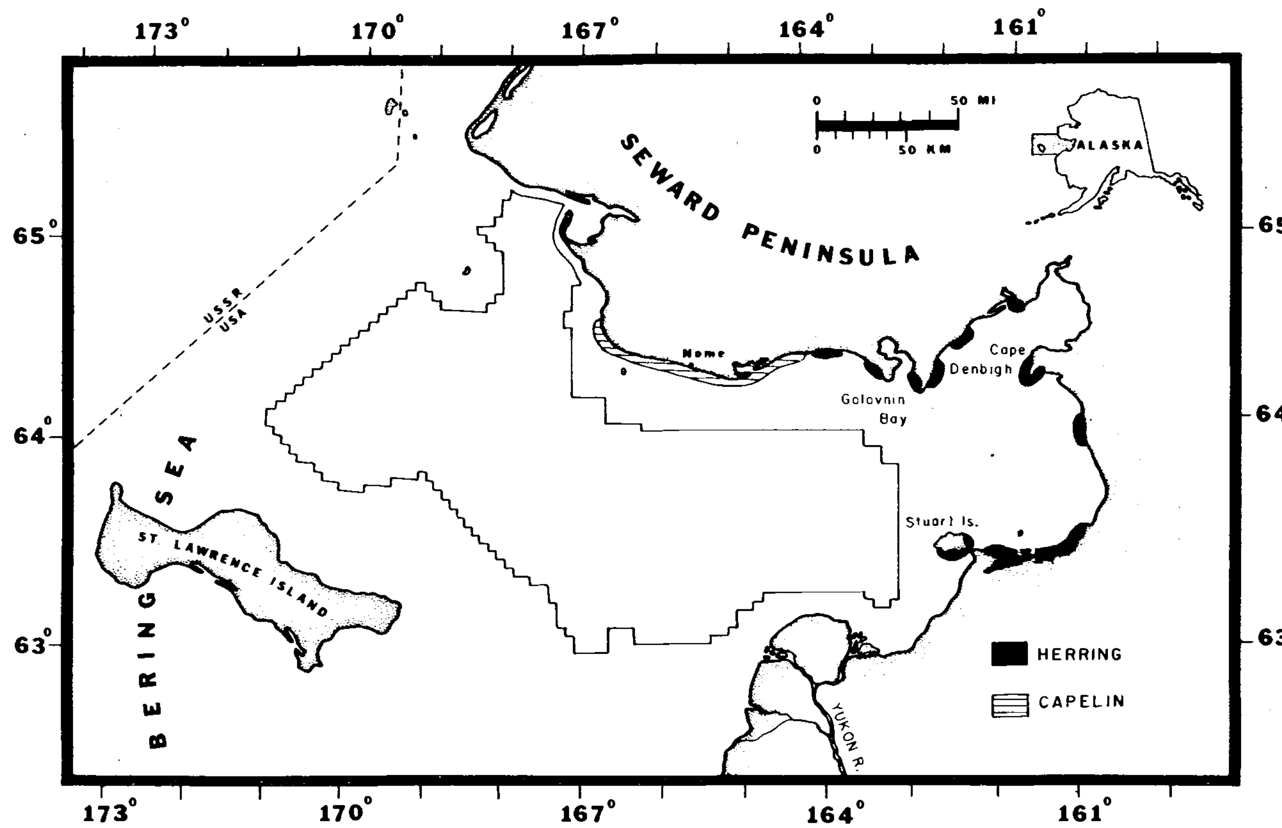

FIGURE 4.12—Herring and capelin spawning areas, including several potential spawning areas (from Starr *et al.* 1981).

have been highly variable (from almost nil to over 200 metric tons), depending on fish abundance and the availability of markets (Wolotira 1980). The subsistence fishery nearest the Yukon delta is located at Cape Romanzof where 915 metric tons were harvested in 1982 (Geiger *et al.* 1982).

The life cycle of herring follows a cyclical pattern of spring spawning in shallow coastal waters, larval and juvenile rearing in shoreline environments, then a migration to deeper offshore waters for feeding and maturation. The time when herring spawn in Norton Sound is greatly influenced by climatological conditions, particularly the extent of the Bering Sea ice pack (Barton 1978). In general most spawning occurs immediately after ice breakup in mid-May and continues through June. Barton (1978) notes that these fish remain in nearshore waters both before and after spawning throughout the early spring and summer months. In fall, herring are widely distributed throughout coastal and offshore waters of Norton Sound (Wolotira *et al.* 1977; Barton 1978).

Spawning occurs at various locations in Norton Sound (Fig. 4.12), generally in subtidal waters on kelp (*Fucus* sp.) in areas of exposed rocky headlands, and also on eelgrass (*Zostera* sp.) in shallow bays, inlets, or lagoons (Barton 1978). The duration of spawning may range from a few days to several weeks. Eggs take 10–21 days to hatch depending on water temperature. Natural mortality of eggs and larval herring may be very high (50–99%) due to wave action, egg exposure to air, and bird predation (Taylor 1964; Reid 1972; Barton and Steinhoff 1980). After hatching, tremendous numbers of herring larvae and postlarvae may populate coastal surface waters during summer months.

Herring are an important link in the marine food web. Barton (1978) found that herring in the Yukon–Kuskokwim delta and Norton Sound areas fed mostly upon copepods, barnacle larvae, cladocerans, platyhelminths, and mysids. Hart (1973) summarized herring trophic relationships as follows. Early herring larval stages feed on invertebrate eggs, copepods, and diatoms, and in turn are prey for fishes, ctenophores, jellyfish, and chaetognaths. Juvenile herring initially consume ostracods, copepods, diatoms, and fish larvae; larger juveniles consume mostly planktonic crustaceans such as copepods, amphipods, cladocerans, decapods, barnacle larvae, and euphausiids. Adults prefer larger crustaceans and small fishes. The herring adult is in turn eaten by a variety of fishes, seabirds, and marine mammals. It has been estimated that 95% of total herring mortality is by predation

TABLE 4.2—Relative abundance of major fish species at nearshore locations in Norton Sound.

Fish Species		% Composition of Major Species[1]			
		Port Clarence	Golovnin Bay	East Norton Sound	Yukon Delta
Pond smelt	*Hypomesus olidus*	68			
Pacific herring	*Clupea harengus pallasi*	13		7	
Pink salmon	*Oncorhynchus gorbuscha*	6			
Saffron cod	*Eleginus gracilis*	5		17	
Sand lance	*Ammodytes hexapterus*		81	9	
Rainbow (boreal) smelt	*Osmerus eperlanus*			37	
Bering cisco	*Coregonus laurettae*				39
Humpback whitefish	*Coregonus pidschian*				21
Sheefish	*Stenodus leucichthys*				10
Chum salmon	*Oncorhynchus keta*				8
Longnose sucker	*Catostomus catostomus*	7			7
Total Catch		15,227	80,836	7,843	884

SOURCE: Barton 1979.

[1] >5% relative abundance (27 less abundant species were also collected).

(Laevastu and Favorite 1978), which might account for wide fluctuations in herring abundance despite seemingly small changes in fishing pressure or environmental factors (Wespestad and Barton 1981).

In the event of a coastal oil spill or other disturbance, herring would be particularly vulnerable because their spawning, incubation, and nursery stages all occur in shallow shoreline environments. Barton (1978) also indicates that at least a portion of the region's herring population remains in nearshore waters year-round and thus would be more vulnerable to disturbance than if they were dispersed offshore as usually occurs with this species.

4.3.3 Other Fishes

Other fishes in nearshore waters include several anadromous species harvested in subsistence fisheries (whitefishes, ciscoes, Arctic char/Dolly Varden), forage species which are key elements in the food web (sand lance, cod, capelin, and other smelt), and freshwater fishes (longnose sucker) which occasionally venture into nearshore habitats. The abundance of these species varies greatly by location (Table 4.2). Barton (1978) attributes some of this variability to differences in salinity occurring in nearshore habitats (Fig. 4.13). Catches of larval fishes at these same locations consisted primarily of rainbow (boreal) smelt (92%) with lesser numbers of pond smelt, cods, and sculpins.

The sand lance occurs in a variety of habitats—offshore and nearshore, demersal and midwater—and is sometimes thought of as a demersal species. It is occasionally abundant in nearshore waters of Norton Sound. Sand lance were most abundant in Golovnin Bay and widely distributed in the Port Clarence and Grantley Harbor areas (Barton 1978; Wolotira 1980). The reproductive cycle of sand lance in northern waters in not known, but larvae have been encountered in surface waters at several offshore locations in Norton Sound in early summer. Farther south at Kodiak Island, sand lance spawn intertidally in coarse-sand and fine-gravel beaches on extreme low tides (Dick and Warner 1982). Sand lance larvae feed on phytoplankton; adults consume crustaceans, barnacle larvae, copepods, and chaetognaths.

Similar to sand lance, little is known about rainbow smelt and capelin in Norton Sound. Rainbow smelt are anadromous, assembling in shallow water and then migrating a short distance to spawn soon after breakup. Surveys during summer have found smelt in most of Norton Sound (Wolotira *et al.* 1977); nearshore surveys have encountered smelt at nearly every location sampled (Barton 1978). Young rainbow smelt feed on mysids and amphipods; older fish are largely piscivorous, consuming cod and other small fishes (Macy *et al.* 1978). The capelin is a marine smelt that spawns in spring, usually in intertidal sandy regions (Fig. 4.12). It feeds on fish and small crustaceans including copepods, euphausiids, amphipods, and decapod larvae (Macy *et al.* 1978).

Saffron cod are often abundant in nearshore habitats, particularly the Golovnin Bay and Port Clarence areas (Wolotira *et al.* 1977), but they are also distributed throughout Norton Sound and thus are described in Chapter 5.

Of this assorted group of fishes, the most vulner-

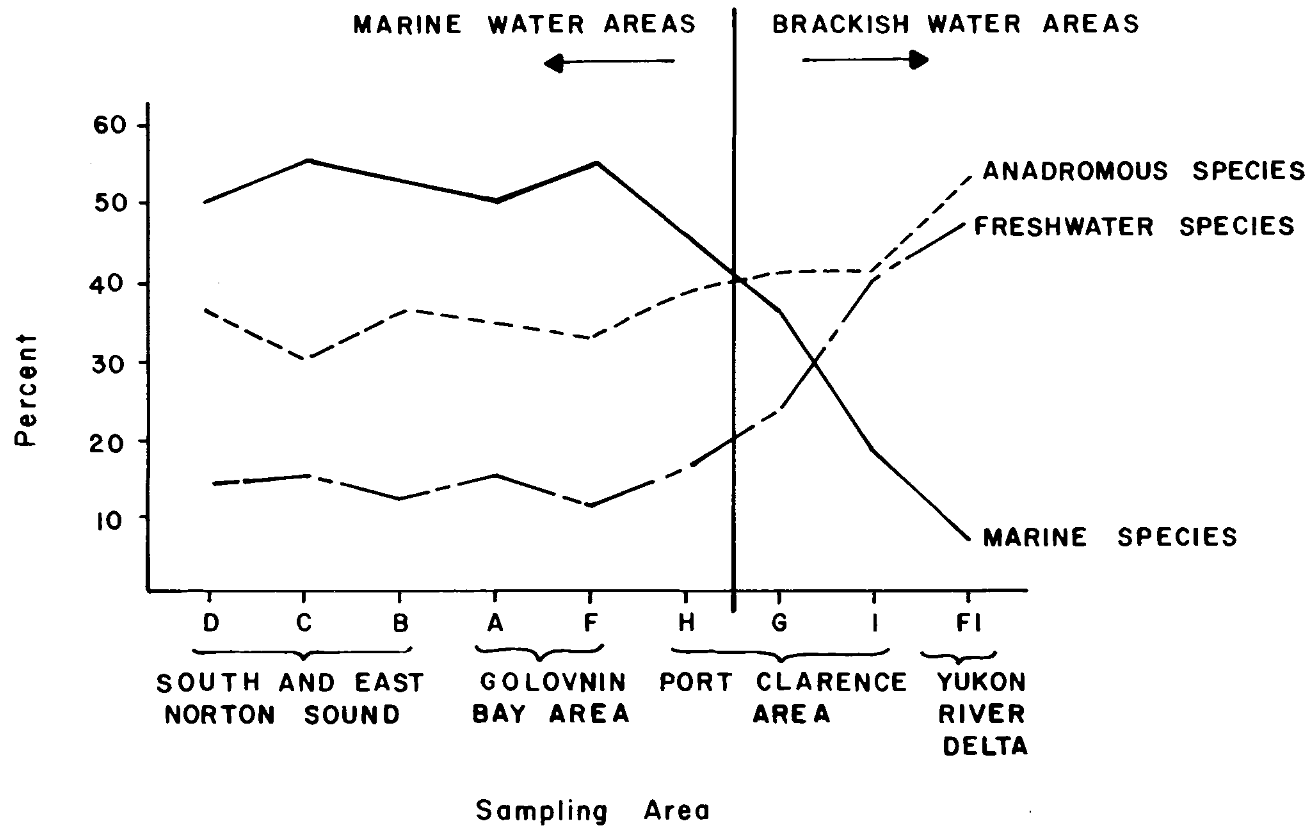

FIGURE 4.13—Species composition of fish in marine and brackish waters of Norton Sound from the Yukon River delta to Port Clarence, 1976–77 (from Barton 1979).

able to OCS impacts are probably the two species which spawn in nearshore waters—sand lance and capelin. Their buried eggs and newly emerged larvae, and the spawning habitat itself, could be directly impacted by an oil spill or other disturbance. The response to perturbations by adults of these species, which characteristically travel along the coast in dense schools, is not known. Most of the remaining species enter coastal waters as older juveniles or adults which presumably would be able to avoid or vacate oiled areas, though experience with past oil spills indicates that fish inhabiting relatively enclosed coastal habitats are indeed vulnerable to oil spill impacts, and mortalities have occurred (LGL 1982).

4.4 INVERTEBRATES

Invertebrates in the Norton Basin are important because they are harvested in commercial or subsistence fisheries (primarily king crab with some clams and mussels) and because they are an essential link in the coastal food web. Though a considerable amount is known about invertebrates in the Norton Basin (see Section 5.4), very few data have been gathered in nearshore habitats.

Virtually no epifaunal or infaunal sampling has been conducted in shallow coastal waters anywhere in Norton Sound. It may be assumed that in waters less than a few meters deep, infaunal populations are sparse because of freezing and ice action on the substrate, and, in fact, Nelson *et al.* (1981) found little bioturbation of the substrate on the Yukon delta platform. However, observations of scoter concentrations in shallow waters off the delta (C. P. Dau unpubl. data) suggest that infauna, on which scoters commonly feed, may be more abundant than presumed.

Successful invertebrates in these shallow waters are generally the mobile, epibenthic species such as mysids, amphipods, and copepods which are tolerant of the widely fluctuating temperatures, salinities, and turbidities characteristic of nearshore environments. Neimark *et al.* (1979) found the coastal waters in extreme eastern Norton Sound (which they believed were freshened appreciably by Yukon River water) to contain zooplankton species adapted to widely ranging temperatures and salinities. The major groups he found there were cladocerans and copepods (particularly calanoid copepods). His sampling techniques were unsuitable for capturing epibenthic or benthic species, but he found fish in these coastal waters to

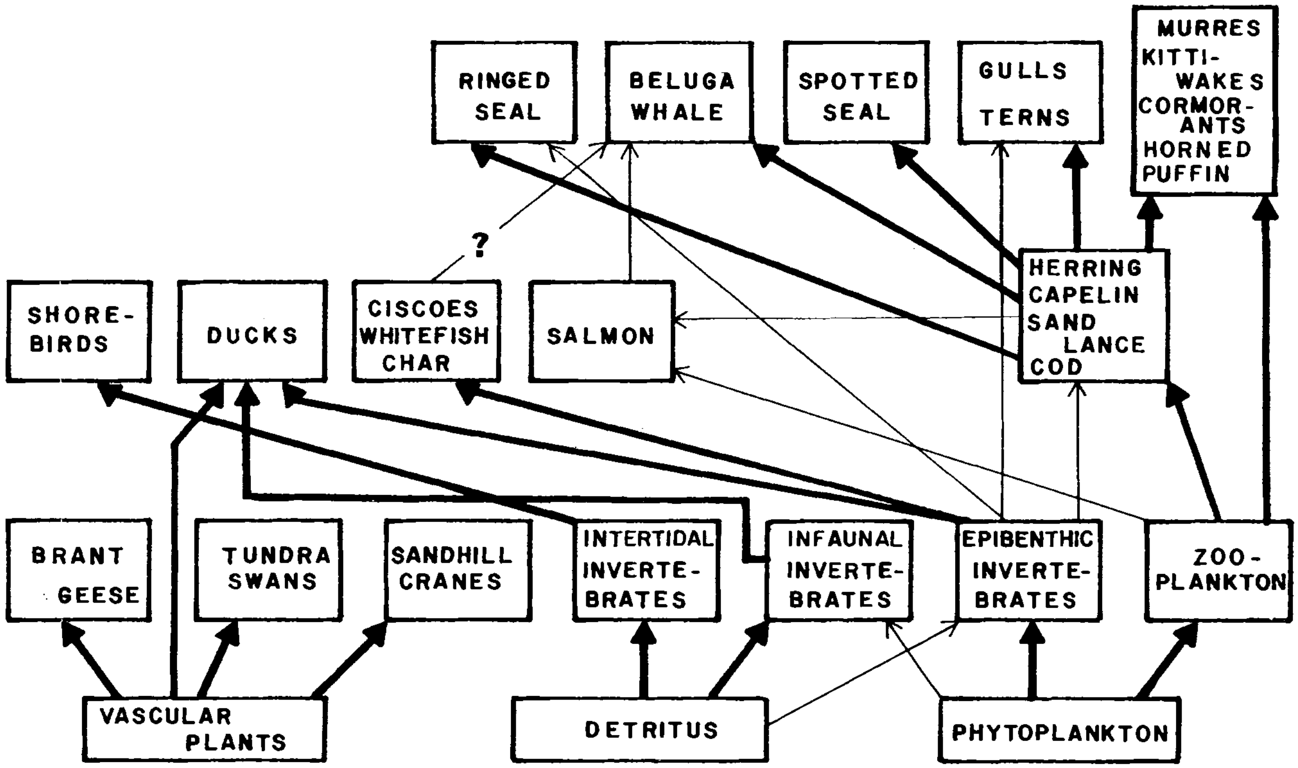

FIGURE 4.14—Simplified food web of the nearshore and coastal ecosystem of the Norton Basin. Heavy arrows indicate major sources of food for consumers.

feed heavily on epibenthic mysids (*Neomysis rayii, N. czerniawskii, N. mirabilis*) and to some extent on benthic oligochaetes, polychaetes, bivalves, and insect larvae (Neimark *et al.* 1979), suggesting these invertebrates are common estuarine inhabitants. Kirchhoff (1978) found that the very shallow mudflat areas (<1 m deep) just off the Yukon delta contained many individuals of the mysid *Neomysis intermedia* and the isopod *Saduria entomon* shortly after the disappearance of shorefast ice in early June. *Neomysis* was especially abundant later in the summer.

The vulnerability of epibenthic invertebrates and plankton to OCS impacts would be locally high, but regionally negligible due to their large numbers, wide distributions, and ability to recolonize affected areas. The consequences of reduced or contaminated invertebrate populations to organisms which feed upon them are not readily predictable, but could be locally important.

4.5 IMPORTANT FOOD WEBS

Figure 4.14 depicts a simplified food web of the nearshore and coastal ecosystem, developed from information presented in preceding sections. Only the major components and links in consumer food chains are shown. Several patterns are evident.

Much of the waterbird food web is short and essentially terrestrial, based mainly on terrestrial and intertidal vascular plants. Diving ducks and shorebirds vary from this pattern, frequently feeding on intertidal and subtidal invertebrates.

Two general feeding patterns appear in fish food webs. The non-salmon anadromous species such as the whitefishes, ciscoes, and Arctic char eat mainly epifauna (probably mostly estuarine and freshwater species). The salmon juveniles and the marine species—herring, capelin, sand lance, cod—appear to feed mainly on marine-derived zooplankton or on each other. (Most salmon adults probably feed little in the nearshore environment.)

The major food web base for top consumers in nearshore waters is probably the marine zooplankton and marine forage fish component, as opposed to the estuarine invertebrate and anadromous fish component. The non-salmon anadromous species, and perhaps the salmon as well, appear not to be eaten in large quantities by any consumers in the nearshore ecosystem. There may be some exceptions; for example, belukha whales in some other places (Bristol Bay) feed heavily on salmon smolts (Lensink 1961), and some have been observed to feed on adult salmon

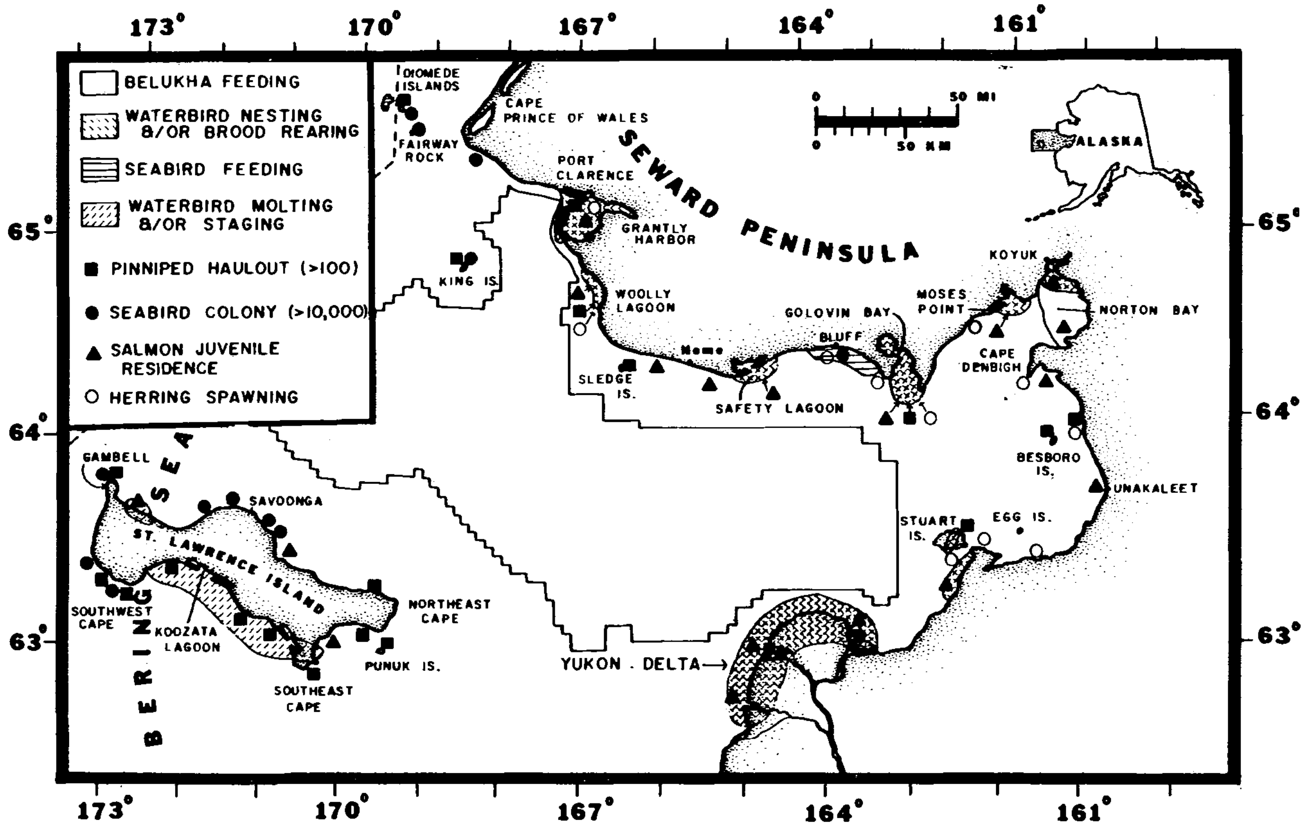

FIGURE 4.15—Important habitats for marine mammals, birds, and fishes during the open-water season (June–October) in the nearshore environment of the Norton Basin.

in the Yukon delta area (Seaman *et al.* 1982). Further, little information is available on trophics of fishes in the nearshore zone. But based on available data it appears that at least the marine mammals, the gulls and terns, and the seabirds that feed in the nearshore zone have mainly a marine-based food web.

4.6 IMPORTANT HABITATS

We define important habitats in the nearshore ecosystem to be places where mammals, birds, and/or fishes concentrate for important life functions, including breeding, feeding, resting, or in some cases, migratory passage. In this section we summarize information from preceding sections to identify these important habitats and to briefly describe their importance.

Figure 4.15 depicts coastal habitats deemed important and indicates which animals use them during the open-water season. Below we discuss in more detail why the habitats are important. Criteria for evaluating general levels of habitat importance include (1) proportions of Norton Basin populations that use the area, (2) proportions of world populations that use the area, and (3) importance of animals that use the habitats (*e.g.*, apparent commercial, subsistence, aesthetic, or scientific value).

In terms of animal abundance, two habitats stand out as extremely important: the Yukon River delta and the major seabird colonies. Other habitats are in comparison secondary in importance, because the number of animals that use them is generally an order of magnitude lower in comparison to animals using the Yukon delta and the seabird colonies.

4.6.1 Yukon River Delta

Belukha whales, most water birds (cranes, swans, ducks, geese, shorebirds), and most anadromous fishes (*e.g.*, most salmon, ciscoes, whitefishes) use the Yukon River delta area in much greater abundance than they use any other area of the Norton Basin nearshore environment. Many species are more abundant here than in all other areas of the Norton Basin combined.

The estuarine waters seaward of the delta margin, and the outer portions of the distributary channels and sloughs, are used in summer and/or early fall by large proportions of the Norton Basin populations of feeding and calving belukhas, feeding and molting ducks, broods of swans and geese, juvenile salmon moving from upstream spawning areas to the sea, and adult ciscoes, whitefishes, and other anadromous fishes. Intertidal habitats are used by large proportions of the Norton Basin populations of brant, geese, sandhill cranes, dabbling ducks, and shorebirds, particularly from midsummer to early fall. Above the normal high-tide level on the delta, large numbers of brant, geese, and dabbling ducks nest. The entire delta and its adjacent waters are very important habitat for biota of the Norton Basin (Fig. 4.15).

4.6.2 St. Lawrence and Other Islands

As is obvious in Figure 4.15, the islands are important habitat in summer for mostly different groups of animals than are common on the Yukon delta. They are prime habitat for seabirds and for pinnipeds that haul out on land.

The most impressive biological aggregations on the islands are the seabird colonies. St. Lawrence Island hosts about 2.7 million birds and Little Diomede Island has about 1.2 million; these are the largest and the third largest seabird aggregations, respectively, in the Bering Sea. King Island and Fairway Rock also have large seabird colonies; the other islands have smaller numbers. Norton Sound islands have generally small numbers. Most of the seabirds on the islands feed considerable distances from their colonies, in the offshore environment. These offshore feeding habitats are discussed in Chapter 5.

Walruses, Steller sea lions, and spotted seals haul out to rest on a number of the islands. St. Lawrence Island attracts the largest numbers of these mammals, partly because it is by far the largest island, and partly because it is located in the normal migratory pathway of walruses, sea lions, and perhaps spotted seals. In addition, substantial numbers of walruses haul out on King and Little Diomede islands (also near their migratory pathway) and on Besboro Island in eastern Norton Sound. Neither sea lions nor spotted seals haul out in substantial numbers on any of the small islands, but Stuart Island in Norton Sound has a spotted seal haulout area.

St. Lawrence Island has, in addition to marine mammal and seabird use, a midsummer molting concentration of emperor geese that come from nesting areas on the Yukon–Kuskokwim delta and perhaps Siberia (Starr *et al.* 1981). These geese, 10,000 to 20,000 in number, inhabit mostly the southern coastal areas of the island (Fig. 4.15).

4.6.3 Norton Sound Coast

Several coastal areas in Norton Sound from Cape Prince of Wales to the Yukon delta are moderately important in summer for mammals, fishes, and birds, though numbers of inhabitants of these areas do not approach those of the Yukon delta or the major seabird islands. These habitats include the Port Clarence–Grantley Harbor area, Woolley Lagoon, Safety Lagoon, nearshore waters near Bluff, Golovnin Bay, stream delta areas near Moses Point and Koyuk, Norton Bay, coastal wetlands southwest of Stebbins, and a few minor river deltas (Fig. 4.15). Areas in Port Clarence and Grantley Harbor are used by hauled out spotted seals, by nesting diving and dabbling ducks, as a late spring stopover for ducks, as a summer molting area for oldsquaws, as a staging area for shorebirds, and as a herring spawning area. Woolley Lagoon hosts nesting and staging ducks, staging cranes and shorebirds, hauled out spotted seals, and spawning herring. Safety Lagoon has spring migrant, nesting, and staging populations of dabbling ducks, and staging cranes and shorebirds. Nearshore waters near Bluff are foraging areas for seabirds (mostly murres and kittiwakes) from the large colony at Bluff. Golovnin Bay is important for summering belukha whales; nesting diving ducks; staging swans, geese, dabbling ducks and shorebirds; and spawning herring. Norton Bay is a summer feeding area for belukhas, and the associated wetlands near Moses Point, Koyuk, and the south part of the bay are used for nesting by dabbling and diving ducks, for late spring migration stops by brant and ducks, and for late summer–early fall staging by swans, dabbling ducks, Canada geese, and cranes. Herring spawn southwest of Moses Point and off Cape Denbigh. There is a spotted seal haulout between Cape Denbigh and Unalakleet. Stebbins has a herring spawning area nearby, and an area to the southwest is used by nesting and staging ducks and staging cranes and swans. Most of the river delta areas along the coast are probably used to some extent by outmigrating salmon juveniles.

4.6.4 Winter Habitats

When ice is present in the nearshore zone of the Norton Basin, there is a much-diminished use of nearshore habitats, but a few areas are important at this time. One important winter habitat is the ice-free water on the north and south sides of St. Lawrence Island. These waters extend from nearshore to offshore, shift in location with the moving ice, and are used by large numbers of oldsquaws and eiders throughout winter (Fig. 4.3). Some river deltas, in particular the Yukon delta but also probably others, serve as overwintering sites for anadromous fishes such as ciscoes, sheefish, and blackfish. Further, though most herring and other marine fishes winter offshore, Barton (1978) reports herring in winter in Golovnin Bay and Safety Sound. Presumably, these marine fish may also occur elsewhere at this time in the nearshore zone.

4.7 POTENTIAL IMPACTS OF OIL AND GAS DEVELOPMENT

This analysis deals with the potential impacts of Norton Basin petroleum development on biota in the nearshore zone. A relatively intensive analysis of potential impacts on birds of the Yukon River delta is presented, because of the importance of the Yukon delta as habitat for many species and because of its proximity to potential OCS development. A less intensive analysis of expected impacts on other species and in other areas is presented.

4.7.1 Birds of the Yukon Delta

This analysis considers the impacts of Norton Sound petroleum development on birds of the Yukon River delta. It was contributed for this report by Calvin Lensink, U.S. Fish and Wildlife Service, Anchorage, Alaska as an outcome of his participation in the Norton Basin Synthesis Meeting. Because of the detailed discussions presented, it also serves as a good basis for helping to evaluate impacts to water birds in other coastal habitats.

Potential for impacts in this analysis are classified as high, moderate, low, or nil according to definitions used by the Minerals Management Service. These definitions, slightly modified for clarity, are:

High: A species declines in abundance within a region or other large geographic area to a level at which natural recruitment would not return it to its former abundance within several generations.

Moderate: A local population changes in abundance and/or distribution over more than one generation but the remainder of the population is relatively unaffected.

Low: A local population is reduced for a short period (one to two generations), but the regional population is not measurably affected.

Nil: Mortality or loss of productivity of a few to many individuals may occur, but local or regional populations are not measurably altered in size and/or distribution.

These definitions clearly focus on populations and not individuals. The assessment of potential impacts on individual species considers only the sizes of populations within areas potentially at risk relative to the size of regional (Yukon delta), Alaska, and North America populations. Vulnerability of principal habitats used, and the distribution, behavior, and food habits of individual species are considered in the analysis. Impacts are those that conceivably could result if substantial disturbance and/or oil pollution were to occur; the analysis does not evaluate the likelihood that such events would occur.

Data on populations, use of habitats, and assessment of potential impacts are summarized in Table 4.3. The area considered includes only the coastal part of the Yukon delta from Cape Romanzof to Stuart Island and inland to the extent of significant tidal influence. Primary sources of data used in the analysis include Lensink (1968), Jones and Kirchhoff (1978), Gill and Handel (1981), King and Dau (1981), King and Conant (1983), and Dau (*In prep.*). There are no census data for any species that are specific to the region being considered, thus estimates of the sizes of populations and percentages they form of different reference populations are approximations that indicate the general order of abundance and relative contribution to reference populations. Habitats are broadly characterized in order of their relative vulnerability as follows:

1) Nearshore marine waters
2) Unvegetated intertidal
3) Tidal rivers and sloughs
4) Saline meadows and marshes
5) Upland transition

Category 5 includes areas that are generally uplands but which are dissected by numerous tidal rivers and sloughs. Species using such areas continue to be vulnerable to pollution, although the probability of contamination for such areas is much lower than for habitats of the coastal fringe.

Use of habitats is indicated as migrant (M), breeding (B), and postbreeding (P). Identification of migrant or post breeding populations is included only when such populations originate in areas other than the area of concern. Thus black brant are identified as breeding and also as migrant in reference to that part of the population that breeds in arctic regions of Alaska, the U.S.S.R., and western Canada. Assessment of levels of potential impacts is as described above, but additionally some species are identified as being of particular sensitivity (S). These species are all of particular public concern and most are species already substantially reduced from former abundance and for which any additional mortality or loss to production may have much more serious consequence than indicated by the more restrictive definitions of impact levels.

Loons

Arctic and red-throated loons nest sympatrically throughout the delta, but both species, and particularly the red-throated loon, are most abundant in coastal regions. Generally the arctic loon nests and forages on large lakes whereas the red-throated loon nests on smaller lakes and forages on larger tidal rivers and in nearshore waters that are more vulnerable to pollution. Use of such areas substantially increases

SPECIES[1]	POPULATION OF AREA[2]	PERCENT OF REFERENCE POPULATION: Yukon Delta	Alaska	Pacific Flyway	N. America	USE OF MAJOR HABITATS[3]: Nearshore Marine Waters	Unvegetated Tidal Flats	Tidal Rivers and Sloughs	Salt Meadows and Marshes	Upland Transition	NATURE OF USE[4]	PERIOD OF USE	POTENTIAL[5] IMPACT LEVEL
Red-throated Loon	f 1,000s	30	10	-	-	M	N	H	H	M	B	May-Sep	Moderate
Arctic Loon	f 10,000s	30	10	-	-	L	N	M	H	H	B	"	Low
Pelagic Cormorant	f 100s	30	t	t	t	H	N	N	N	N	B	"	Low
Tundra Swan	s 1,000s	20	10	10	10	N	N	L	H	H	B	"	Low (S)
White-fronted Goose	s 10,000s	30	10	20	10	N	N	H	H	H	B	"	Moderate
Snow Goose	s 10,000s	30	20	10	10	N	N	N	M	H	M	May & Sep	Low
Black Brant	s 10,000s	50	50	50	50	L	M	H	H	L	MB	May-Sep	High
Cackling Canada Goose	f 1,000s	20	20	20	20	L	M	H	H	H	B	"	High
Taverner's Canada Goose	s 10,000s	30	30	30	30	L	L	H	H	H	B	"	Moderate
Emperor Goose	s 10,000s	40	40	40	40	L	M	H	H	H	B	"	High
Green-winged Teal	s 10,000s	30	10	-	-	N	L	M	H	H	B	"	Low
Mallard	s 1,000s	30	10	-	-	N	L	L	H	H	B	"	Low
Pintail	f 100,000s	40	10	-	-	L	H	H	H	M	BP	"	Moderate
Northern Shoveler	f 10,000s	40	10	-	-	N	L	L	H	M	BP	"	Low
American Widgeon	s 1,000s	30	10	-	-	N	L	L	H	M	BP	"	Low
Greater Scaup	s 10,000s	20	10	-	-	L	N	L	M	H	B	"	Low
Common Eider	f 10,000s	50	10	10	-	H	L	H	H	L	BM	"	Moderate
King Eider	? 10,000s	50	10	10	-	H	N	N	N	N	M	Apr-May	Low
Spectacled Eider	f 10,000s	50	50	50	50	H	L	M	H	L	B	Apr-Sep	Moderate
Steller's Eider	f 1,000s	50	10	10	10	H	N	H	H	N	BP	"	Low
Old Squaw	f 100,000s	30	10	-	-	L	L	M	H	H	B	Apr-Oct	Nil
Block Scoter	f 10,000s	30	20	-	-	M	N	H	H	M	BP	"	Low
Surf Scoter	f 10,000s	50	10	-	-	H	N	N	N	?	MP	"	Moderate
White-winged Scoter	f 1,000s	20	10	-	-	H	N	N	N	?	MP	"	Low
Sandhill Crane	f 10,000s	30	10	-	-	N	N	N	H	H	BP	May-Sep	Nil
Black-bellied Plover	s 10,000s	30	-	-	-	N	M	N	M	H	B	"	Low
American Golden Plover	f 10,000s	30	-	-	-	N	H	H	H	M	BP	"	Low
Whimbrel	f 1,000s	50	-	-	-	N	H	H	H	N	P	Jun-Aug	Low
Bristle-thighed Curlew	f 1,000s	40	40	40	40	N	L	L	H	N	P	"	Low (S)
Hudsonian Godwit	f 1,000s	60	30	-	-	N	H	N	H	N	P	Jul-Aug	Low
Bar-tailed Godwit	f 10,000s	50	50	-	40	N	H	N	H	H	BP	May-Sep	Moderate (S)
Ruddy Turnstone	f 1,000s	30	-	-	-	N	M	M	M	M	BP	May-Sep	Low
Black Turnstone	s 10,000s	40	30	-	-	N	H	H	H	L	BP	"	Moderate
Red Knot	f 10,000s	40	-	-	-	N	H	N	N	N	P	Jun-Sep	Low
Semipalmated Sandpiper	f 1,000s	40	-	-	-	N	H	H	H	N	P	"	Low
Western Sandpiper	s 100,000s	40	40	-	-	N	H	H	H	H	BP	May-Sep	Moderate
Sharp-tailed Sandpiper	s 1,000s	40	-	-	-	N	H	H	H	N	P	Aug-Sep	Low
Rock Sandpiper	s 10,000s	40	-	-	-	N	H	M	M	M	BP	May-Sep	Moderate
Dunlin	s 100,000s	40	-	-	-	N	H	H	H	L	BP	"	Moderate
Long-billed Dowitcher	s 1,000s	40	-	-	-		H	H	H	L	P	Jul-Sep	Low
Red-necked Phalarope	s 100,000s	30	-	-	-	H	M	M	H	M	B	May-Sep	Moderate
Red Phalarope	s 10,000s	50	-	-	-	H	M	M	H	L	B	"	Moderate
Parasitic Jaeger	f 1,000s	30	-	-	-	L	H	L	H	H	B	May-Aug	Nil
Long-tailed Jaeger	s 1,000s	30	-	-	-	L	H	L	H	H	B	"	Nil
Mew Gull	s 1,000s	30	-	-	-	L	H	M	H	H	B	May-Sep	Nil
Glaucous Gull	s 1,000s	40	-	-	-	M	H	H	H	M	B	"	Nil
Black-legged Kittiwake	s 100s	50	-	-	-	H	N	N	N	N	B?	"	Nil
Sabine's Gull	s 1,000s	50	-	-	-	L	L	M	H	M	B	May-Aug	Nil
Arctic Tern	s 1,000s	40	-	-	-	M	L	M	H	M	B	"	Nil

[1]Species considered include only common birds of wetland habitats that may be adversely affected by petroleum development
[2]f = few, s = several
[3]L = low, M = medium, H = high, N = not used (relative levels of use)
[4]B = breeding, M = migrant, P = post-breeding
[5]See text for definitions of levels of impact.

potential for significant mortality.

Pelagic Cormorant

Although pelagic cormorants are highly vulnerable to oil (because they dive for food), populations within the region are very small, and except locally, populations would not be affected.

Tundra Swan

Tundra swans nest throughout the delta but highest populations are near the coast where tidal meadows are used extensively by nesting pairs, as staging areas for nonbreeding swans in spring, and by both breeders and nonbreeders prior to migration in fall. Tidal rivers and sloughs receive only minor use. Potential for significant losses seems low, even for local populations. Public concern for this species is high, but populations are stable or increasing and this trend is unlikely to be altered by proposed developments.

Black Brant

Black brant are the most coastal of all geese. Nesting is confined to salt meadow habitats, and both unvegetated tideflats and tidal rivers or sloughs are critical habitats. These areas are most vulnerable to marine sources of pollution. Migrants (birds nesting or molting in arctic areas) use these habitats in spring and fall and half or more of the continental population occurs seasonally within the area. Although major nesting areas occur south of Cape Romanzof and are not at significant risk, substantial losses could occur within the area of concern. Further, the current trend of decline in continental populations of this species, and the more significant decline of brant on the delta than elsewhere, indicate that even relatively small increases in mortality or decreases in production may have serious impacts on both regional and continental populations.

Cackling Canada Goose

The entire population of cackling Canada geese nests in coastal habitats of the Yukon delta, with approximately 20–30% within the area of concern. Habitats used by breeding and nonbreeding geese are all vulnerable to pollution and direct losses of this species are likely to occur. Populations are now much reduced from former levels and both recreational and subsistence hunting have been restricted accordingly. Although losses that may potentially result form oil spills in Norton Sound will at most affect a small number of geese relative to the size of the population, even these small losses may have significant long-term consequences on the restoration of the population.

Taverner's Canada Goose

Taverner's Canada geese nest throughout the delta region, with largest numbers near the coast but inland from areas used by cackling Canada geese. Other Taverner's Canada geese nest in tundra areas of western and northern Alaska. Nesting birds for the most part are secure from adverse effects of developments in Norton Sound, but a number of nesting birds and a unique concentration of migrant and molting birds use the coastal fringe of the north delta, and would be highly vulnerable. While losses in this group could be high, the overall population of Taverner's Canada geese, including that of the Yukon delta, is increasing, and this species is not as sensitive to losses as other geese.

Emperor Goose

The distribution of emperor geese is similar to that of cackling Canada geese, but a small part of the population, about 10%, nests at scattered locations north to Kotzebue Sound and on the coast of the Seward Peninsula. In addition, a large number of subadult and nonbreeding geese summers on St. Lawrence Island and an unknown number in the U.S.S.R. Overall, more than half of the population may be at risk at some period in their life-span. Although the proportion of total geese likely to be affected is small, the population has recently declined to approximately 50% of its former numbers, and even small losses will have significant effects on restoration of the population.

Snow Goose

A large number of snow geese that originate on Wrangel Island, U.S.S.R., occurs in coastal areas during migration. Most use is made of inland habitats, and impacts of developments in Norton Sound are likely to be low or negligible for this species.

Ducks

The impact of development is likely to be negligible or low for most species of ducks except pintails, four species of eiders, and surf scoters. Pintails, mostly males, make extensive use of tidal areas and unique concentrations occur on the north delta. Large numbers could be affected but impact on the population would be low to moderate because of its large size and widespread distribution. Nonbreeding surf scoters are the most numerous duck of the nearshore waters of the delta and are among the most vulnerable of all species to direct losses from oil pollution. Scoters using the nearshore region probably originate in nesting areas throughout western and interior Alaska. Because breeding populations are everywhere low, losses of molting birds may have significant adverse effects in many nesting areas. King, common, spectacled, and Steller's eider all occur in offshore waters, and all but king eiders nest in coastal lowlands of the delta. Both king and Steller's eiders occur primarily as migrants, and numbers of both are small relative to the total population. Although both species are highly vulnerable to oil pollution, likely impact on their populations is low. Impacts on common eiders, which nest on the coastal fringe of the delta, may be locally, perhaps regionally, significant but are unlikely to affect overall size or distribution of populations. Impacts on spectacled eiders may be most obvious because the delta provides the primary nesting area for this species and losses in even local areas could have significant effects on the population.

Shorebirds

Coastal areas of the delta, particularly the unvegetated tidal flats and the coastal fringe of salt meadows and marshes, are uniquely important to numerous species of shorebirds. Worldwide, there is probably no area of comparable value. The primary impact on shorebirds will be indirect, through reduction or contamination of food resources. Although such impacts are difficult to evaluate and will not be immediately apparent, long-term effects may be of major significance to those shorebirds whose main Alaskan or North American population depends on delta habitats. These include 10 species: black turnstone, western sandpiper, rock sandpiper, dunlin, bristle-thighed curlew, American golden plover, bar-tailed godwit, whimbrel, red knot, and sharp-tailed sandpiper. Of these, bar-tailed godwit, black turnstone, western sandpiper, rock sandpiper, and dunlin are most vulnerable (Gill and Handel 1981). Significant numbers of red and red-necked phalaropes may be directly affected. However, populations of these species are widespread on the delta and only a small part of Alaskan or continental populations depends on delta habitats, thus impacts on their populations will be insignificant.

Jaegers, Gulls, and Terns

Species in these groups are widely distributed, have behavior and foraging patterns that are likely to reduce vulnerability to pollution, and in some cases have proven highly adaptable to human disturbance. The overall potential impact on populations is considered nil.

Summary

Potential impacts of petroleum development in the Norton Basin on birds of the Yukon delta are considered to vary from nil to high for individual species. Potential impacts are considered high only for those species of geese which are already much reduced from former numbers. The added losses, even if relatively small, could seriously affect efforts to restore these populations. Potential impacts are considered to be moderate for one species of loon, two species of goose, five species of duck, and seven species of shorebird. All of these species are dependent on habitats most vulnerable to pollution and most occur in unique abundance in coastal areas of the delta. Impacts on all other species are considered low or nil.

Although not considered in this analysis, many populations of species for which impacts may be moderate to high on the Yukon delta will also be at risk when they occupy other vulnerable habitats such as Safety Lagoon, Golovnin Bay, or Norton Bay on the Seward Peninsula. This added risk is most serious to black brant and emperor geese.

4.7.2 General Vulnerabilities and Sensitivities: All Species

Attempts at the Norton Basin Synthesis Meeting to evaluate impacts on all species in nearshore habitats to the same level as birds of the Yukon delta are addressed above were not successful. The time available was too short, adequate information seemed to be lacking for many species, and knowledgeable specialists were not present in some cases (*e.g.*, for nearshore fishes). Consequently, a different way of describing impacts was used, one that was relatively descriptive of causes of impact but relatively imprecise in terms of level of impact.

A selected group of synthesis meeting participants evaluated the general sensitivity and vulnerability of each major species or species group in the Norton Basin nearshore zone. Sensitivity referred to the susceptibility of individual animals to activities or pollutants with which they came in contact; vulnerbility referred to the proportions of Norton Basin populations that could be affected. Sensitivity is thus a function of an individual animal's reaction; vulnerbility is a function of distributional characteristics of the population.

Table 4.4 summarizes the sensitivities and vulnerbilities of Norton Basin nearshore vertebrates and their food web components to eight categories of OCS activity. The sensitivity and vulnerability ratings of low, moderate, and high are used to compare general susceptibility to impact among types of activity and among species and species groups; these ratings do not equate with the relatively precise definitions of levels of impact (nil, low, moderate, high) developed by MMS (see Section 4.7.1). Also, in developing the vulnerability ratings that follow, it was assumed that the industrial activity in ques-

Biological Population		Large Oil Spill	Small Pollutant Release	Chronic Operational Discharge	Seismic Testing	Vessel Traffic	Aircraft Traffic	Onshore Construction	Dredging & Pipeline Construction
		OCS ACTIVITIES							
Spotted Seal	v[1]	l	l	l	l	l	l	l	l
	s[2]	l	l	l	(?)	(?)	(?)	l	l
Beluga Whale	v	m-h	l	l	h	l	l	l	l
	s	l(?)	l	l	(?)	m	l	l	l
Brant	v	h	l	l	l	l	h[3]	l	l
	s	h	h	m	l	l	h	l	l
Other Geese	v	h	l	l	l	l	m[4]	l	l
	s	h	h	m	l	l	m	l	l
Dabbling Ducks	v	m	l	l	l	l	h	l	l
	s	m	m	m	l	l	l	l	l
Diving Ducks	v	m	l	l	l	l	m	l	l
	s	h	h	m	l	l	l	l	l
Sandhill Crane	v	l	l	l	l	l	l	l	l
	s	l	l	l	l	l	l	l	l
Gulls & Terns	v	l	l	l	l	l	l	l	l
	s	m	l	l	l	l	l	l	l
Shorebirds	v	m[5]	l	l	l	l	l	l	l
	s	m	l	l	l	l	l	l	l
Anadromous Fish	v	l[6]	l	l	l	l	l	l	l
	s	l[7]	l	l	l	l	l	l	l
Herring	v	l[8]	l	l	l	l	l	l	l
	s	l[9]	l	l	l	l	l	l	l[10]
King Crab	v	m(?)[11]	l	l	l	l	l	l	l
	s	h	h	l	l	l	l	l	l
Epibenthos	v	m	l	l	l	l	l	l	l
	s	h	h	l	l	l	l	l	l
Intertidal Infauna	v	m	l	l	l	l	l	l	l
	s	h	h	l	l	l	l	l	l
Low Intertidal Vegetation	v	h	l	l	l	l	l	l	l
	s	m	l	l	l	l	l	l	m
High Intertidal Vegetation	v	l	l	l	l	l	l	l	l
	s	h	h	l	l	l	l	l	m

[1] Population vulnerability. Mainly a function of population distribution patterns.
[2] Sensitivity. Susceptibility of individual organisms to adverse effect from contact with activity.
[3] During nesting.
[4] Taverner's Canada goose highly vulnerable.
[5] Summer staging and migration only; otherwise low.
[6] Juvenile salmon moderately vulnerable.
[7] Juveniles moderately sensitive.
[8] Eggs and juveniles highly vulnerable.
[9] Eggs and juveniles highly sensitive.
[10] Assuming spawning areas avoided.
[11] Data needed on breeding distribution.

tion is present when the animals are present in the Norton Basin.

Reflection on the implications of Table 4.4 suggests that only those organisms with ratings of medium to high in both the vulnerability and sensitivity categories are at all likely to have their populations adversely affected by the activities listed. A rating of low in either category suggests that populations of the organisms are relatively immune to significant adverse effect from that activity, even though a rating of high might be given for the other category. A rating of low in both categories suggests high immunity to adverse effect by both individuals and populations. By this measure, only waterfowl (particularly geese), eggs or juveniles of herring, salmon juveniles, and intertidal foods of (mainly) birds are at all likely to receive appreciable adverse impact. Furthermore, of the various types of development activity considered, only major oil spills constitute major threats to any of the biota (though under certain circumstances aircraft traffic might adversely affect geese).

Seabirds were not addressed at the workshop. It appears likely that some of them would be both highly vulnerable and highly sensitive to oil, and perhaps to aircraft traffic, in the nearshore zone.

4.8 SUMMARY

The nearshore ecosystem, defined herein to extend seaward to about the 10-m depth contour and landward to the maximum extent of influence of marine water, is important habitat for selected mammals, birds, fishes, and their prey. This chapter discusses the common vertebrates in the Norton Basin that depend largely on this nearshore environment for an important function or functions.

Three marine mammals—spotted seal, ringed seal, and belukha whale—are mainly nearshore in habitat preference. Spotted seals and belukhas are essentially summer residents; ringed seals are abundant only in winter. All are piscivorous; the ringed seal in addition consumes shrimps and other invertebrates. The ringed seal is widespread in winter in the fast-ice habitat, where it breeds and gives birth. Spotted seals and belukhas feed (and belukhas give birth) in more localized areas; both tend to concentrate in river delta, bay, or lagoon habitats. Although these animals are relatively insensitive to most types of OCS activities, including spilled oil, the tendency for spotted seals and belukhas to concentrate makes their populations relatively vulnerable to activities in their coastal habitats.

Included among the abundant and conspicuous birds in the nearshore environment are tundra swans; several species each of geese, dabbling ducks, diving ducks, and shorebirds; sandhill cranes; glaucous gulls; Arctic terns; and several colonial seabirds. Loons, jaegers, and passerines are present but normally less abundant. Except for wintering concentrations of oldsquaws and eiders in the waters surrounding St. Lawrence Island, these birds are numerous only during the open-water period (May–November).

Waterfowl as a group use the nearshore environment for four general purposes: overwintering; prenesting assembly in spring; breeding, brood-rearing, and/or molting in summer; and migratory staging in fall. As noted above, only oldsquaws and eiders are common overwintering species. Brant, some dabbling and diving ducks, and cranes are conspicuous at selected coastal wetlands in spring prior to nesting. Swans, brant, cackling and Taverner's Canada geese, white-fronted geese, emperor geese, dabbling ducks (particularly pintails), and diving ducks (particularly black scoters and oldsquaws) nest, rear broods, and/or molt in selected nearshore environments from June to August. Swans, brant, three races of Canada geese, white-fronted geese, snow geese, and many dabbling and diving ducks stage in coastal wetlands in fall. Swans and geese tend to feed on wetland vegetation; ducks eat partly vegetation (dabbling ducks) but largely aquatic invertebrates (dabbling and diving ducks). Most species congregate at some time during the year in coastal environments where they would be relatively vulnerable to oil in nearshore waters; brant, emperor geese, pintails, and diving ducks are particularly vulnerable.

Sandhill cranes and shorebirds tend to nest inland from the coast. But like waterfowl, they congregate to feed at times in and near coastal waters where they would be vulnerable to effects of spilled oil. Unlike waterfowl, however, most (except phalaropes) do not commonly swim in the water and would probably be able to avoid most adverse effects of spilled oil.

With the exception of the cliff-nesting black-legged kittiwake, glaucous gulls and Arctic terns are the only common gulls and terns in the nearshore zone. They tend to be widespread in this zone, but may assemble locally in feeding or small nesting groups. They feed on a variety of invertebrates and fishes. Because of their adaptability and their foraging behavior, their populations are probably not particularly vulnerable to the effects of oil or other OCS activities.

Cliff-nesting seabirds are the most abundant avian inhabitants of the nearshore zone; 4.3 million are estimated to nest in the Norton Basin. Crested and least auklets (the most numerous of the seabirds) and thick-billed murres consume large quantities of zooplankton; these species dominate the island colonies near areas where oceanic currents tend to provide a zooplankton source. Coastal and Norton Sound colonies tend to be smaller than island colonies and are dominated by fish-eating species—common murre, black-legged kittiwake, and puffins. Of the common seabirds only the murres, kittiwakes, and horned puffins feed to any extent in the nearshore zone; most forage in the offshore environment. Those that feed in the nearshore zone or that, upon fledging, swim from their natal cliffs (*e.g.*, murres) are highly vulnerable to effects of spilled oil in the vicinity of their colonies.

The fish community of the nearshore zone consists of a relatively few species that represent a transition between faunas of the northern Pacific Ocean and those of the Arctic Ocean. Major constituents of the nearshore fish fauna are salmon (five species), other less abundant anadromous species (*e.g.*, whitefishes, ciscoes, char), herring (the most abundant marine species), and marine forage fishes (*e.g.*, sand lance, smelt, capelin).

Most use of the nearshore zone by fish is in the open-water period. At this time adult salmon pass through estuaries on their way up spawning streams, and salmon juveniles arrive in estuaries from upstream to feed and to acclimate to oceanic conditions. Many of the other anadromous species feed in stream deltas and estuaries. Herring, and probably sand lance and capelin, spawn in nearshore waters, and their young inhabit them for some time before moving offshore. The only significant use of the nearshore zone in winter appears to be by some anadromous and marine fishes that may overwinter in large river deltas and bays.

Little is known about invertebrates in the nearshore zone. Mobile epibenthic species such as mysids and amphipods and zooplanktonic species such as copepods appear to predominate. These are important in nearshore food webs. The commercially important species—mainly king crabs—are linked more with the offshore ecosystem.

Food webs in the nearshore environment appear to have three bases: terrestrial plants, estuarine invertebrates, and marine invertebrates. The waterfowl—swans, geese, diving ducks—feed heavily on vascular plants in wetlands. The non-salmonid anadromous fishes probably eat mainly estuarine epifaunal invertebrates. The marine fishes—herring, cods, capelin, sand lance—and the juvenile salmon probably feed mainly on marine zooplankton, or on each other. The top consumers—seals, belukha whale, seabirds—probably depend mostly on marine prey for their sustenance.

Important habitats in the nearshore zone are mainly in and near major river deltas, bays, and lagoons. From the standpoint of water birds, marine mammals, and fishes, the single most important habitat is the Yukon delta and vicinity. From the standpoint of local abundance of animals, the seabird colonies are certainly important; most of the large ones are on St. Lawrence Island and other islands in western parts of the Norton Basin. Haulout areas for walruses and other pinnipeds are also mostly on islands. Along the mainland coastline of Norton Sound the important habitats are generally the bays and lagoons (*e.g.*, Port Clarence, Grantley Harbor, Woolley Lagoon, Safety Lagoon, Golovnin Bay, Norton Bay) and associated river deltas. A few other wetlands (*e.g.*, near Stebbins) attract water birds. The only winter habitat of major significance is the open water off St. Lawrence Island which is used by overwintering sea ducks.

Potential impacts of oil and gas development are of greatest concern where they relate to water birds of the Yukon delta. Here potential impacts are expected to vary among species from no appreciable effect to major effects that could cause declines in regional populations for several years. Spilled oil is the greatest threat. The most sensitive species are the waterfowl that use habitats at the land's margin—brant, cackling Canada geese, and emperor geese. Elsewhere in the Norton Basin, diving ducks, dabbling ducks, and seabirds may be susceptible to appreciable adverse impact should large oil spills occur. Marine mammals and fishes are probably relatively immune to large-scale population effects, though juveniles of salmon and eggs and juveniles of herring could suffer locally severe consequences should a large oil spill occur.

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5

The Offshore Ecosystem

by Joe C. Truett and Peter C. Craig

With major contributions from Lloyd F. Lowry, Denis H. Thomson, and Douglas A. Woodby

In this chapter we describe the important mammals, birds, fishes, and invertebrates of the Norton Basin offshore ecosystem. As in Chapter 4, information on distribution and abundance, diet, and important habitats is presented on a species-by-species basis, and the vulnerabilities and sensitivities of the species to OCS development in the Norton Basin are presented. (See Chapter 4 for definitions of vulnerability and sensitivity.) Summaries of food webs, important habitats, and potential impacts of OCS oil and gas development follow the species accounts.

The offshore ecosystem as here defined extends seaward from about the 10-m depth contour in the Norton Basin OCS Planning Area. Emphasis is on the Norton Sound and Chirikov Basin regions, bounded on the northwest by the U.S.A.-U.S.S.R. boundary, on the north by the Bering Strait, on the east by the 10-m depth contour of Norton Sound, and on the south by an east-west line south of the Yukon delta and St. Lawrence Island (Fig. 1.1).

The focus in this chapter is on the animal species that spend most of their time in the Norton Basin in this offshore system. Those that are mainly nearshore in their ecological affiliations have been addressed in Chapter 4. As in Chapter 4, sensitivities of the species to oil pollution and other activities are not discussed in detail, but recent reviews of the effects of these activities are referenced.

5.1 MARINE MAMMALS

Seven mammal species are seasonally common components of the offshore environment: ringed seal, bearded seal, walrus, polar bear, belukha whale, gray whale, and bowhead whale. Somewhat less common in the offshore area are ribbon seal, spotted seal, Steller's sea lion, and minke, killer, humpback, fin, and sei whales (Cowles 1981).

5.1.1 Ringed Seal

As noted in Chapter 4, ringed seals (*Phoca hispida*), except for some juveniles, are resident in the Norton Basin only during the ice season—late fall, winter, early spring—but they are the most widely distributed and abundant seal in the Norton Basin (Starr *et al.* 1981). They commonly occur where there is pack ice or landfast ice, and appear to prefer landfast ice for breeding in spring. During summer the adults and most juveniles move northward into the Chukchi and Beaufort seas.

The diet of ringed seals is seasonally and spatially variable. Predominant food items in the Norton Basin in winter are Arctic and saffron cods. Shrimps and other crustaceans become important in spring (March through June). Pups eat more small invertebrates than do adults; adults eat more fish (Lowry *et al.* 1980, 1981).

Within the Norton Basin, it is not evident whether any particular offshore habitats are more important than others for ringed seals except that, as discussed in Chapter 4, the nearshore fast-ice habitat is generally more preferred for breeding and pupping than is the offshore pack ice (Fig. 5.1).

Ringed seal populations are relatively invulnerable to the effects of OCS development because of their widespread and dispersed pattern of distribution. Adults are not highly sensitive to the activities of people (see review by Davis and Thomson 1984), though the seals, especially the pups, may be relatively sensitive to oil contact (Geraci and Smith 1976).

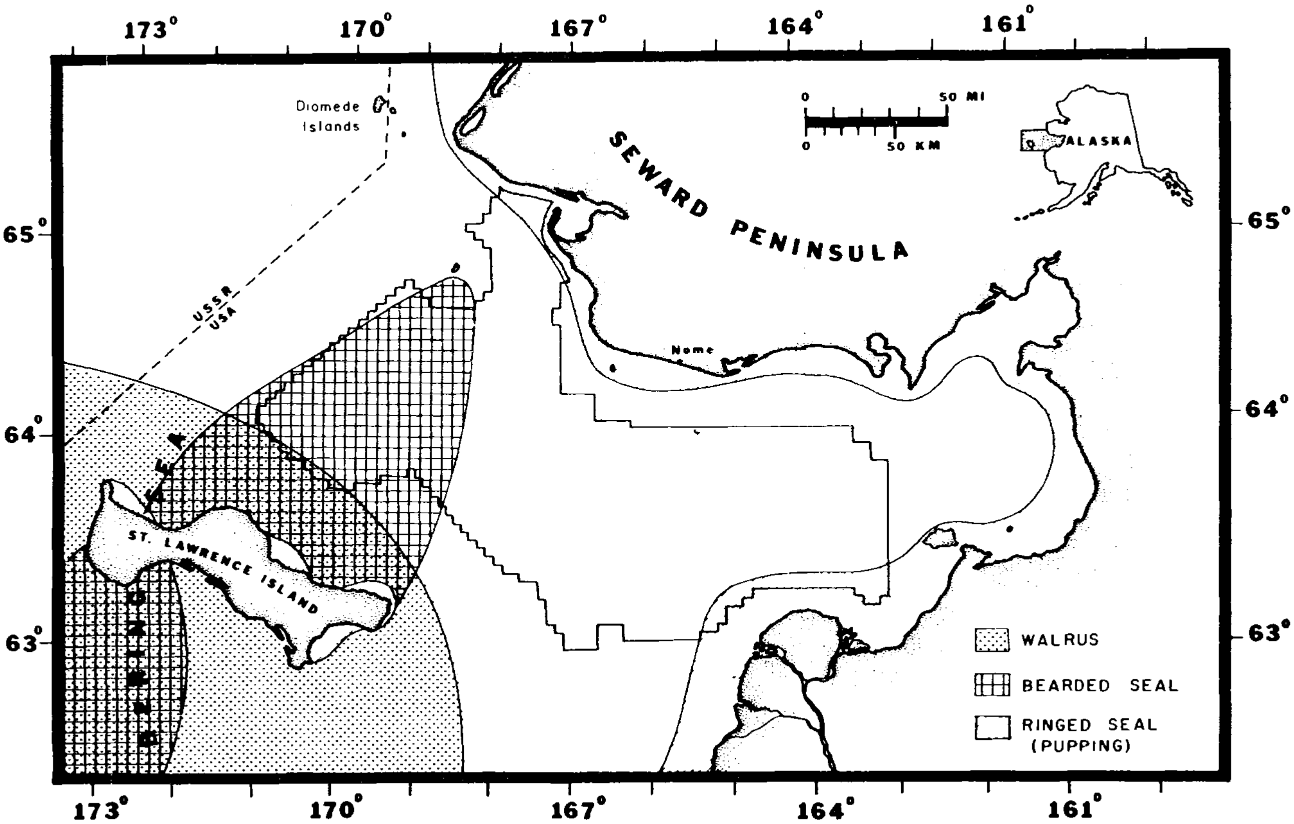

FIGURE 5.1—Late winter-early spring (February-April) areas of abundance of ringed and bearded seals and walrus in the Norton Basin OCS Planning Area, Alaska (after Cowles 1981).

5.1.2 Bearded Seal

Bearded seals (*Erignathus barbatus*), like ringed seals, are abundant residents of the offshore Norton Basin during months when sea ice is present. Like ringed seals, they move north with the moving ice in spring and south with the ice front in fall. Many that move through the Norton Basin in spring and fall are winter residents of more southerly parts of the Bering Sea (Lowry *et al.* 1981).

Bearded seals, unlike ringed seals, are almost exclusively benthic feeders. They eat mostly shrimps, brachyuran crabs, and clams. Young seals eat more shrimps; older seals eat more clams and crabs (Lowry *et al.* 1981).

In winter, bearded seals are restricted to the pack ice where openings in the ice are common (Fig. 5.1). In Alaska they normally do not maintain holes in the shorefast ice as ringed seals do. In this pack ice environment, they prefer areas where leads, polynyas, and other openings in the ice are present and where the sea floor is at depths less than about 150 m (Starr *et al.* 1981).

Like ringed seals, bearded seal populations are relatively widespread and thus relatively invulnerable to effects of OCS activities. Whether individuals are sensitive to contact with oil is not known; it is possible that their sensitivity may be of the same general level as that of ringed seals.

5.1.3 Pacific Walrus

The Pacific walrus (*Odobenus rosmarus*) population winters in the southern and central Bering Sea. Walruses migrate through the Norton Basin on their way to (spring) and from (fall) summer feeding grounds in the Chukchi Sea, and a small part of the population remains in the Norton Basin throughout the summer (Lowry *et al.* 1981). These summer residents, mostly males, haul out at traditional sites (mostly on islands), and presumably feed in nearby offshore areas. Migrants also haul out at traditional sites along their migration routes (*e.g.*, St. Lawrence Island, Big and Little Diomede islands).

Walruses, like bearded seals, are benthic feeders. Their foods are mostly clams; they eat lesser amounts of snails, priapulids, polychaete worms, echiuroid worms, and other invertebrates. Walruses appear to compete with bearded seals for food (mainly clams) in areas where clams are important in the seal diet (Lowry *et al.* 1981).

In general, important walrus habitats are places where walrus foods are abundant and accessible. In fall and spring, migrating walruses haul out on, and feed from, moving ice. Thus they do not appear to be restricted to particular feeding areas, as long as the areas are somewhere along their normal migratory route (*i.e.*, western parts of the Norton Basin, St. Lawrence Island region to the Bering Strait). But in summer, major feeding habitats are presumably concentrated near traditional haulout sites (Fig. 4.2), and these habitats are probably more important than others that may be equally rich in food. In winter the area southwest of St. Lawrence Island may be critical habitat because of the favorable broken ice conditions there at that time of year (Starr *et al.* 1981).

Walrus populations migrating through the Norton Basin are probably not especially vulnerable to OCS activities except in narrow migratory pathways (such as the Bering Strait) or at haulout areas of migrants (such as near the eastern end of St. Lawrence Island) (Fig. 4.2). Even at these sites, the walruses probably congregate for only brief periods, thus diminishing their vulnerability to activities that are intermittent in time. But the summering male groups are probably more vulnerable, because they congregate at and near specific haulout sites for relatively long periods. Walruses appear to be somewhat sensitive to disturbance from such activities as aircraft overflights, which at haulout areas sometimes cause stampedes that result in mortality among the young (Salter 1979). They may tend to avoid sites of human activity, as evidenced by their hauling out only in remote areas (Frost *et al.* 1982). But they are probably relatively insensitive to being oiled (see review by Davis and Thomson 1984).

5.1.4 Other Pinnipeds

Less common than ringed seals, bearded seals, and walruses in the offshore area are ribbon seals (*Phoca fasciata*), spotted seals (*P. largha*), and Steller's sea lions (*Eumetopias jubatus*). Ribbon seals, rarely found in nearshore environments, are associated with the ice front in winter and take up a pelagic existence in the Bering Sea in summer. Summer distribution and the importance of pelagic environments of Norton Sound to ribbon seals are virtually unknown; a major winter concentration has been reported southwest of St. Lawrence Island (Cowles 1981). The spotted seal takes up a coastal existence in summer (Section 4.1.1), but in winter is associated with the ice front. By late winter in most years, its population center is along the ice front far south of the Norton Basin, but spotted seal densities in the Norton Basin are substantial during the seasonal transition periods (April to June, late November to early January) (Cowles 1981). Little is known of the Steller's sea lion's offshore distribution, but it is undoubtedly most abundant near its haulout sites on St. Lawrence and other islands (Section 4.1.5). It is not present in winter.

Ribbon seals, spotted seals, and Steller's sea lions, all have pelagic and semidemersal fishes as major dietary items. In addition, ribbon seals eat large amounts of demersal fishes, spotted seal juveniles consume large proportions of pelagic and epibenthic invertebrates, and sea lions consume large amounts of squid (Lowry and Frost 1981).

Favored habitats vary seasonally and among species. The ice-edge environment is the most important habitat for spotted seals and ribbon seals in the offshore environment in winter. Sea lions are not present in winter. In summer, sea lions probably find important feeding habitats in the vicinities of haulout sites on St. Lawrence Island, and to a lesser extent near a few other islands (Fig. 4.2). It is not known whether ribbon seals select particular habitats in summer. Spotted seals are present to some extent in offshore areas in summer, but haul out on coasts.

Because of the wide distribution and transient nature of spotted seals and ribbon seals in fall, winter, and spring, they, as a population, are not very vulnerable at these times. In summer also, ribbon seals are probably widely distributed and thus, as a population, invulnerable. Spotted seals are absent and thus also invulnerable at this time, but sea lions may be relatively vulnerable because they are relatively concentrated. Little is known about the sensitivities of these species to disturbance or environmental pollutants, but they perhaps respond similarly to other pinnipeds.

5.1.5 Polar Bear

There is very little information about the distribution and abundance of polar bears (*Ursus maritimus*) in the offshore zone of the Norton Basin environment. Bears move into the area from the north as winter progresses and ice cover forms; they leave in spring as the ice pack ablates and moves north (Cowles 1981). They presumably are a small southerly part of the "western" subpopulation of Alaskan polar bears, which numbers about 3,800 individuals and is found mainly in the Chukchi Sea (Lentfer 1974).

Polar bears generally eat primarily ringed seals and secondarily other mammals such as bearded seals (Cowles 1981). Ringed seals are probably the most available mammal prey to them in the Norton Basin in winter and spring.

In winter and spring in the Alaskan Chukchi Sea, bears are mostly restricted to a zone within about 160 km of shore, and densities average about one animal per 70–130 km^2 (J. Lentfer, Juneau, Alaska, pers. comm.). Densities presumably are lower than this in the Norton Basin.

Polar bears are widely and sparsely distributed in the Norton Basin, so would be relatively invulnerable

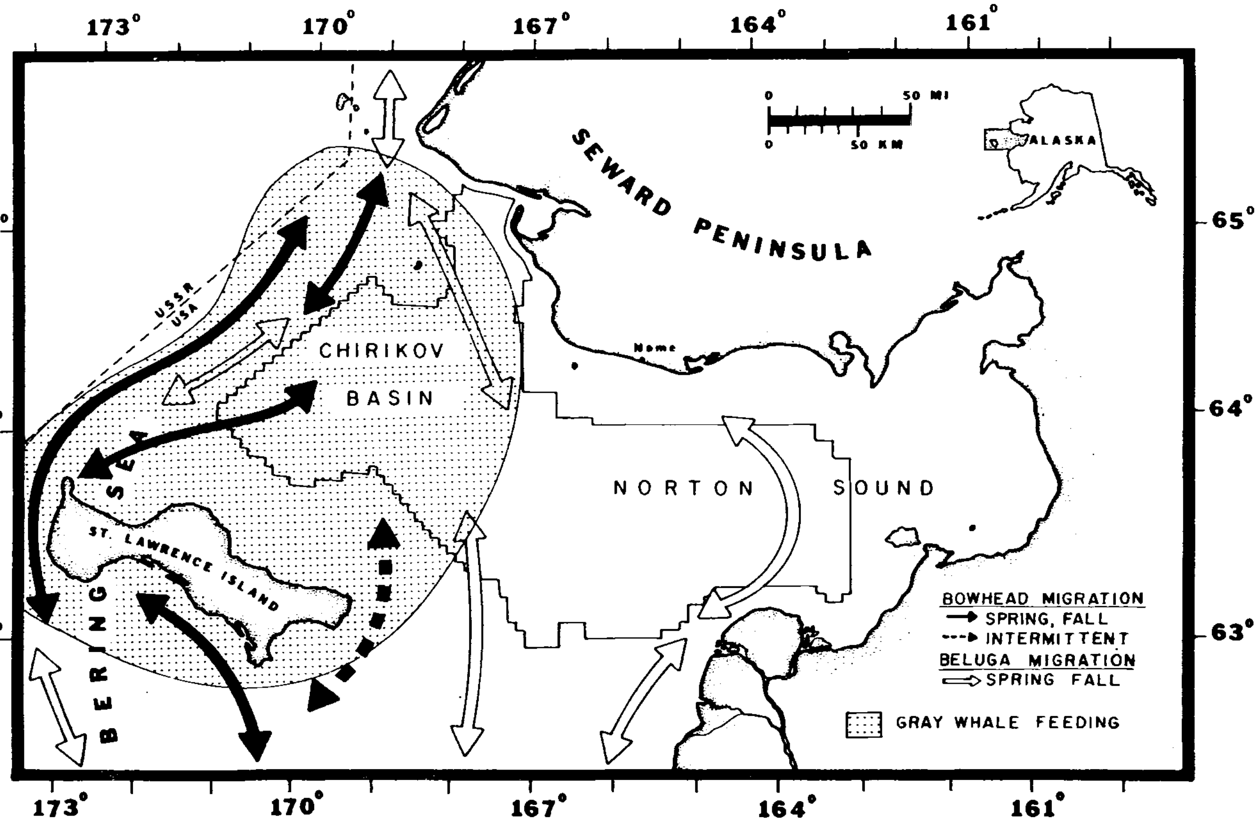

FIGURE 5.2—Migration routes of bowhead and belukha whales and main summer feeding areas of gray whales in the Norton Basin (after Cowles 1981; Ljungblad *et al.* 1983; Miller 1983).

as a population to the effects of OCS activities. However, individuals may be relatively sensitive should they encounter these activities. Increased levels of human activity in the Norton Basin in winter and spring could result in increased encounters between bears and people, requiring increased bear harvests and/or removal of bears to protect human life. Further, should bears encounter spilled oil, they might suffer various adverse consequences, perhaps even death (reviewed by Davis and Thomson 1984).

5.1.6 Belukha Whale

Though belukha whales (*Delphinapterus leucas*) appear to be more a part of the nearshore ecosystem in summer (in terms of apparent importance of habitats) than they are of the offshore environment, the offshore region is a migratory pathway for belukhas in spring and late fall-early winter (Fig. 5.2). In spring (late March), belukhas that have wintered in the ice front zone of the Bering Sea move northward; most of these (at least 5,000) move through the Norton Basin toward summering areas in the Chukchi Sea and Canadian Beaufort Sea (Cowles 1981; Davis and Thomson 1984). (Some spend the summer in the nearshore zone of the Norton Basin, as we have seen in Section 4.1.3.) Again in early winter (December) there is a migratory pulse of these animals as they move back southward toward wintering grounds (Cowles 1981). Some belukhas appear to overwinter in the Norton Basin area northwest of St. Lawrence Island (Nelson 1980); depending on winter ice conditions, some could overwinter in other parts of the Norton Basin as well (Cowles 1981).

Presumably both the spring and fall migrants and the overwintering individuals feed in the Norton Basin. Based on what is known of belukha diets in nearshore areas in summer, and in other areas in winter (see Cowles 1981), these belukhas probably feed on Arctic cod, saffron cod, and other marine fishes.

The vulnerability of belukha whale populations to OCS activities in the offshore areas of Norton Sound is perhaps similar in some respects to what it is in the nearshore zone, because in both areas they typically occur in herds. However, individuals would seem to be less spatially restricted in offshore environments; this might enable them to better avoid environmental perturbations such as noise or oil. Little is known about their sensitivity to oil; they appear to respond variably to noise, depending on the nature of the noise and perhaps on their past experience with similar kinds of noise (Davis and Thomson 1984).

5.1.7 Gray Whale

The gray whales (*Eschrichtius robustus*) that inhabit the Norton Basin in summer belong to the "California" or "east Pacific" stock that winters in the coastal waters of Mexico. The whales migrate along the west coast of North America in spring, reaching the Norton Basin in late May and June (Cowles 1981). A large proportion of this stock of gray whales (total estimated at about 15,000 animals by Rugh and Braham 1979) may feed in the Norton Basin area during the summer months (Cowles 1981); some continue northward into the Chukchi and western Beaufort seas. Fall migration out of the area occurs mostly from late September through October (Cowles 1981).

The center of abundance of gray whales in summer, based on sightings of the whales, appears to be the Chirikov Basin and southeast and west of St. Lawrence Island; probably most of the east Pacific stock summers in these areas (Cowles 1981). This region is presumably of great importance, for the whales are mainly summer feeders, obtaining and storing most of their year's supply of energy here. Thomson and Martin (1984) found that the distribution of sonar-detected gray whale feeding features (gouges made on the sea floor by the whales as they feed) closely parallels the distribution of whales as observed during shipboard and aerial transects. The distribution of the whales and their feeding features also correspond closely to the area of the Chirikov Basin occupied by dense concentrations of ampeliscid amphipods as found by Stoker (1978).

Thomson and Martin (1984) estimated quantities of food removed by gray whales feeding in the Chirikov Basin and St. Lawrence Island areas. (The whales selectively fed in areas and in benthic substrate depths with high biomasses of amphipods and low biomasses of other benthic taxa.) By using four different methods of estimating food consumption by whales, these authors derived a consumption estimate that, when compared with productivity estimates of ampeliscid amphipods, suggests that the whales in the Chirikov Basin consume about 4% of the annual production of their food base. But they also noted that gray whales fed selectively in areas with higher than average standing stocks of benthos, and may have to select these areas to acquire enough food to survive. Thus the proximity of the whale population to the level supportable by the existing prey base may be closer than first appears.

Thomson and Martin (1984) theorized that if gray whales have to feed in areas with unusually high biomasses of amphipods to get adequate food, and if these prime areas represent only a small fraction of the area whales are known to occupy in the Norton Basin, then disruption in these areas might have an effect on the whales out of proportion to the area affected. They thought the primary concern with regard to potential impacts of development on whales might be disruption of, or denial of whale access to, these "pockets" of prime feeding habitat.

5.1.8 Bowhead Whale

There are at least four stocks (distinct populations) of bowhead whales (*Balaena mysticetus*) in the world (Cowles 1981). The entire western arctic stock of about 3,800 animals (the largest extant population) migrates north through the Norton Basin in spring to summer habitat primarily in the Canadian Beaufort Sea, and south in fall to wintering areas in the central and south central Bering Sea (Cowles 1981; Davis and Thomson 1984) (Fig. 5.2). Spring migration usually occurs in April, at which time most whales travel north between St. Lawrence Island and Siberia, thence through the Bering Strait (Fig. 5.2). During fall migration, the whales move south through the Norton Basin in November and December, following a more diffuse route than that used during their northward migration (Cowles 1981). It is possible that some bowheads winter immediately southwest of St. Lawrence Island (Brueggeman *et al.* 1984).

The greatest extent of bowhead feeding is presumably in summer habitat, outside the Norton Basin (Cowles 1981). The importance of the lease area for bowhead feeding is uncertain, but probably of little significance. Most bowheads taken in the spring near the lease area by Eskimo whalers have had empty or nearly empty stomachs. But a whale taken at Gambell, St. Lawrence Island, in 1982 had fed substantially on gammarid amphipods (Lowry and Frost 1984), and interviews with Eskimo whalers indicate that bowhead spring feeding behavior is not unusual in the vicinity of St. Lawrence Island (Hazard and Lowry 1984). Whether bowheads feed in the Norton Basin during their fall migration is not known, though they appear to feed in fall immediately to the north in the Chukchi Sea (Davis and Thomson 1984).

The preferred foods of bowheads in their summer and early fall range (Beaufort Sea) are planktonic crustaceans (*e.g.*, euphausiids, mysids, amphipods, copepods) and to some extent other invertebrates (Lowry *et al.* 1978; Lowry and Burns 1980; Cowles 1981). But a whale taken near the west end of St. Lawrence Island on 1 May 1982 had consumed an estimated 20–40 liters of gammarid amphipods (benthic invertebrates); no planktonic organisms were found in its stomach (Hazard and Lowry 1984). Little other information on bowhead foods in the Norton Basin is available.

There has been much speculation and some recent investigation relative to the vulnerability of bowheads to OCS activities. The population would seem to be more vulnerable in spring than in fall in the Norton Basin because of the relatively confined migration pathway in spring. But at no time would it be as vulnerable as it is in the Chukchi Sea in spring, where the migrating animals are confined to a very narrow ice lead system off the fast ice (Davis and Thomson 1984). There have been no demonstrations that bowheads are particularly sensitive to either noise (*e.g.*, seismic testing, drilling) or spilled oil. But because these impact issues have not been thoroughly researched, and because scientists continue to speculate that bowheads could be very sensitive to both, there is as yet no clear answer about responses of whales to OCS development (see review by Davis and Thomson 1984).

5.1.9 Other Whales

Less common than belukha, gray, or bowhead whales in the Norton Basin are minke, killer, humpback, fin, and sei whales (Cowles 1981). The minke whale occurs broadly over the North Pacific, venturing into the Norton Basin only in summer. Killer whales are commonly observed in the Norton Basin, particularly near St. Lawrence Island. They may exhibit some distributional shifts southward in winter, but do not migrate long distances to southern waters (Cowles 1981). Some humpback whales come into the western Norton Basin in summer, particularly near St. Lawrence Island. Fin whales also come into the western Norton Basin in small numbers in summer. Sei whales have been sighted southwest of St. Lawrence Island in August; they have not been observed in the Norton Basin proper. It is clear that these species, with the exception of killer whales, are summer residents only, and in the Norton Basin are near the northern limits of their ranges (Cowles 1981).

All except the killer whale are baleen whales, which feed on invertebrates and small fishes in the water column or at the surface. Euphausiids and forage fishes (*e.g.*, herring, capelin) are frequently dominant in their diets. The killer whale eats fish, squid, octopus, dolphins, porpoises, seals, walruses, and baleen whales. Some of these species, perhaps most, acquire a large portion of their annual energy reserves on their summer feeding grounds; the Norton Basin may thus be relatively important to some individuals.

Because all these whales are near the peripheries of their ranges in the Norton Basin and are relatively uncommon, and none have been observed to repeatedly concentrate in any particular area, the vulnerabilities of their populations to OCS activities in the Norton Basin are probably quite low. Little is known about the sensitivities of individuals to activities and pollutants likely to accompany OCS development, though some of the concerns about bowheads and gray whales may apply to other baleen whales as well.

5.2 SEABIRDS

During the open-water season, the Norton Basin supports a population of seabirds of over 4 million individuals (Drury *et al.* 1978; Starr *et al.* 1981). The most numerous species, in approximate order of abundance, are least auklet, crested auklet, short-tailed shearwater, thick-billed murre, common murre, parakeet auklet, black-legged kittiwake, tufted puffin, and horned puffin (Hunt *et al.* 1981a,b,c; Starr *et al.* 1981). All of these, except short-tailed shearwaters, breed on coastal cliffs of the Norton Basin; shearwaters breed in the southern hemisphere (Hunt *et al.* 1981a) and many spend the southern winter (northern summer) in the Norton Basin.

All these birds use the offshore ecosystem for feeding. During winter most are absent because of the ice cover; in summer and fall their pelagic distributions seem to be tied to the proximity of breeding colonies and/or to concentrations of food organisms. Figures 5.3 and 5.4 depict the general distributions and abundances of these seabirds during the open-water season. The following account of the general distribution and abundance patterns of seabirds is exerpted from Starr *et al.* (1981).

In the spring, birds begin occupying areas deep in the ice pack as soon as the ice begins to decompose (Divoky 1981). All three species of auklet form dense rafts in open leads in the ice at this time (Hunt *et al.* 1981c). Parakeet auklets occupy the lead near St. Lawrence Island breeding sites as soon as it forms.

During the summer months, seabirds feed throughout the northern Bering Sea. Numbers of birds are highest in the Chirikov Basin, where average densities as high as 200 birds/km² have been observed. In Norton Sound few birds are observed over the water except within 10 km of the cliffs at Sledge Island, or 20 km of the cliffs at Bluff. In the Chirikov Basin, high densities of birds are found in the deeper water near the west end of St. Lawrence Island, near King Island, and in the Bering Strait (Drury *et al.* 1981).

Variations in distribution occur among species and over time as the summer season progresses (Hunt *et al.* 1981c). Pelagic cormorants are seldom seen more than 9 km from a nesting or loafing rock. Black-legged kittiwakes are seen within 32 km of their nesting areas, and beyond that are very sparse and highly clumped. Feeding melees occur east and southeast of King Island, between Point Spencer and the York Mountains, east of Little Diomede Island,

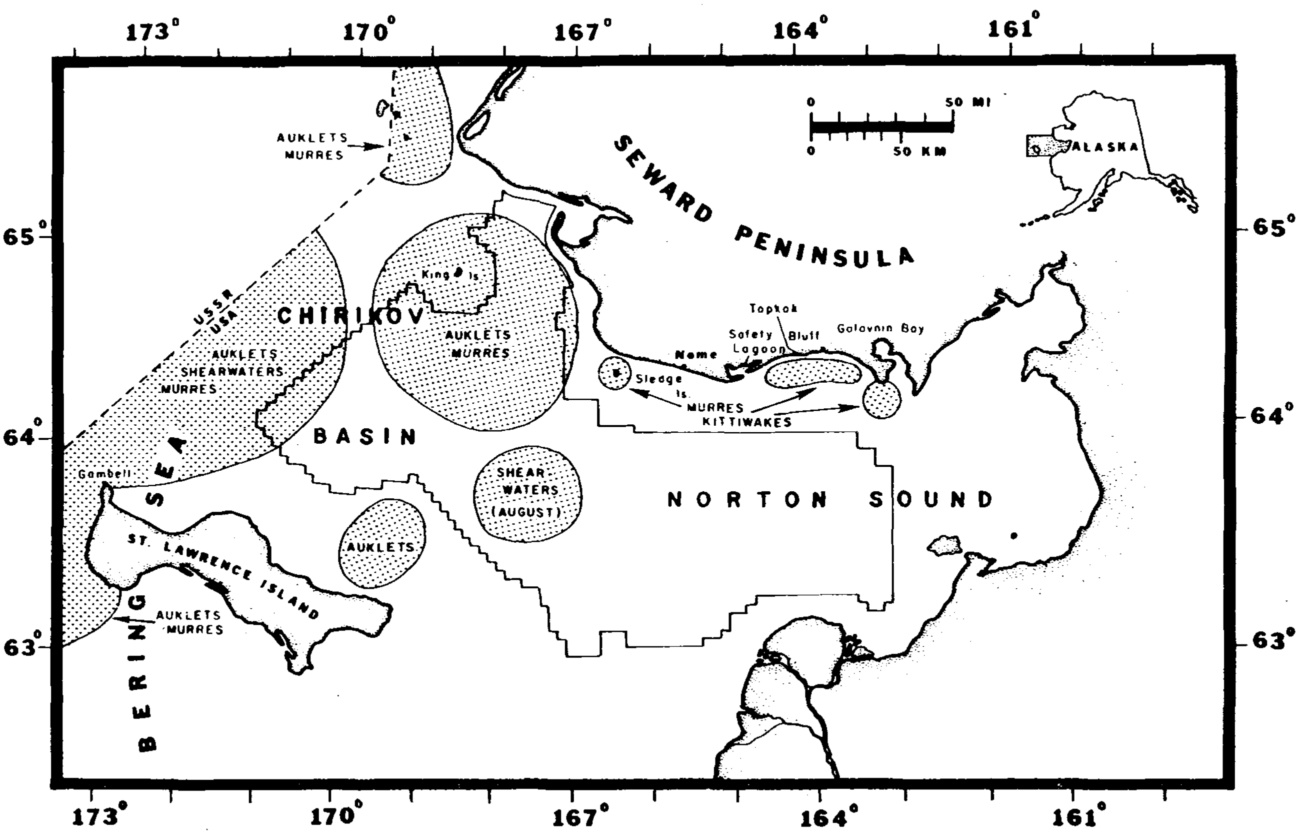

FIGURE 5.3—Concentrations of seabirds in pelagic habitats in summer (after Starr *et al.* 1981).

and between Sledge Island and the mouth of Golovnin Bay (Drury *et al.* 1979).

Thick-billed murres and common murres occur in a half-moon-shaped pattern extending east to south about halfway between Sledge Island and King Island. Loose aggregations are scattered between King Island and Savoonga or Gambell. Murres are numerous to the northwest of King Island, and occasionally occur in moderately dense groups between King Island and Wales. In Norton Sound, murres are scattered out to about 40 km south of the cliffs at Bluff, and gather near the mouth of Golovnin Bay, and to a lesser extent between Topkok and Safety Lagoon. The largest numbers of auklets occur southwest, west, and northwest of St. Lawrence Island, and in the Bering Strait (Drury *et al.* 1979). Least auklets are regularly distributed in considerable numbers in the littoral zone as well as 30–50 km offshore (Bédard 1969).

Moderate numbers of horned puffins are observed within 16 km of nesting areas. Beyond this is a ring of sparse distribution, outside of which a few are seen again out to 65 km. The tufted puffin distribution resembles that of the horned puffin. There is a gap between those feeding near shore and those feeding farther out. Large numbers of tufted puffins occur southwest of Sledge Island and southeast of King Island toward St. Lawrence Island (Drury *et al.* 1979).

Accounts of the feeding ecology and vulnerability of the most abundant seabirds follow.

5.2.1 Least and Crested Auklets

Least and crested auklets (*Aethia pusilla* and *A. cristatella*) are specialized foragers on zooplankton in mid-depth and surface waters. The least auklets take smaller items than do the crested auklets. Least auklets feed mainly on *Calanus* copepods and secondarily on amphipods. Crested auklets feed mainly on euphausiids and secondarily on amphipods (Hunt *et al.* 1981a).

The breeding ranges of least and crested auklets are restricted to islands near water masses that have large forms of zooplankton characteristic of upwelling areas. In the Norton Basin, they feed abundantly north and west of St. Lawrence Island and in the Bering Strait (Hunt *et al.* 1981c) from colonies in those areas (Section 4.2.6).

Because these birds concentrate to feed, feed by diving, and are very sensitive to being oiled, they are among the most susceptible of bird populations to direct adverse effects of spilled oil. But because of the rapid turnover and mobility of their prey base, it is unlikely that these auklets would be vulnerable through the food chain to OCS activities.

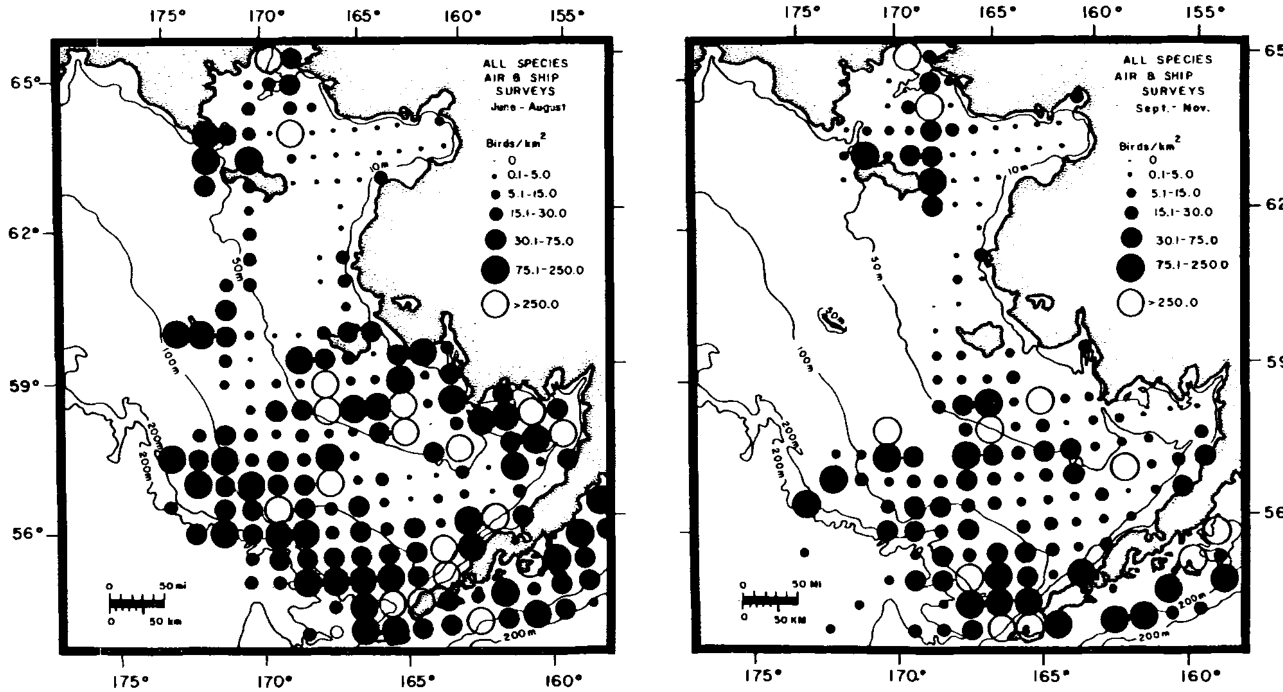

FIGURE 5.4—Pelagic distributions of all seabird species in the Norton Basin in summer (June–August) (left) and in fall (September–November) (right) as determined by air and ship surveys (from Hunt *et al.* 1981c).

5.2.2 Parakeet Auklet

The parakeet auklet (*Cyclorrhynchus psittacula*) feeds mainly on euphausiids, polychaetes, and fish, and to a lesser extent on copepods and amphipods. In addition to taking a wider variety of prey types, this species also takes larger prey items than do the other auklets. It nests on and feeds in offshore waters near the same islands used by least and crested auklets, but unlike these two species, the parakeet auklet also commonly nests on coastal islands and headlands, where it demonstrates its greater trophic flexibility by feeding on demersal and epibenthic invertebrates and fishes (Hunt *et al.* 1981a,b,c).

Like the other auklets, parakeet auklets are highly vulnerable to potential adverse effects from spilled oil. This species feeds by diving and is sensitive to being oiled. It may be slightly less vulnerable to localized oil spills than are the other auklets because of its more widespread distribution. Its vulnerability to food-chain effects of OCS development is probably low.

5.2.3 Short-tailed Shearwater

The short-tailed shearwater (*Puffinus tenuirostris*) feeds mainly within the top 0.5 m of water by pursuit plunging, hydroplaning, and surface seizing. Euphausiids (summer) and hyperiid amphipods (fall) form the bulk of its diet; cephalopods and small fishes are also important, in both summer and fall (Hunt 1981a). These birds are generally most abundant in the Chirikov Basin area of the Norton Basin (Fig. 5.3); large concentrations have also been seen in the Bering Strait area in fall.

The most striking feature of shearwater distribution is its patchiness; foraging or resting flocks of immense size (100,000 to over 1 million birds) have been recorded. Most aggregations seem to occur near and inside the 50-m isobath (Hunt *et al.* 1981c).

Because of their tendency to aggregate in huge flocks to feed or to rest on the water, shearwaters are relatively vulnerable to adverse effect from localized oil spills. Their vulnerability to food-chain effects of OCS activities is undoubtedly very low in comparison.

5.2.4 Thick-billed and Common Murres

Thick-billed and common murres (*Uria lomvia* and *U. aalge*) feed by diving, often to great depths. They forage on small fishes and (particularly thick-billed murres) on large zooplankters such as *Parathemisto* (Hunt *et al.* 1981a,c). In the Norton Basin in summer, most murres are found within several tens of kilometers of cliff colonies in the Norton Sound and Bering Strait; few nest on St. Lawrence Island. After nesting is over, there is a general dispersal southwestward, and in fall most murres in the Norton Basin are found in the Chirikov Basin and near (north and east of) St. Lawrence Island (Hunt *et al.* 1981c).

Like other diving seabirds, murres are highly sensitive to oil spilled in their feeding habitat. They are less clumped in their distribution in Norton Sound than are some other birds such as least and crested auklets and shearwaters, so in a population sense are somewhat less vulnerable to local disturbances.

5.2.5 Horned and Tufted Puffins

Both the horned puffin (*Fratercula corniculata*) and the tufted puffin (*Lunda cirrhata*) feed primarily on fishes and secondarily on invertebrates such as vereid worms and amphipods. Both forage by diving but, at least during the breeding season, their feeding habitats differ. Horned puffins tend to restrict their foraging efforts to the vicinities of breeding colonies, and shallow-water subtidal fishes and invertebrates predominate in their diets. Tufted puffins travel much longer distances to forage, feeding mainly on prey in deep waters far offshore (Hunt *et al.* 1981a). Especially in fall, tufted puffins are very abundant in the northern Chirikov Basin.

Like other diving seabirds, puffins are likely to suffer severe effects if oil reaches their feeding habitat when the birds are present. Horned puffins are probably more vulnerable in a population sense than are tufted puffins, because horned puffins tend to concentrate their foraging efforts in the vicinity of colonies. Tufted puffins, on the other hand, are generally widely distributed and tend to be individual foragers, though some rafting in groups occurs in summer and fall (Hunt *et al.* 1981c).

5.2.6 Black-legged Kittiwake

The black-legged kittiwake (*Rissa tridactyla*), one of the most pelagic of gulls, forages by surface seizing or dipping on a wide variety of small fishes and large zooplankters; most prey is taken within about 0.25 m of the water's surface. During summer, kittiwakes appear most abundant relatively near the mainland in western Norton Sound and the eastern Chirikov Basin. In fall, after the breeding season, they shift westward and are widespread from the Bering Strait to St. Lawrence Island. The birds tend to forage as scattered individuals, but quickly assemble when an abundant source of food is discovered. They appear to be the major catalysts in the formation of mixed-species feeding flocks of seabirds (Hunt *et al.* 1981c).

Black-legged Kittiwakes are probably less vulnerable to the potential adverse effects of oil in their feeding habitats than are most seabirds. They forage as solitary individuals, and though they congregate when much food is discovered, perhaps would tend to avoid oily waters. Further, they pick much of their food from the surface, and thus, even should they feed in oiled habitats, would perhaps detect and then avoid oil on water before they would become heavily oiled.

5.3 FISHES

Introductory remarks in Section 4.3 described the fish community in the Norton Basin as representing a faunistic transition between North Pacific and Arctic Ocean communities and consisting of relatively few species (about one-third the number occurring in the southern Bering Sea). The Norton Basin fish community also differs in species composition from other oceans (it has a higher proportion of sculpins and snailfishes), and the abundance of offshore demersal fishes is low compared with that of other Alaska coastal regions (Fig. 5.5). Norton Sound bottomfish account for less than 3% of the potential eastern Bering Sea bottomfish resource (Kaimmer *et al.* 1976), despite an abundance of benthic invertebrates in these waters (see Section 5.4). Low water temperatures are thought to inhibit bottom-feeding fishes from invading the richly concentrated benthos of this area (Alton 1974). The data base for offshore fishes consists primarily of bottom trawl data gathered during the open-water period, June–October (Wolotira *et al.* 1977; Sample and Wolotira *In prep.*), supplemented by offshore gill-netting, surface tow netting, and midwater trawling (Wolotira *et al.* 1977; Barton 1978).

The demersal marine fish resource of the Norton Basin is dominated by cods and flatfishes, which comprise over 75% of the demersal fish biomass present (Table 5.1). Saffron cod is by far the most abundant species, accounting for nearly one-half the total demersal fish biomass.

The overall distribution and abundance of demersal fishes (species combined) illustrate several areas of fish concentration (Fig. 5.6). In 1976, the greatest densities of fish were located in central and western Norton Sound; lowest catches were in eastern Norton Sound and the central Chirikov Basin. Most of the dominant fish species were found in greatest abundance where bottom waters were warmer than 4°C and shallower than 30 m. The Arctic cod was an exception to these trends; it was found at nearly all bottom temperatures and at depths greater than 30 m. Subsequent surveys in 1979 revealed considerable annual variation in the distributions of some abundant species (Sample and Wolotira *In prep.*).

Much less is known about offshore pelagic fishes such as salmon, herring, and smelts because these species are not readily caught by trawling and they are present in offshore waters only at certain times of the year. Some preliminary evidence obtained by gill-netting indicates that these fish, too, are not very abundant in offshore waters of the Norton Basin. The

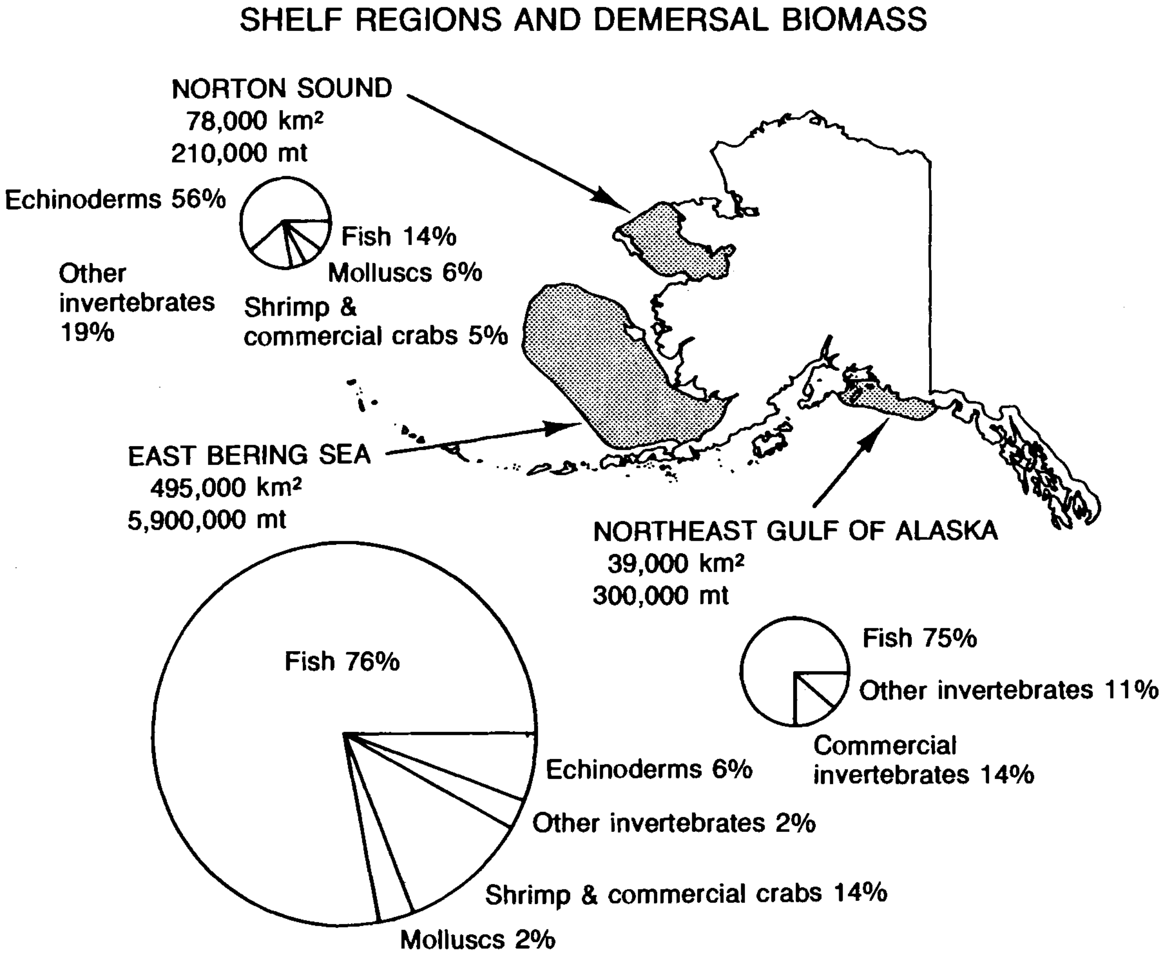

FIGURE 5.5—A comparison of demersal fishery resources for regions of the Alaska continental shelf (from Wolotira in Burns *et al.* 1982).

average catch per unit effort was only 1–2 fish/h in the Norton Basin, and most of the gill-net catch consisted of herring (Wolotira *et al.* 1977; Barton 1978). However, salmon migrate through these waters to and from their spawning streams and a Japanese commercial fishery for herring has operated in central Norton Sound (Wolotira *et al.* 1977).

The generally low catch rates of both pelagic and demersal fishes in the Norton Basin are supported by hydroacoustical soundings which revealed no extensive off-bottom fish concentrations, thus Wolotira *et al.* (1977) concluded that almost no fish species was encountered in either sufficient size or quantity to be considered as potential for new commercial harvest. Pacific herring is the only non-salmonid species presently taken in a commercial fishery in the region, and recent harvests have been small.

5.3.1 Demersal Fishes

Saffron cod are found throughout the Norton Basin during ice-free months. It was one of the most widely distributed and frequently encountered fish species in coastal and offshore surveys in 1976, 1977, and 1979 (Wolotira *et al.* 1977; Barton 1978; Sample and Wolotira *In prep.*). Greatest abundances were found in the Port Clarence–Grantley Harbor area, in Golovnin Bay, and in western Norton Sound out to about the 25-m isobath. The winter distribution of saffron cod in the region is not known, though cod appears to be a major food item in the diets of marine mammals occurring near shorefast ice. Additionally, it is caught by coastal inhabitants through nearshore ice throughout the winter months (Wolotira 1980). Spawning of saffron cod in Norton Sound probably occurs from December through February. Eggs are demersal but larvae have been found in surface waters of Norton Sound in early summer (Barton 1978). This species feeds on crustaceans (shrimps, amphipods, and mysids), polychaete worms, and other fishes (Morrow 1980).

Arctic cod are also abundant in the Norton Basin, probably more so than is suggested by catches because this semipelagic species is under-represented by trawl data (Wolotira 1980). This important forage species is widely distributed in the Norton Basin (Wolotira *et al.* 1977; Sample and Wolotira *In prep.*). It feeds on a variety of planktonic (copepods) and epibenthic (mysids, amphipods) invertebrates.

The starry flounder is the most abundant flatfish in the Norton Basin, where it comprises 12% of the total demersal fish biomass (Table 5.1). Starry flounders occur primarily in shallow water, at least during ice-free months (Barton 1978; Wolotira 1980), although very few starry flounders have been found in inner Norton Sound. Offshore concentrations appear to center in the outer portion of Norton Sound. The winter distribution of starry flounders in the Norton Basin is not known. Spawning times have not been documented for the Norton Basin, but in the Gulf of Anadyr in the western Bering Sea, spawning apparently occurs mostly in June (Pertseva-Ostroumova 1960). The principal foods of starry flounders in Norton Sound are clams and brittlestars; echinoderms and sand dollars are also eaten (Jewett and Feder 1980).

Other relatively abundant demersal fish species in the region are shorthorn sculpin, yellowfin sole, Alaska plaice, and walleye pollock (Wolotira 1980). Little feeding information on the sculpins is available from the Bering Sea, but based on their known foods elsewhere they probably feed primarily on benthic invertebrates and fishes. Existing data suggest that yellowfin sole may feed mainly on mysids and euphausiids in Norton Sound; plaice on bivalve molluscs, amphipods, and polychaetes; pollock on euphausiids, copepods, hyperiid amphipods, and fishes; and Arctic cod on copepods, mysids, and amphipods (Feder and Jewett 1981; Smith 1981).

Demersal fishes might suffer somewhat less than other fishes in the event of an oil spill or other OCS-related disturbance because of the slightly deeper waters they inhabit. The greatest potential damage bears upon those species having pelagic eggs or larvae that would be susceptible to oil spills. This sensitive pelagic phase in the life history of groundfish generally occurs from January to July, at least in more southerly latitudes. The young of some demersal species also have a rearing phase in shallow coastal waters and would similarly be exposed to oil. Although loss of eggs or larvae might be locally significant, the overall impact would be negligible in a regional context due to the wide distribution and high fecundity of groundfish species and the gradual dispersal of eggs and ichthyoplankton from uncontaminated areas. As summer progresses, groundfish tend to move into deeper water and are then less likely to be affected by an oil spill.

5.3.2 Pelagic Fishes

Salmon migrate through offshore waters of the Norton Basin twice—as outgoing juveniles and as adults returning to spawn. These migrations are species- and stock-specific for smolts entering coastal waters (see Section 4.3) and returning adults. Little is known about the seaward migration of juvenile salmon. Starr *et al.* (1981) note that such movements are dependent on the size of the fish, and timing can be expected to display seasonal and annual variations. Buklis and Barton (1984) describe the migration patterns of chum salmon from the Yukon River:

> After spending several weeks nearshore, possibly in southern Norton Sound, juvenile chum salmon from the Yukon River apparently move seaward in late summer and throughout autumn. In winter, these juveniles, along with other immature chum salmon rearing in the Bering Sea, migrate southward into the Gulf of Alaska and the North Pacific Ocean. In late May or June of the following summer, the pattern is reversed with immature chum moving northward to summer feeding areas in the central Bering Sea.

TABLE 5.1—Estimated biomasses and numbers of the seven most abundant demersal fish species in the Norton Basin.

Species	Biomass Estimate (metric tons)	Population Estimate (thousands of fish)
Saffron cod	16,844 (48)[1]	763,038
Starry flounder	4,033 (12)	5,744
Shorthorn sculpin	3,929 (11)	15,948
Alaska plaice	1,058 (3)	10,921
Yellowfin sole	1,235 (4)	30,723
Arctic cod	660 (2)	38,978
Walleye pollock	87 (-)	5,503

SOURCE: Wolotira *et al.* 1977.

[1] Number in parentheses indicates percentage of total demersal fish biomass.

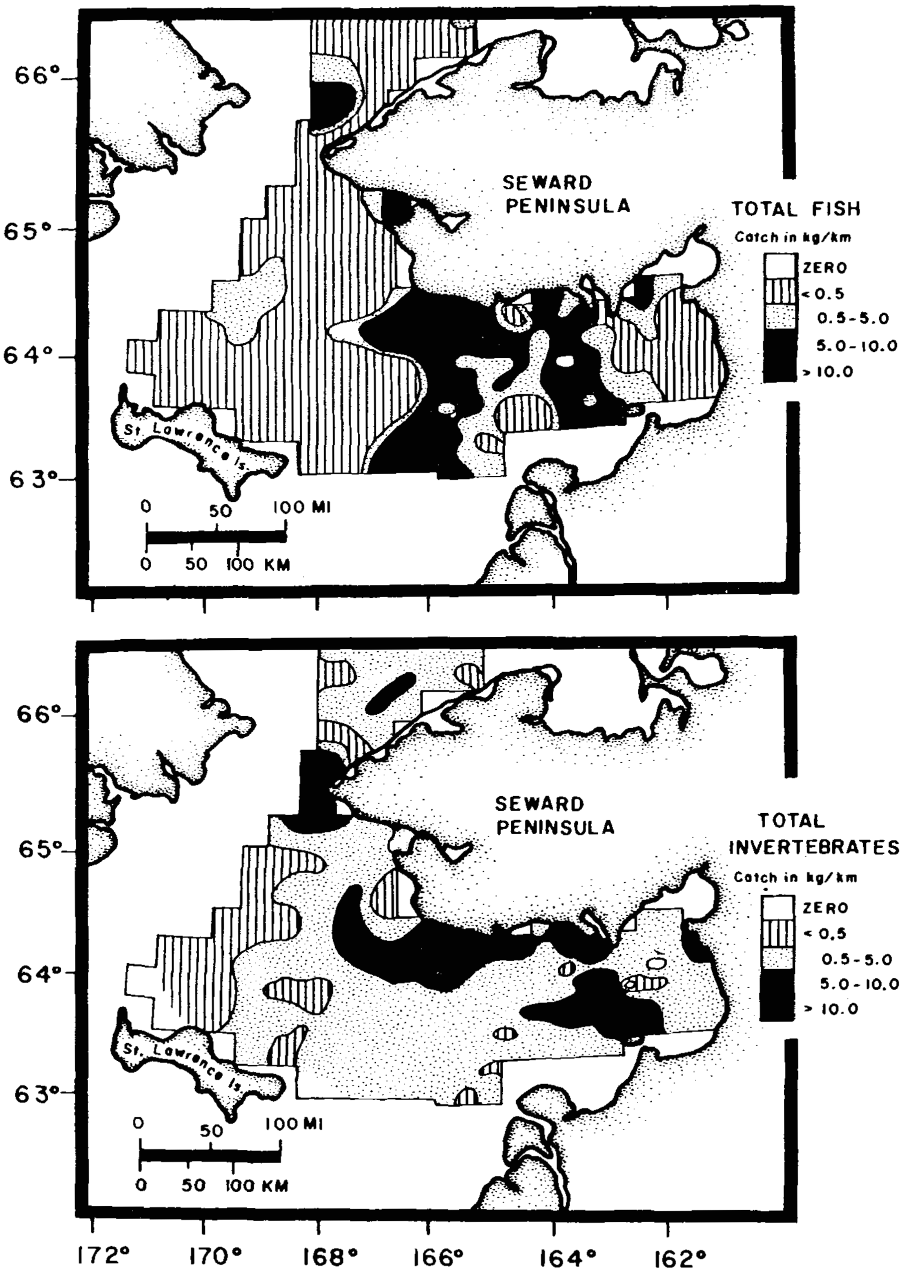

FIGURE 5.6—Distribution and abundance of fish and invertebrates (species combined, respectively, by weight) in the Norton Basin, 1976 (from Wolotira *et al.* 1977).

Starr *et al.* (1981) describe the pattern of returning adults:

> Maturing king salmon are the first to enter the shelf, followed in order by sockeye, summer chum, pink, fall chum, and coho salmon. Peak migration in Norton Sound occurs between May and September, and while little information is available on routes taken by Norton Sound salmon as they migrate toward their home stream, some patterns have emerged from studies in the area. Adult salmon appear to remain in the offshore waters of the shelf until they are near the coastal area or the estuary containing their home river or stream. Maturing sockeye appear to migrate eastward north of St. Lawrence Island, while maturing pink salmon appear to migrate eastward south of the island. Migrating chum have been found moving eastward both north and south of St. Lawrence Island (Straty 1981). Migrating salmon in Norton Sound appear to be a mixture of Norton Sound, Yukon River, and Kotzebue Sound salmon.

Although the run timing of returning adult salmon may cover a span of weeks or months as they pass through the Norton Basin to reach their spawning streams, tagging data suggest that the residence time of an individual adult salmon in the Norton Basin could be as brief as 6 to 9 days (based on a migratory rate of 30 nautical miles per day for Bristol Bay adult sockeye salmon—Nishiyama 1977). This estimate is considered a minimum residence time because a variety of factors might delay passage.

Diets of large salmon in offshore waters consist of euphausiids, amphipods, copepods, decapod larvae, pteropods, squids, and fishes (Hart 1973).

Other pelagic species (herring, smelts) are described in Section 4.3. Herring are dispersed throughout offshore waters of the Norton Basin, occurring at 50% of offshore trawl stations and accounting for 6% of the biomass of all species combined (mostly demersal fishes) (Wolotira *et al.* 1977). Herring also accounted for 69% of offshore gill-net catches, but catch rates were very low, about 1–2 fish/h. During 1968–75 the Japanese harvested an average of 20,440 tons of herring in central Norton Sound; catches were particularly large near Stuart Island (Wolotira *et al.* 1977).

Rainbow smelt were also widely dispersed. They were caught at 67% of the offshore stations sampled and accounted for 5% of the fish biomass trawled and 15% of the fish caught by gill net (Wolotira *et al.* 1977).

Vulnerabilities of offshore pelagic species to oil spills or other disturbances are considered to be low because salmon, herring, and smelts are widespread and the individuals present are older juveniles and adults that are generally less sensitive to disturbance than the egg and larval stages of these fishes. Adult salmon in offshore waters have low vulnerability to an oil spill or other disturbance unless it interferes with their return migration to spawning grounds from May to September. Although adults may avoid a contaminated area, it has been suggested that the presence of oil could interfere with their chemical homing cues and adversely affect local migration patterns or timing (Waldichuk 1978). Probably the most important potential impact of an oil spill would be the tainting of fish flesh with a petroleum-like flavor that would render the fish unusable in commercial or subsistence fisheries.

5.4 INVERTEBRATES

The invertebrate community in the Norton Basin consists of over 185 species of Pacific boreal origin. Wolotira (1980) notes that the absence of higher arctic forms probably results from a restricted northern access to the Bering Sea (*i.e.*, Bering Strait) and prevailing northward water currents, both of which impede southerly dispersals of invertebrates.

In contrast to the fish fauna (Section 5.3), invertebrates (at least benthic forms) in the Norton Basin are abundant, and possibly the highest benthic biomass per unit area in the Bering Sea occurs in the Chirikov Basin (Fig. 5.7) (Stoker 1981). Invertebrates accounted for 86% of the total demersal biomass (including fish) in the Norton Basin and their biomass was estimated at 290,000 mt (Wolotira *et al.* 1977). Starr *et al.* (1981) discuss several possible reasons for this abundance:

> An analysis of biomass estimates shows a rapid increase in benthic standing stock from south to north in the Bering Strait region. Interpretations concerning this fact are varied. It has been noted that demersal fish populations may decrease in this region in response to colder bottom temperatures, thus causing a subsequent decrease in predation on benthic populations (Neiman 1964; Alton 1974; Stoker 1981). Another factor may be the high primary productivity rate that has been observed during early to late spring in this area (McRoy *et al.* 1972). Still another explanation is the current regime inherent to this region; detrital sediments from the Yukon River, Siberian coast, and the central and northwestern shelf are transported northward through the Bering Strait and into the Chukchi Sea, with some settling occurring along the way, thus providing for a continual influx of nutrients. A fourth and last consideration must be extended to the Pacific walrus population and its impact on benthic resources both south of St. Lawrence Island and north of the Bering Strait. It has been estimated that the entire population could consume as much as 4.38 million mt of benthos per year (mainly clams) in normal feeding activity (Fay *et al.* 1977). Since concentrated feeding in the Norton Sound–Bering Strait region occurs mainly during migration, the impact on benthic resources is thought to be less than in adjacent areas.

The epibenthic invertebrate community is dominated by echinoderms (particularly starfish), which account for 80% by weight of reported invertebrate catches (Wolotira *et al.* 1977; Jewett and Feder 1980). The starfish *Asterias amurensis* is by far the most abundant invertebrate of those present (Table 5.2) that feed on infauna to a large degree. Trawl catches of invertebrates of possible commercial importance are, in a regional context, low (Table 5.3), although red and blue king crab stocks in some areas are utilized extensively in commercial and subsistence fisheries.

The distribution and abundance of invertebrates (species combined) illustrate similarities with concentrations of demersal fishes (Fig. 5.6). Both groups are most abundant near Nome, near Golovnin Bay, and in east-central Norton Sound. The general composition and distribution of the invertebrate community are correlated with substrate and water mass characteristics. Burns *et al.* (1982) state:

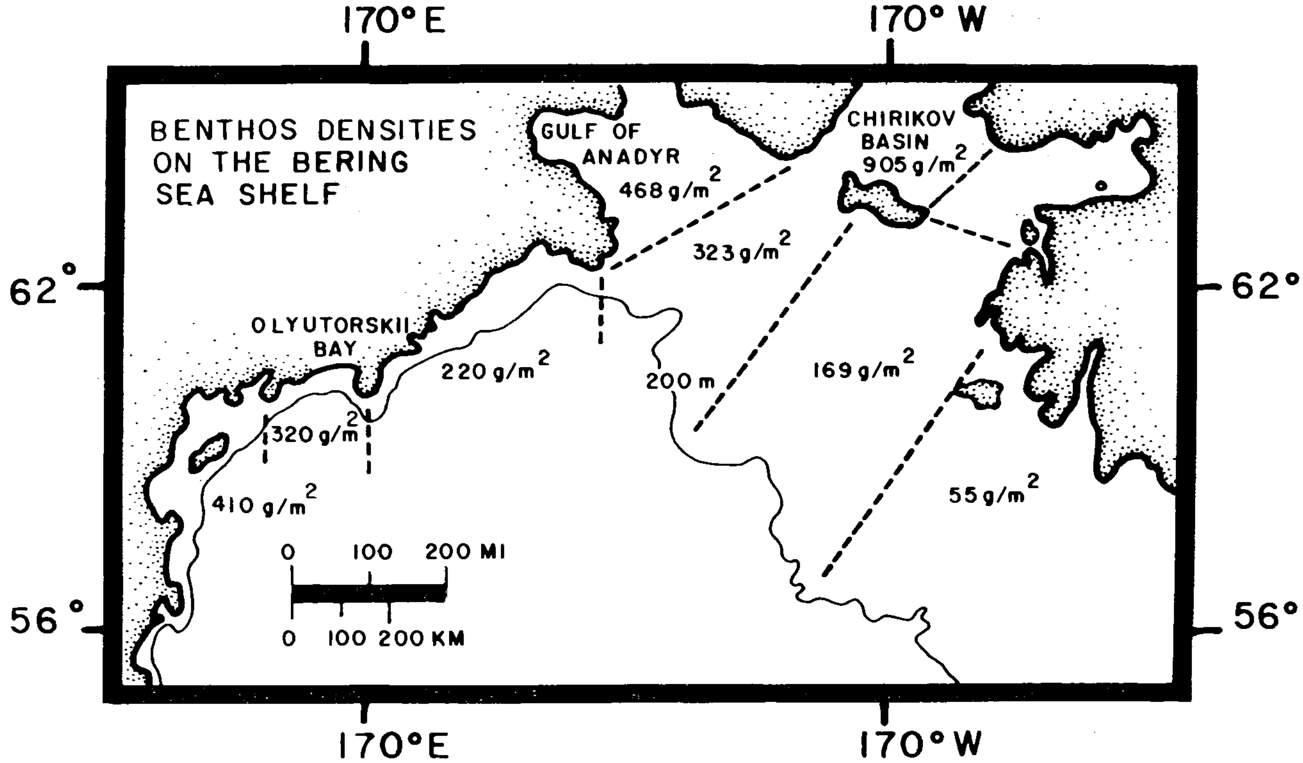

FIGURE 5.7—Benthos biomass in various sectors of the Bering Sea shelf and slope (from Alton 1974).

TABLE 5.2—Species composition and feeding methods of epibenthic invertebrates in the Norton Basin.

Phyla	Species	Feeding Method[1]		Catch Composition (%)
Echinoderms	Starfish, *Asterias amurensis*	P		54
	Basket star, *Gorgonocephalus caryi*	Sus–P		7
	Starfish, *Lethasterias nanimensis*	P		6
	Starfish, *Evasterias echinosoma*	P		4
	Starfish, *Leptasterias polaris*	P		3
	Sea urchin, *Strongylocentrotus droebachiensis*	H–S–P		3
	Others			3
			Subtotal	80
Arthropods	Red king crab, *Paralithodes camtschatica*	P–S		4
	Spider crab, *Hyas coarctatus*	P–S?		1
	Hermit crab, *Pagurus trigonocheirus*	P–S?		1
	Crab, *Telmessus cheiragonus*	P–S?		1
	Others			3
			Subtotal	10
Molluscs	Snail, *Neptunea heros*	P–S		3
	Others			1
			Subtotal	4
Misc. Phyla				6

SOURCE: Feder and Jewett 1980.

[1] Feeding method: P (predator), S (scavenger), Sus (suspension feeder), H (herbivore).

In the sluggishly rotating eastern sector of Norton Sound, where large amounts of detrital organic carbon from the Yukon River and other sources accumulate, soft organic sediments rich with microbial populations are found. In this area, deposit feeders (*e.g.*, polychaete worms, small clams, cockles) and associated predators (large snails, crabs, bottomfishes) are common.

The western sector of inner Norton Sound (still east of the boundary zone) is also a depositional environment, but sediments there are resuspended and redistributed by more vigorous currents. Species present are characteristically those of unstable depositional environments (*e.g.*, the polychaete worm, *Pectinaria;* the sand dollar, *Echinarachnius;* the clam, *Yoldia*).

Outside of Norton Sound (west of the boundary zone), sedimentation rates are lower, currents are more vigorous, and benthic organisms are primarily suspension feeders, depending primarily on water column productivity and resuspended local materials rather than detritus for their sustenance (*e.g.*, ampeliscid amphipods).

Invertebrate distributions also tend to be correlated with depth, with most organisms occurring in shallow waters (Fig. 5.8).

The vulnerability of offshore invertebrates to OCS activities is generally low because of the widespread distributions of the species. The eggs, the larval stages, and sometimes the adults of many species might be sensitive to oil contamination, but even so, the consequences of such contamination to consumers of invertebrates would be negligible because of the low vulnerability of the populations of invertebrates. Perhaps the most significant effect would be contamination (tainting) of the flesh of species used by man (*e.g.*, the crabs).

5.4.1 King Crabs

In terms of human usage, the most important invertebrates in the Norton Basin are king crabs, which are harvested commercially and for recreation and subsistence. Two species occur in the region, the red king crab (*Paralithodes camtschatica*) and the blue king crab (*P. platypus*), and they are relatively well studied because of their commercial value (Wolotira *et al.* 1977; Powell *et al.* 1983; Schwarz and Lean 1983). These crabs represent the northernmost populations of king crabs that support a commercial

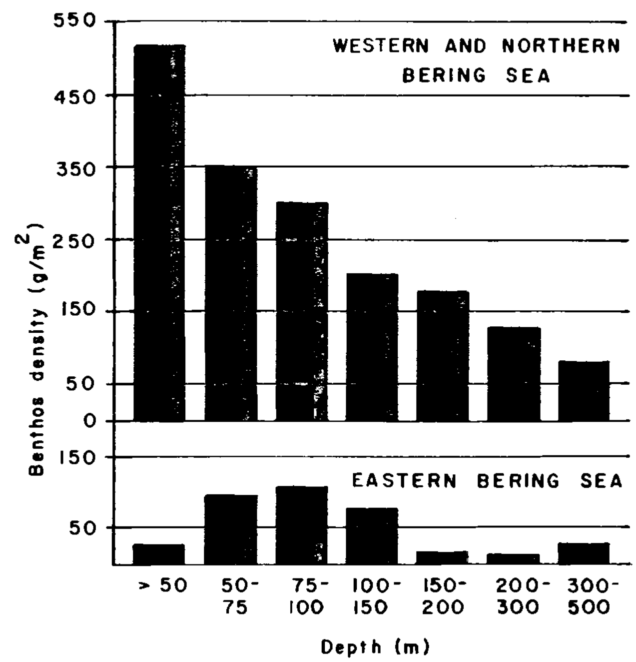

FIGURE 5.8—Bathymetric trends in benthos biomass in the Bering Sea (from Alton 1974).

fishery; however, the catch per unit area is only 6% of that occurring farther south in the Bering Sea (Powell *et al.* 1983).

The two king crab species differ in distribution and abundance (Fig. 5.9). Both species grow slower and reach smaller maximum sizes than do populations to the south.

TABLE 5.3—Relative abundance and catch per unit effort (CPUE) of potentially commercially important invertebrates caught by trawl in the Norton Basin.

	Chirikov Basin		Norton Sound	
	CPUE (kg/km)	% of Catch	CPUE (kg/km)	% of Catch
Red king crab	0.1	0.1	1.9	3.4
Blue king crab	0.5	1.3	—	—
Tanner crab	—	—	0.03	0.1
Telmessus crab	0.1	0.3	0.6	1.0
Shrimps	3.0	0.9	0.3	0.5
Molluscs (snails, etc.)	2.3	5.9	1.7	3.1

SOURCE: Wolotira *et al.* 1977.

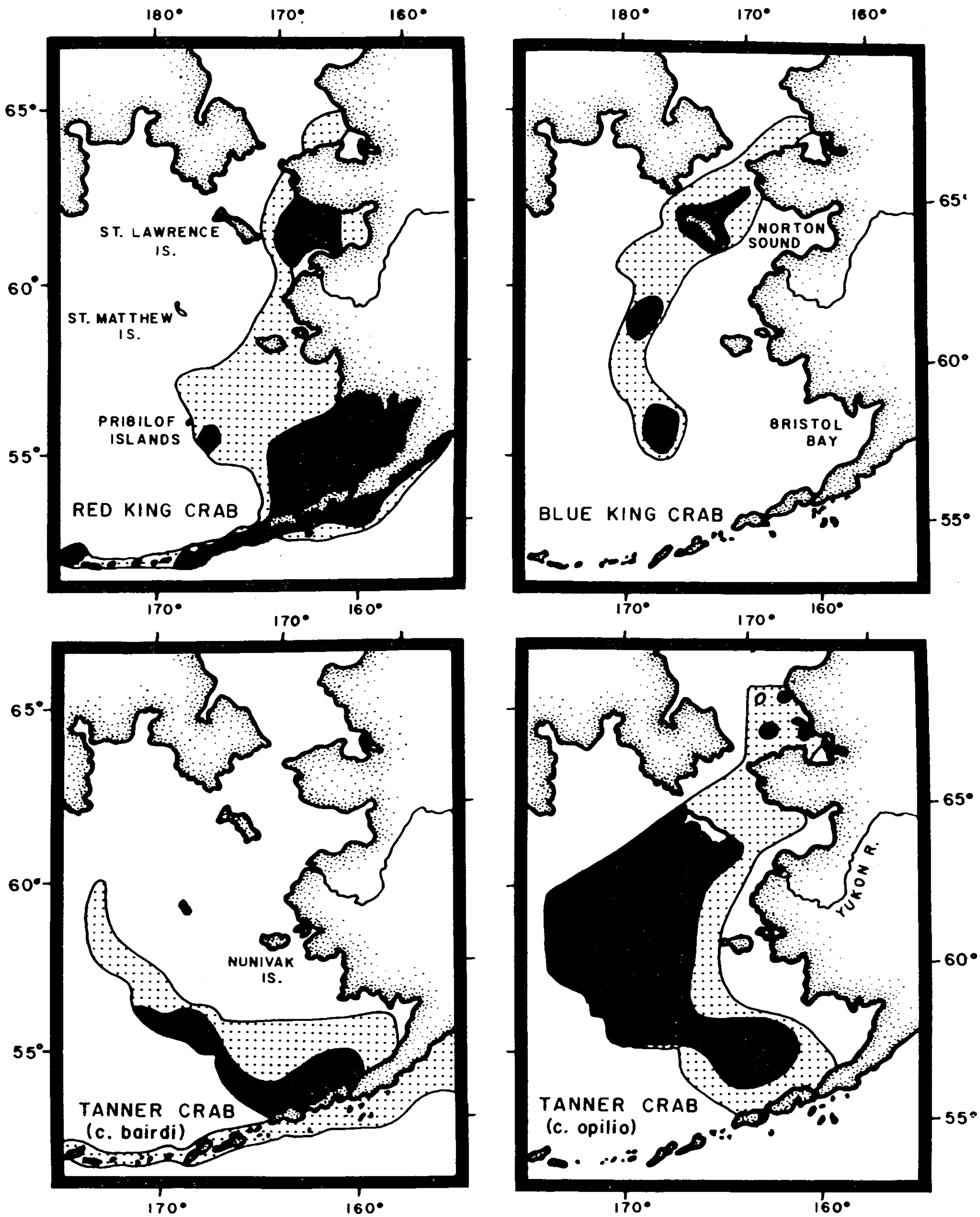

FIGURE 5.9—Distribution of king and Tanner crabs in the Bering Sea (from Otto 1981, cited by LGL 1982). Areas of high abundance are shaded.

Red king crab are more abundant, with an estimated biomass of 1.2–8.1 million pounds (1976–82 estimates of legal males only) of which 0.2–2.9 million pounds have been harvested annually. Numbers of male crabs have declined since 1978 (Powell *et al.* 1983), perhaps reflecting commercial fishing pressures. Most red king crab are distributed over a relatively small area (111 km^2) to the south and east of Sledge Island near Nome, and highest commercial catches have been in the area immediately south of Sledge Island. Tagging data indicate that these king crab spend their lives within a relatively small area with movements tending to be seaward to the south and west in July and August and a return migration probably in fall (Powell *et al.* 1983).

Blue king crab occur mostly in western areas of the Norton Basin (Fig. 5.9). Commercial fishing for blue king crab began in 1977 in the St. Matthew Island area south of the Norton Basin, and by 1979 harvests were being made as far north as St. Lawrence Island. Commercial harvests have not been made in other parts of the Norton Basin (Otto 1981).

Blue king crab mate during April–June in Norton Sound; eggs are carried by the female for almost a year and hatch during March–June (Powell *et al.* 1983). The larvae are planktonic for 2 to 3 months before settling to the sea bottom.

5.4.2 Tanner Crab

The Tanner crab (*Chionoecetes opilio*) is by far the most abundant crab species in Norton Basin waters, but all individuals are very small. Wolotira *et al.* (1977) estimated the Norton Basin population biomass in 1976 at about 1,400 mt and its numbers at over 52 million. Average size (carapace width) for this species was only about 4 cm and nearly all were juveniles. Available evidence suggests that these crabs represent a juvenile segment of populations outside the Norton Basin. Centers of abundance of this northern Tanner crab appear to be outside of Norton Sound in waters west of 166° west longitude, especially in areas off St. Lawrence Island and northward through the Bering Strait (Fig. 5.9).

5.4.3 Snails

Gastropod molluscs are abundant and comprise nearly half of the biomass of invertebrates of potential economic importance. Wolotira *et al.* (1977) estimated their biomass at over 9,000 mt. The most abundant taxa are the neptunes, particularly the northern neptune, *Neptunea heros*. This shallow-water snail has an estimated population size of about 56 million (Wolotira *et al.* 1977). The distribution of *N. heros* is centered in two areas of the Norton Basin: the nearshore area west of Golovnin Bay, and somewhat offshore and east of St. Lawrence Island. The average size (10-cm shell) and weight (110 g) of *N. heros* in the Norton Basin are similar to those of the same species commercially harvested by Japan in the eastern Bering Sea.

5.4.4 Starfish

Starfish concentrations in Norton Sound probably represent the highest density of these taxa on the entire Alaska continental shelf. Wolotira *et al.* (1977) estimated their biomass to be more than 100,000 mt. Areas of abundance are shallow waters off the south coast of the Seward Peninsula and in middle Norton Sound. Although starfish are not typically utilized at higher trophic levels, their significance should not be overlooked. At spawning time, they release substantial amounts of gametes which may represent an important food source for other organisms in the Norton Basin (Jewett and Feder 1980).

5.4.5 Zooplankton

In contrast to the foregoing discussion of epibenthic invertebrates, much less is known about invertebrates in the water column such as pelagic copepods, euphausiids, jellyfish, and squid. In eastern parts of the Norton Basin, densities of pelagic invertebrates are low, presumably because the high sediment load of the Yukon River causes coastal waters to be turbid, thereby inhibiting growth of phytoplankton for pelagic invertebrates to feed upon. Consequently, this region is characterized by a detritus-based food web. The western portion of the Norton Basin is less affected in this manner and densities of pelagic invertebrates are higher (but still low compared with other Bering Sea areas—Fig. 5.10); consequently, both pelagic- and detritus-based food webs are important there.

5.5 IMPORTANT FOOD WEBS

The offshore ecosystem, at least that part supporting most of the vertebrates, appears to be fueled almost entirely by phytoplankton production (Fig. 5.11). This production is dependent on nutrients upwelled from the deep North Pacific and perhaps also from Yukon River discharge (McRoy *et al.* 1983; Truett 1984). This production finds its way into the major consumers via two food chains—benthic and pelagic.

The benthic component of the food web is an important one; it is presumably based largely on detritus generated mainly from settling plankton, though quantitative demonstration of this is lacking. Invertebrates on and within the sea floor (*e.g.*, amphipods, shrimps, clams) contribute to the support of a large biomass of mammals (gray whales, walruses, bearded seals) and fishes (saffron cod, Arctic cod to some

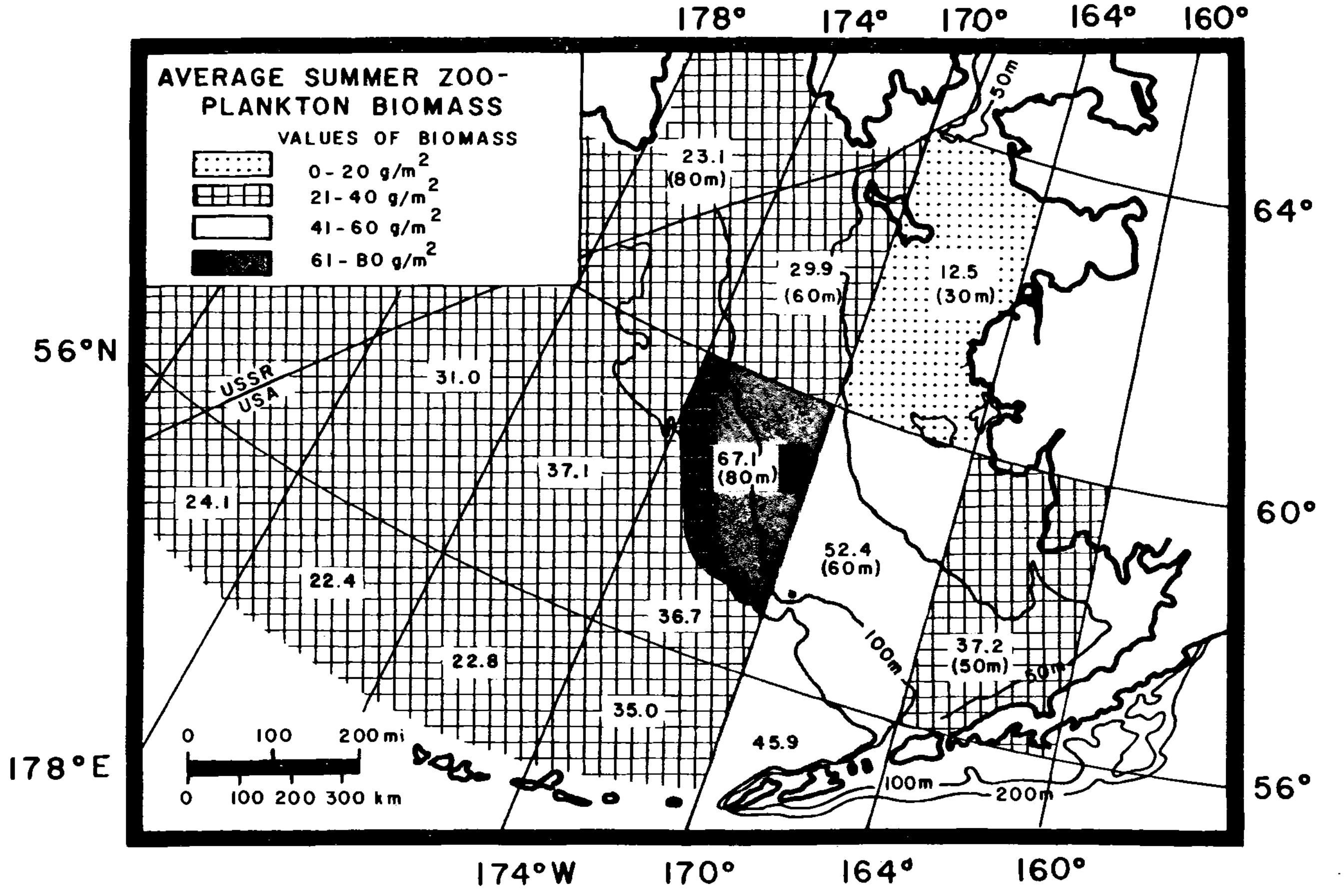

FIGURE 5.10—Average summer zooplankton/micronekton biomass for 15 years from 1956 to 1970 in each 5-degree grid. Values are expressed in wet wt g/m² in 80-m water column (from Motoda and Minoda 1974).

extent, flounders, sculpins, and others). The red and blue king crabs also feed on benthic invertebrates. The fishes, particularly saffron and Arctic cods, support other mammals (ringed seals, belukha whales). Polar bears are a top consumer in this food chain, eating mainly ringed and bearded seals. Humans are of course the dominant top consumer, harvesting to some extent all of the mammal species, many of the fishes, and some of the epifauna (*i.e.*, crabs). (A large biomass of benthic invertebrates—*e.g.*, starfish and other echinoderms—is apparently not fed upon to any extent by vertebrates, and these may be an ecological "dead end" in terms of man's immediate interests.)

The pelagic component of the food web, likewise important, is based on the zooplankton. Zooplankton consumers are mainly fishes (*e.g.*, Arctic cod, salmon, herring, smelts) and birds (*e.g.*, least and crested auklets, shearwaters, kittiwakes, murres). It is also possible that migrating bowheads feed on zooplankton here in fall. Some of the fish are in turn consumed by birds (puffins, kittiwakes, murres) and mammals (belukha whales, ringed seals).

5.6 IMPORTANT HABITATS

Important habitats are defined as specific sites where important species perform important biological functions such as breeding, feeding, and migrating. Marine mammals and seabirds are emphasized in this section. These animals are "high profile" species, the distributions of which are relatively well known due to their commercial, subsistence, or recreational value. Though some fish and invertebrate species have similar values, most of them usually do not concentrate in well-demarcated habitats; their biological functions are often accomplished over large and imprecisely defined areas. Furthermore, fishes and invertebrates in offshore waters are less vulnerable to OCS-related impacts than are marine mammals and seabirds.

For most areas identified as important habitats, use by vertebrates is directly related to the seasonal cycle of ice conditions in the Norton Basin. The dominant migration pattern of marine mammals and seabirds is to follow the northward retreat of the pack ice front in springtime, feed and reproduce (for some species)

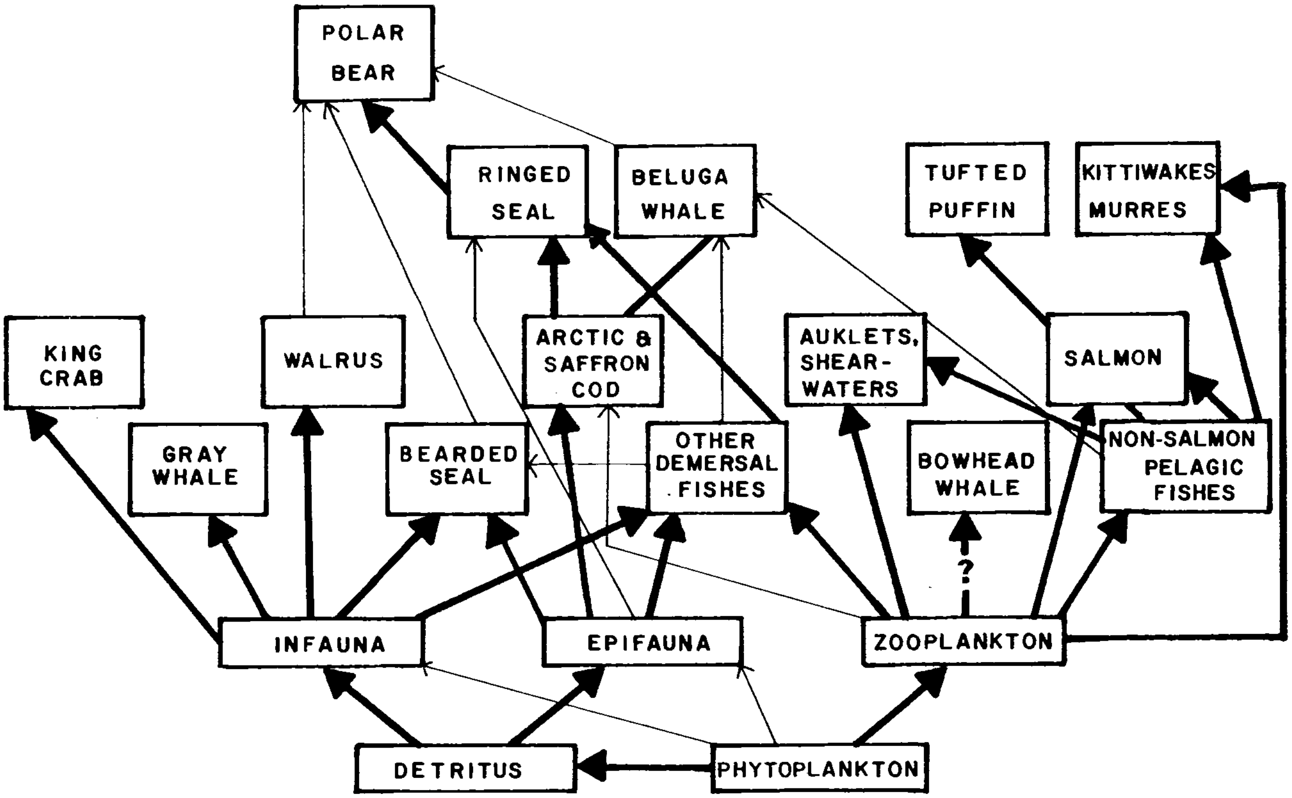

FIGURE 5.11—Simplified food web of the offshore ecosystem of the Norton Basin. Heavy arrows indicate major sources of foods for consumers.

in arctic waters, and then return in early winter as the pack ice grows southward.

Figure 5.12 suggests very different patterns of habitat importance among regions in the Norton Basin. The entire western region (Chirikov Basin and around St. Lawrence Island) is an important feeding area and migratory pathway for many marine mammals and seabirds. The eastern region (Norton Sound) receives much less use by these groups, and important habitats are largely restricted to coastal (as opposed to offshore) waters (see also Section 4.6).

These patterns of habitat usage reflect important oceanographic and biological differences between the two regions. Norton Sound is relatively isolated from the supply of Pacific Ocean nutrients that enter the Chirikov Basin; also, the water column in Norton Sound tends to be highly stratified in comparison to the well-mixed waters of the western Norton Basin. This isolation and stratification of Norton Sound waters creates persisting cold and unproductive waters at the bottom in comparison with benthic environments farther west in the Norton Basin.

5.6.1 Chirikov Basin

Spring

Large numbers of seabirds; bowhead, gray, and belukha whales; walruses; and bearded, ringed, and spotted seals (including nursing females and the young of several species) migrate northward through the Chirikov Basin from March through June from southern overwintering areas. Specific migration timings and routes are species-specific and annually variable depending on the distribution of open-water leads and retreat of pack ice.

Summer

The Chirikov Basin is a major feeding area for gray whales and seabirds in summer. Seabird densities of 200 birds/km² may occur there.

Fall

The return migration of marine mammals and seabirds comes through the Chirikov Basin, generally along migration pathways followed in spring, from September through December (bowheads sometimes as late as January), depending on rate of freeze-up.

Winter

The Chirikov Basin is less important for marine mammals and seabirds in winter. Bearded and ringed seals remain throughout the broken pack ice, from November to June, but are not restricted to the Chirikov Basin. Few seabirds are present except in "light" ice years when the pack ice does not extend far into the Norton Basin.

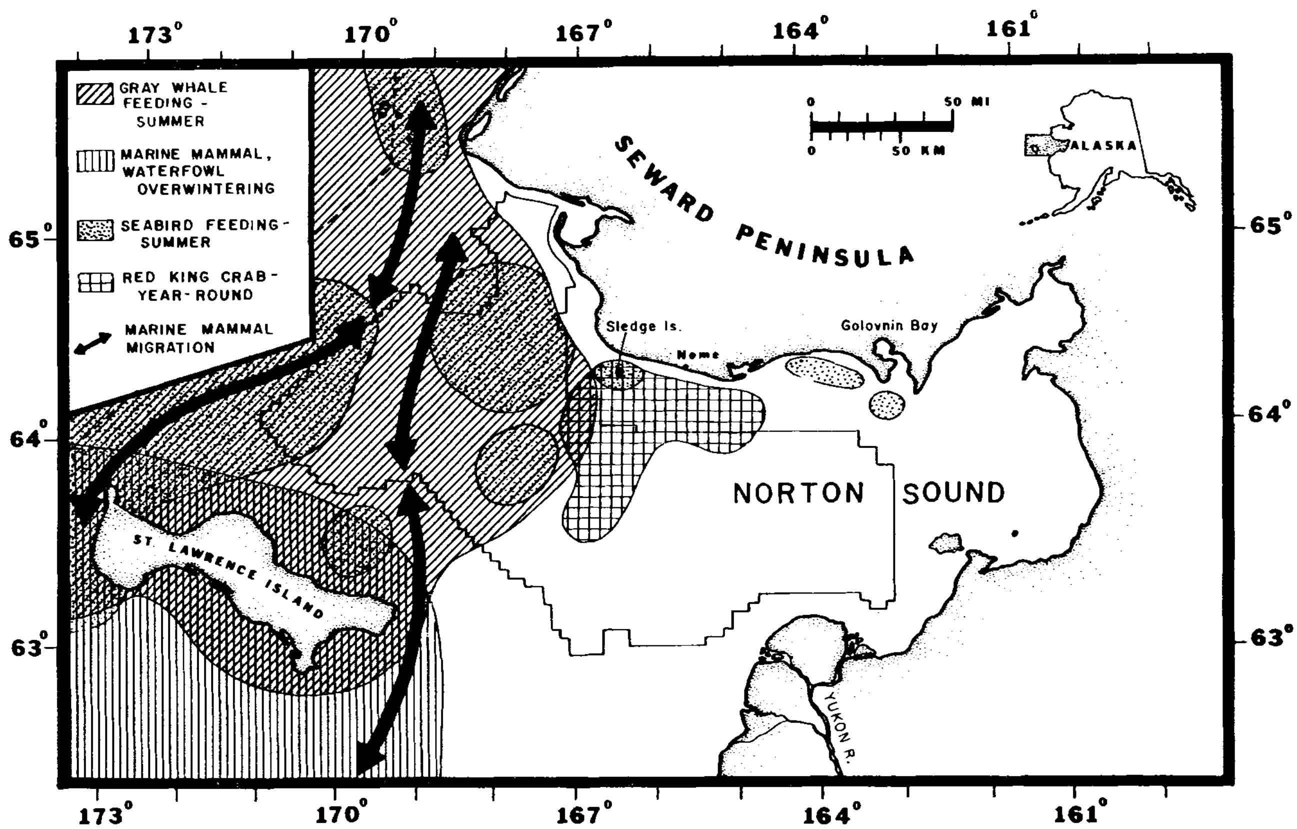

FIGURE 5.12—Schematic representation of biologically important habitats in offshore waters of the Norton Basin (after Starr *et al.* 1981; Ljungblad *et al.* 1983; Miller 1983).

5.6.2 St. Lawrence Island Area

Spring

Marine mammals migrate northward past St. Lawrence Island prior to crossing the Chirikov Basin. The vicinity of the island is a feeding area for murres and auklets.

Summer

Waters near the western end of the island are a feeding area for birds from seabird colonies on St. Lawrence Island. Minke and killer whales and harbor porpoises feed around St. Lawrence Island during the open-water season. Waters near the east and west ends of the island are a feeding area for gray whales.

Fall

Marine mammals migrate southward past the island on their way to winter habitats farther south.

Winter

Waters around the island are an important overwintering area for oldsquaws and eiders. Belukha and bowhead whales and walruses may overwinter near the island, particularly to the southwest. Locations of overwintering areas of the various species are annually variable depending on the distribution of sea ice.

5.6.3 West-Central Norton Sound

In addition to a high biomass of fishes and invertebrates in west-central Norton Sound, highest concentrations of red king crab occur here year round.

5.6.4 Coastal Waters of Norton Sound

The coastal waters of Norton Sound are a residence area for belukha whales feeding on spring herring runs and remaining in coastal waters through the open-water season. It is a feeding area also for murre and kittiwake colonies between Sledge Island and Golovnin Bay. In winter it is a breeding and pupping area (March–April) for ringed seals on shorefast ice. Greater detail about the importance of these coastal waters can be found in Section 4.6.

5.7 POTENTIAL IMPACTS OF OIL AND GAS DEVELOPMENT

This section analyzes the potential impacts of petroleum development on biota in the offshore zone of the Norton Basin. The analysis is based mainly on consensus of individuals at the Norton Basin Synthesis Meeting. In cases where information presented at the meeting was incomplete, interpretations about impacts are based also on proceedings of the Barrow Arch Synthesis Meeting (Truett 1984), which dealt with effects of OCS activities on most of the same species but in greater detail.

The format for evaluating potential impacts is the same as that used in Section 4.7. The vulnerability and sensitivity of each species or species group to several classes of industrial activities are rated on a low-moderate-high scale. This scale is qualitative only, useful mainly for comparing relative susceptibilities to impact among activity types and among species and species groups. The ratings do not equate with the categories (nil, low, moderate, high) developed by the Minerals Management Service to describe impact levels (see Section 4.7.1).

Table 5.4 depicts vulnerability and sensitivity ratings developed for major vertebrate groups and food web components in the offshore ecosystem. As noted in Section 4.7.2, if either vulnerability or sensitivity of an organism to an activity is rated as low, then the general susceptibility of the populations of the organism to adverse impact is considered low. Only when both vulnerability and sensitivity are medium or high is the organism's population expected to be threatened to any extent by the activities depicted.

Using this basis for predicting potential adverse impact, a scrutiny of Table 5.4 shows that large oil spills are probably the only consequence of OCS development that may have major impacts on populations in the offshore ecosystem. Most organisms have low vulnerability, low sensitivity, or both, to activities other than large oil spills. Exceptions to this may be related to the effects of seismic testing and vessel traffic on gray whales or to the effects of aircraft traffic on seabirds. The sensitivities of these animals to these activities are not well documented.

The ratings in Table 5.4 suggest that some of the marine mammals (walrus, gray whale, and perhaps bearded seal) and the seabirds are the only animals judged to be at major risk from large oil spills. Walruses are vulnerable only in spring, when females and young are highly aggregated. Gray whales are vulnerable more or less throughout summer. Of the seabirds, murres, auklets, and puffins are probably the most vulnerable to oil spills at sea; behavioral characteristics of shearwaters and kittiwakes probably make them less vulnerable. Detailed reviews of the potential effects of oil in marine waters on these mammals and birds may be found in Davis and Thomson (1984) and Roseneau and Herter (1984).

5.8 SUMMARY

The offshore ecosystem, defined to extend seaward beyond the 10-m depth contour, is important habitat for marine mammals, seabirds, marine fishes, and prey of these animals.

Seven mammal species are common in the offshore environment: ringed seal, bearded seal, walrus, polar bear, belukha whale, gray whale, and bowhead whale. Somewhat less common are ribbon seal, spotted seal, Steller's sea lion, and minke, killer, humpback, fin, and sei whales.

Ringed seals, bearded seals, and polar bears are mainly winter residents, though migrants of both seal species move through in spring and fall. Most individuals of these species move out as the ice ablates. Ringed seals feed mainly on fish and crustaceans, bearded seals on infauna and epifauna, and polar bears on ringed seals and to some extent on bearded seals and other mammals. The polar bear is perhaps the most sensitive of these to oil and other consequences of OCS development, because of the adverse effects it suffers from being oiled and the potential for bears to be killed by people near sites of human activity.

Walruses, belukhas, and bowhead whales use the Norton Basin offshore environment primarily as a spring and fall migratory pathway between winter ranges farther south and summer ranges farther north, though some individual walruses and belukhas are present in both winter and summer. Each of these species has a different feeding mode: the walrus consumes mainly infauna, the belukha eats fish, and the bowhead normally feeds on zooplankton (though limited evidence suggests that benthic ampeliscid amphipods could be important to bowheads in the Norton Basin). None of these species is known to be particularly sensitive to oil or to other consequences of OCS development, though much concern has been raised about potential adverse consequences of oil and noise to bowheads.

The main summer marine mammal resident of the Norton Basin offshore zone is the gray whale. It forages mainly in the Chirikov Basin and St. Lawrence Island areas, consuming mostly ampeliscid amphipods that it scoops up from the sea floor. It is hypothesized to be potentially sensitive to activities that disrupt, or prevent whale access to, areas where these amphipods are especially abundant. Less common summer residents which are mostly at the northern periphery of their ranges in the Norton Basin are ribbon seal, Steller's sea lion, and minke, killer, humpback, fin, and sei whales.

During the open-water season, the offshore zone is feeding habitat for several million seabirds. The most numerous, in approximate order of abundance, are least auklet, crested auklet, short-tailed shearwater, thick-billed murre, common murre, parakeet auklet, black-legged kittiwake, tufted puffin, and horned puffin. All except shearwaters breed on coastal cliffs of the Norton Basin area.

In spring some of these seabirds, particularly the auklets, begin occupying areas in the ice pack as soon as the ice begins to melt. During summer many species feed throughout the Chirikov Basin and off St. Lawrence Island; few use Norton Sound except off the south side of the Seward Peninsula near Bluff. As summer progresses, some (*e.g.*, murres) leave natal cliffs and move farther to sea in the Chirikov Basin.

Several seabird species—the auklets, short-tailed shearwater, thick-billed murre—feed to a large extent on pelagic zooplankton and concentrate mostly

TABLE 5.4—Vulnerabilities and sensitivities of vertebrates and food web components in the offshore zone of the Norton Basin to activities potentially associated with OCS oil and gas development. Ratings were developed primarily by group consensus during the Norton Basin Synthesis Meeting augmented by data from Truett (1984) (l = low, m = moderate, h = high).

		OCS ACTIVITIES							
Biological Population		Large Oil Spill	Small Pollutant Release	Chronic Operational Discharge	Seismic Testing	Vessel Traffic	Aircraft Traffic	Offshore Drilling	Dredging & Pipeline Construction
Walrus	v[1]	h[3]	l	l	l	l	l	l	l
	s[2]	h	h	l	l	(?)	l	(?)	(?)
Bearded Seal	v	m(?)	l	l	l	l	l	l	l
	s	m(?)	m(?)	l	(?)	(?)	l	(?)	(?)
Ringed Seal	v	l	l	l	l	l	l	l	l
	s	l	l	l	(?)	(?)	l	(?)	(?)
Polar Bear	v	l	l	l	l	l	l	l	l
	s	h	h	l	l	(?)	l	l	(?)
Gray Whale	v	h	l	l	m	m	l	l	l
	s	h(?)	l	l	(?)	(?)	l	(?)	(?)
Beluga Whale	v	m	l	l	l	l	l	l	l
	s	m	m	l	(?)	(?)	l	(?)	(?)
Bowhead Whale	v	m-h[4]	l	l	l	l	l	l	l
	s	(?)	(?)	l	(?)	(?)	l	(?)	(?)
Seabirds[5]	v	h	l	l	l	m	m	l	l
	s	h	h	(?)[7]	l	l	(?)	l	l
Marine Fishes	v	l	l	l	l	l	l	l	l
	s	m[6]	m[6]	(?)[7]	l	l	l	l	l
King, Tanner Crabs	v	l	l	l	l	l	l	l	l
	s	l	l	l	l	l	l	l	l
Zooplankton	v	l	l	l	l	l	l	l	l
	s	m-h	m-h	(?)[7]	l	l	l	l	l
Epibenthic Crustacea	v	l	l	l	l	l	l	l	l
	s	h	h	(?)[7]	l	l	l	m	m
Infauna	v	l	l	l	l	l	l	l	l
	s	l-m	l-m	(?)[7]	l	l	l	h	h
Starfish	v	l	l	l	l	l	l	l	l
	s	m	m	(?)[7]	l	l	l	m	m

[1] Population vulnerability. Mainly a function of population distribution patterns.
[2] Sensitivity - susceptibility of individual organism to adverse effect from contact with activity.
[3] Vulnerability high in spring only, low in fall and winter.
[4] Vulnerability medium-high in spring only, low in fall.
[5] Includes murres, auklets, shearwaters, kittiwakes, and puffins. Ratings may vary slightly among species.
[6] Sensitivity medium in larval fishes only, low in adults.
[7] Sensitivity may vary depending on nature of discharge.

in areas where water circulation and upwelling patterns promote zooplankton abundance (*e.g.*, Bering Strait, near St. Lawrence Island, in the Chirikov Basin). Others—common murre, the puffins, pelagic cormorant—are mainly fish-eaters; these are more widely distributed but tend to be less abundant.

Most seabirds are highly sensitive to oil in their foraging habitats, because they feed by diving. Those that are heavily concentrated at feeding sites—auklets, short-tailed shearwater, horned puffin—are also highly vulnerable as populations to the effects of local perturbations such as major oil spills.

The offshore fish community has a much lower biomass than do offshore fish communities farther south in the Bering Sea; it is dominated by demersal or semidemersal species. Saffron cod and probably Arctic cod are the biomass dominants of this demersal community. The major foods of the cods are epibenthic crustaceans and (to some extent for Arctic cod) zooplankton. The less common demersal species—starry flounder, shorthorn sculpin, plaice, yellowfin sole—also eat benthic invertebrates, including molluscs, brittle stars, amphipods, and some fishes. The greatest biomasses of demersal fishes per unit area have been reported where bottom water temperatures in summer exceed about 40°C and are shallower than about 30 m (*e.g.*, central and western Norton Sound, but not eastern Norton Sound, which is too cold, or the central Chirikov Basin, which is too deep). These demersal fishes would probably suffer less in the event of an oil spill than would pelagic or coastal species, because these relatively deeper benthic environments would probably receive low levels of contamination.

Pelagic fishes common in the offshore environment include salmon (five species), herring, and smelts. Many of the salmon that inhabit the Norton Basin are probably migrants—juveniles on their way from natal streams to deep ocean rearing environments or adults on their way back to natal streams to spawn. Migratory pathways followed depend to some extent on the species and stocks. Herring and rainbow smelt are dispersed throughout offshore waters; no particular areas of concentration have been noted. The susceptibility of these pelagic fishes to adverse effects from oil spills (or other disturbances) is thought to be low because the individuals are widespread and are generally the older juveniles and adults, which are less sensitive to perturbations than are eggs and young juveniles.

In contrast to the fishes, invertebrates in the Norton Basin are abundant; the highest concentrations of benthic infauna in the Bering Sea occur in the Chirikov Basin. Possible reasons for the comparatively large standing stocks are that the Norton Basin may have less predation pressure from fishes and mammals and/or a greater influx of nutrients to benthic environments than other areas have. The epibenthic invertebrate community is dominated by echinoderms, particularly starfish. Red and blue king crabs are the only invertebrates of significant commercial or subsistence importance at present. Red king crab are concentrated in a relatively small area south and east of Sledge Island near Nome; blue king crab occur mostly in southwestern parts of the Norton Basin. The benthic invertebrate species are mostly widespread and, because they occur at depth, are not likely to receive high levels of contamination from pollutants. Thus they are relatively invulnerable to the effects of OCS development.

Less is known about zooplankton than is known about the benthos. Zooplankton productivity appears to be lower in eastern Norton Sound than it is elsewhere. Concentrations of plankton-feeding seabirds in the western parts of the Norton Basin suggest that, at least locally, relatively high biomasses of zooplankton must be present. Because of the rapid turnover and widespread distributions of most zooplankton species, the effects of oil spills and other perturbations are expected to insignificant.

The food webs of the offshore ecosystem appear to be fueled almost entirely by *in-situ* phytoplankton production. The western parts of the Norton Basin, which have greater nutrient inputs and less water-column stability than Norton Sound, exhibit a heightened secondary productivity in the water column, as would be expected. But in most areas the consumers supported by the benthic food chain seem to have a larger biomass than those supported by the pelagic food chain. Presumably a relatively large proportion of the water-column productivity settles as detritus to the benthic community.

Important offshore habitats in the Norton Basin are concentrated mostly in the St. Lawrence Island–Chirikov Basin–Bering Strait region. This is partly a function of the location of this area in the migratory pathways of many of the marine mammals, partly a consequence of relatively warm bottom-water temperatures, and partly a consequence of the inherently greater productivity caused by regional physical processes.

The major potential OCS activity of concern offshore is a major oil spill. The biota most susceptible to adverse impacts from OCS development (*i.e.*, oil spills) in the offshore zone are those that have highly clumped populations and individuals that are highly sensitive to expected perturbations. Seabirds are, by these measures, by far the most likely to be adversely affected. Some marine mammals (*i.e.*, gray and bowhead whales) are thought by some researchers to be relatively vulnerable, but existing data do not suggest them to be nearly as vulnerable as birds.

Fish and invertebrate populations appear relatively secure from significant impact.

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6

Socioeconomic and Resource Use Considerations

by Lynn Robbins and Steve McNabb

With major contributions from Michael J. MacFayden and Marsha Bennett-Walter

Oil and gas leasing in the Norton Basin OCS Planning Area is expected to affect the social and economic conditions of local residents, and perhaps alter their use of subsistence resources. This chapter evaluates existing socioeconomic and subsistence use patterns in villages of the Norton Basin region (Fig. 6.1) and discusses the potential effects of OCS development activities on these patterns.

Four aspects of socioeconomics and resource uses are considered. Section 6.1 outlines the basic features of domestic and institutional life in the Norton Basin region, and establishes a descriptive baseline for the social systems in the area. Section 6.2 reviews and summarizes recent analyses of these systems and identifies major social and subsistence trends and plausible response patterns. Section 6.3 addresses the question of OCS activities as motive forces for economic change in the Norton Basin. Section 6.4 discusses the potential results of OCS-related impacts to subsistence and sociocultural organizations.

6.1 REGIONAL DESCRIPTION

6.1.1 Economic Structures

Economies in the Norton Basin region are undeveloped by national standards, showing a low rate of capital investment in economically productive private and public enterprises. Subsistence remains crucial to the economic welfare of most residents. The indigenous cash economic base is narrow. Exports are based on natural resources and there is little value added by local labor. Federal and state government expenditures are the main source of personal income. Per capita incomes and consumer purchasing power are low, and the scope of locally provided goods and services is also very limited. Cash employment is seasonal and erratic. Resident unemployment is generally high, partly due to the low level of overall economic activity and partly due to a poor match between the occupational skills of residents and the skill requirements of available job openings.

A comparison of the Nome and Wade Hampton labor areas reveals significant differences in economic organization between these two regions as they face the advent of OCS development. Referring to Figure 6.1, the Nome labor area encompasses Gambell, Savoonga, and the communities to the north and east of Norton Sound. The Wade Hampton labor area includes Kotlik and the other communities to the south of Norton Sound. The functions and roles of governmental and nongovernmental institutions vary widely. For example, the Nome labor area has a strong services and trade sector but little basic private employment and comparatively little government employment. In contrast, the Wade Hampton area depends heavily on government employment funded through transfers. Although self-employment in commercial fisheries is a major source of personal income throughout the Wade Hampton area, neither region has a major export industry.

Total Wade Hampton employment increased about 113% between 1970 and 1980, though population rose only 19%. Government employment grew by 325% over this decade, compared to an increase of only 19% for nongovernment employment. Although trade employment increased by 92% between 1970 and 1980, service employment declined by 48%. By 1980 government employment and transfer payments together accounted for about 83% of all personal income in the Wade Hampton labor area. Direct

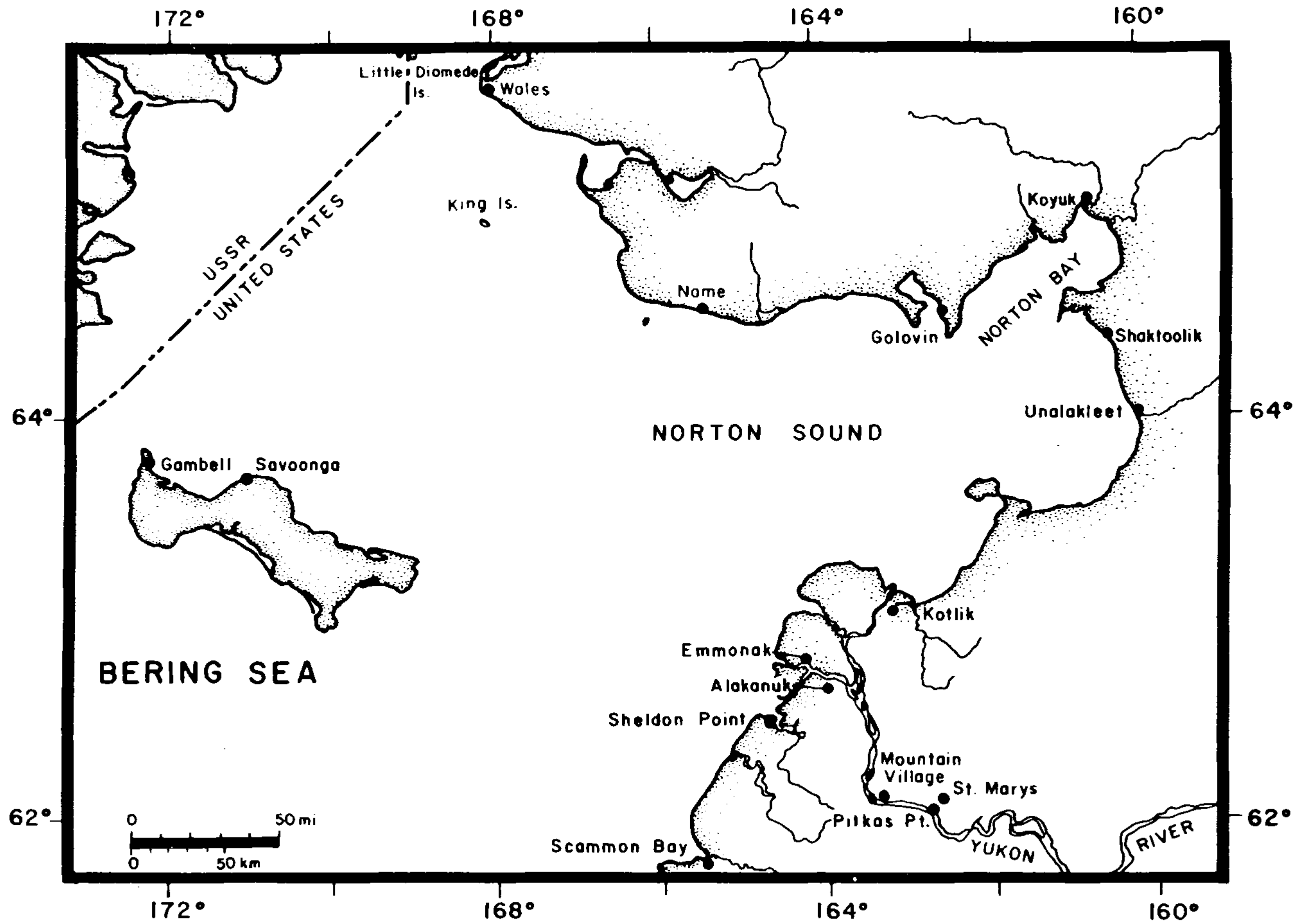

FIGURE 6.1—Communities in the vicinity of the Norton Basin OCS Planning Area, Alaska.

transfer payments alone accounted for 31% of all personal income in 1980, up from 21.3% in 1970 (John Muir Institute 1984).

Employment in the Nome labor area grew by about 134% between 1970 and 1980, while population increased by only about 14%. Government employment increased by only 57% over this decade, compared to an increase of 230% for nongovernment employment. Nome area service industries were by far the fastest growing sector (posting an increase of 595%), followed by trade (117%) and state and local government (57%). By 1980, government employment and transfer payments together accounted for about 54% of all personal income in the Nome labor area. Transfer payment contributions to personal income were stable at 19.3% in 1980, compared to 19% in 1970. The regional center, Nome, dominates the economy of this region (in contrast to the Wade Hampton area, which lacks a regional hub). The relatively robust private sector, centered in Nome, accounted for 57.6% of all personal incomes in 1980, up from 41.6% in 1970 (John Muir Institute 1984).

6.1.2 Subsistence Patterns

Yukon River Delta

Villages located north of the rich herring spawning grounds in the Yukon-Kuskokwim area rely mainly on salmon. Scammon Bay, on the border of these spawning grounds, relies heavily on birds, seals, and herring during spring. Families from Scammon Bay relocate in early June to conduct commercial and subsistence salmon fishing on the Black River (Fienup-Riordan 1981). Families from Emmonak, Alakanuk, and Sheldon Point commonly fish the Black River before the salmon season for nonsalmon species such as sheefish and the whitefishes. Delta residents more often disperse for salmon harvests along the main Yukon tributaries, north of the Black River, when the Scammon Bay summer salmon fishermen move there (Wolfe 1981).

Major passes into the Yukon mouth, such as Kwikluak and Kwiguk, serve as seasonal camp and fishing sites for many Emmonak and Alakanuk households during the intensive summer salmon fishery (Wolfe 1981). Salmon are harvested commercially or for subsistence purposes from early June through September. Wolfe (1981: 67) found that "for most households (in the delta), salmon represented the largest single source of food and income. . . . The economic solvency of Kwikpagmiut households usually pivoted upon the success of salmon fishing." Seals and belukhas may be taken during summer but these are usually incidental to salmon harvest activities.

Waterfowl and vegetable harvesting increases in early fall as the salmon harvest diminishes. Fall seal and belukha hunting or fall fisheries (primarily whitefish) replace late summer activities before freeze-up. Fall fisheries often concentrate families near their villages, but whitefish and sheefish harvesting draws Alakanuk and Emmonak families far to the south toward Scammon Bay and the Black River. Pike harvesting occurs near the Black River or at inland locales near Mountain Village (Wolfe 1981).

In Wolfe's household sample, which includes Emmonak and Alakanuk, "commercial salmon income represented the largest and most consistent source of money . . . commercial salmon earnings comprised 45.8% of their annual monetary income, or $8,026 per household" (Wolfe 1981:92). Although dependencies on cash introduce both demands and insecurities for local families, the search for cash shapes the seasonal round for all. Nonetheless, traditional resource harvests continue to disperse families and harvesting units throughout the delta area since subsistence remains a lynchpin for overall economic adjustment.

In the face of high local costs for food and goods and limited assets, the wisest economic course for families who can afford to do so is to make substantial cash and labor investments in subsistence (Wolfe 1981). However, since many incomes are unpredictable or erratic, families with limited cash may lose potential benefits if they cannot invest at a particular time. For example, price increases for gasoline restrict the mobility of poorer families and inhibit subsistence pursuits in which they otherwise would engage (Wolfe 1981).

Cooperation is essential for adjustments to seasonal, regional, and large-scale economic variations. The domestic network provides the structure and values for this cooperation. Cooperation may be exemplified in the household by activities that are allocated by sex, age, or production and exchange relations among families. Network members assist one another directly in such tasks as fish harvests and indirectly when some members secure wages and others fish and hunt. Differentiated subsistence activities are exemplified by the tendency of older men to surpass the younger in all but salmon and sea mammal harvests, possibly as the result of age cycle trends and different harvest costs (Wolfe 1981).

Additional information on subsistence patterns in the Yukon River delta is available in Fienup-Riordan (1981, 1983), Frank Orth and Associates (1983), John Muir Institute (1984), Lonner (1980), Wolfe (1979, 1981, 1982), Wolfe and Ellanna (1983), and Woodward-Clyde (1984).

Norton Sound–Seward Peninsula

The Norton Sound region has been a nexus of continuing major relocations among the Yupik and Inupiat populations since before the turn of the century. During the nineteenth century, substantial movements of Inupiat from the north (Malimiut from the Kotzebue Sound area) and the east (peninsular Kauwerak) moved into areas previously inhabited by Unalit-speaking Yupik people. Current kinship, settlement, and exchange relations in the area testify to these events, and quadralingual speakers (Malimiut, Unalit, Kauwerak, and English) are present in some communities (Ray 1964, 1975).

Access to fish is easier and abundance of local harvests is greater in eastern Norton Sound than to the west. Fish resources represent a key economic lynchpin for each of the Norton Bay communities both as a crucial food source and as a cash-generating resource that helps to sustain the communities over the balance of the year. Although occurring later than in the Yukon delta, salmon and herring runs occur earlier in Norton Bay than in the remainder of the Norton Basin (Ellanna 1980). The commercial importance of fish resources is tremendous on a local scale, as in Golovin for example, even though in a larger perspective it might appear marginal.

Fish, and to a lesser extent small sea mammals, are primary food resources throughout Norton Sound. After winter sets in, nonmarine subsistence pursuits gain substantial importance. Caribou hunting becomes important in eastern Norton Sound in the winter and continues into spring and early summer, when sea mammal hunting and fishing resumes. Unalakleet and Shaktoolik hunters share the same general area and sometimes travel and hunt together (Thomas 1981). The communities around Golovnin Bay have less ready access to caribou but do obtain some caribou through both harvest and exchange. Nome caribou hunters occasionally hunt in the vicinity of Unalakleet and Shaktoolik (Thomas 1981). Thus, distance may not pose an insurmountable obstacle to harvests in Norton Sound if financial and capital resources are sufficient and if there is willingness to bear the costs.

Salmon is the most important subsistence resource in Norton Sound as a whole (Ellanna 1980), accounting for nearly 40% of the diet in all communities. Sea mammals, especially bearded seals, account for about 20% of the diet (Ellanna 1980). The remainder of the diet consists of various fish, fowl, and mammal species. Consumption of the various species varies seasonally, from year to year, and on the basis of individual and family preferences and harvest strategies.

Fundamental social organization and institutions operate here in much the same way as elsewhere in the Norton Basin. Although domestic and extended family and indigenous sociopolitical forms vary, underlying similarities in form and function prevail. For instance, variations in the structure of social organizations, due in part to historical migrations, are evident in certain locales (*e.g.*, Stebbins and St. Michael) and are visible in different historical or contemporary kinship, socialization, and residence patterns (Ellanna 1980).

Additional details about subsistence patterns in the Norton Sound–Seward Peninsula area may be found in Ellanna (1980), Ender *et al.* (1980), John Muir Institute (1984), Jorgensen *et al.* (1984), Lonner (1980), Magdanz (1981, 1983), Magdanz *et al.* (1981), Sherrod (1982), Thomas (1980, 1982), and Wolfe and Ellanna (1983).

St. Lawrence Island

Life on St. Lawrence Island revolves around marine resources and the ethics of sharing tied to this dependence. More than 80% of all food consumed annually comes from the sea. Specialized technical items and skills, social organization, underlying values, and aspirations all contribute to continuance of the subsistence way of life (Little and Robbins 1984).

Nearly three-fourths of the people leave their villages in summer and early fall to fish, hunt seals, and collect sea plants, invertebrates, and land plants. These forays are economically essential aspects of the yearly round of subsistence activities, and they afford opportunities to visit friends, neighbors, and relatives outside the routines of village life. The Gambell people use the section of island from Taphook Point in the north to Koozata Lagoon in the south, and the Savoonga people use the balance of the island. About 325 Gambell and 420 Savoonga people (about 80% of the island population) camped in 1982. Gambell campers were organized into 54 groups (mainly nuclear families) and Savoonga campers into 67 groups (Little and Robbins 1984).

In 1982 on St. Lawrence Island more than 300 people organized into 79 units (41 from Gambell and 38 from Savoonga) hunted walrus. Bowhead whales were pursued by 218 hunters in 32 crews (22 from Gambell and 10 from Savoonga). Savoonga hunters expected to form two additional whale-hunting crews in the spring of 1983. These data reveal that most of the adult males engage in these subsistence activities, and there is no evidence of declining interest or participation (Little and Robbins 1984).

Nearly 1,200 walruses were taken in 1982. Gambell hunters had a good year (more than 900 animals taken), but because of a persistent buildup of pressure ice Savoonga hunters took only about 300, one of the worst years in their history. Walrus provide more food than any other single resource. Most of the walrus is eaten—muscle meat, liver, intestines, skin, some of the blubber, and the stomach and its contents (clams primarily). The parts are shared among crew members and their kin, friends, and unrelated neighbors, and also with elders and widows and with women and children that have no hunters in their households. Each hunter gives walrus products to an average of 10 households each year, and his household receives similar subsistence goods from four others. The network of the distribution of walrus products extends to many residents of Nome, Anchorage, and some other communities in Alaska as well as a few in the lower 48 states.

The spring whale hunt—brief, dramatic, exhilarating—brings joy and community solidarity unlike any other activity on the island. Each community receives about one-half of each whale taken by the other community. Whale meat moves through the villages and into Nome and other mainland communities, as do the products from walruses. Maktak (skin and blubber) is often eaten on birthdays, holidays, homecomings, and other special occasions. Its use in these circumstances reinforces Eskimo diet and, more importantly, the special character of Eskimo culture. It is the symbolic and ritual idiom of Eskimo life, and special efforts are made to distribute it to as many kinsmen as possible (Little and Robbins 1984).

Each resource is associated with a specific form of social organization for its collection, distribution, and use. Occasionally, unrelated people join together, but they do so when there are no close male kinsmen available to form a crew. Most whale and walrus hunting crews are recruited from patrilineal clans, made up of several families related through the male line who jointly conduct certain important subsistence functions such as hunting, butchering animals, storage, and distribution of subsistence goods. The clans also form the basis for bearded seal hunting crews and summer camps, where fishing and collecting and hunting of smaller seals occur. They are also the foundation for bird and bird egg harvests. Many clans have families in both Gambell and Savoonga, and this bonds the villages in social systems of mutual aid and common purpose in subsistence activities (Little and Robbins 1984).

A 1982 survey of approximately 40% of the Gambell hunters reported a harvest of 554 ringed seals, 459 spotted seals, 324 bearded seals, and 19 ribbon seals the previous year. Overall the village probably takes about two and one-half times this number of seals. The bearded seal is probably the most important of the four species of seal because of its size and the many uses the people make of its flesh and hide. These animals were taken either by crews organized much like walrus-hunting crews or by lone hunters. Seals are a vital part of the island economy and are shared in about the same way as are walruses (Little and Robbins 1984).

Fish are essential to the St. Lawrence Island diet in both summer and winter. Thousands of sculpins, tomcod, and blue cod are taken in winter and the salmon group, Dolly Varden, grayling, and whitefish mostly in summer. Nearly all families use hundreds of birds and bird eggs each year. The major species used include auklets, ducks and geese, gulls, and kittiwakes, among others. Murre, goose, and duck eggs are collected in large numbers. Each Gambell family annually takes about 30 pounds of clams from beaches or from the stomachs of walruses. The people of Gambell and Savoonga use at least 12 species of marine plants and 24 species of land plants. These important food sources yield about 170 pounds of sea plants and 120 pounds of land plants each year per family. These foods are nutritionally and culturally vital to Eskimo diet, and their use frequently underscores celebrations and homecomings (Little and Robbins 1984).

Most of the households in both communities are occupied by nuclear families (parents or surrogate parents and offspring or surrogate offspring). There are some extended families (parents and married offspring with children), some grandparent-grandchild households, some sibling households (brothers or sisters or a combination of the two), and single person households. Many households have adopted children, often grandchildren raised by their grandparents, and there are households that have several people related to the household head such as brothers, nephews, and cousins. The households never stand alone economically. Each is wedded to many others through the complex networks of subsistence activities and crafts production. These networks span not only households but also villages (Little and Robbins 1984).

6.2 BACKGROUND: ECONOMIC AND SOCIAL RESPONSE TO CHANGE

This section identifies several socioeconomic factors that have been uncovered in recent research that illustrate how economic and subsistence patterns can interrelate. Interpretations of basic trends in the areas of subsistence, technology, and domestic mobility and household composition are provided first in order to illustrate current patterns of response to change. These factors and trends may represent the patterns that will be followed in responding to future changes. The final subsections of this section summarize four recent harvest-disruption analyses. Two of the analyses assess low-moderate disruption scenarios, and two evaluate catastrophic scenarios.

6.2.1 Current Trends and Patterns

Research in the Norton Basin region shows that investments of labor and cash in subsistence are high and generally are more productive and efficient than alternate investments or purchases. Wolfe's research in the Yukon delta reveals that family subsistence investments often exceed 30% of family income (Wolfe 1979). He calculated an average overall cost of subsistence foods of about 30 cents per dressed pound, lower than nearly any purchased substitute available locally. This average is derived from a wide range of figures that varies by family and subsistence species. Many extraction costs vary by 1,000%, and differences among families often exceed 100%. These wide variations in unit costs reflect differences in competence, investment, and capital maintenance strategies, and in systematic sharing and redistribution practices. For instance, sharing of capital for such purchases as sleds and snow machines might reduce investment in harvests, thus reducing unit costs. Sharing of harvests might inflate unit costs for those giving the most.

Drawing support from Wolfe, Thomas (1982) found that higher investments seem to mean higher yields in the Shaktoolik case. Fienup-Riordan (1983) found parallel evidence in other parts of the Yukon delta and along the Bering Sea coast. She concluded that access to cash may enhance rather than detract from subsistence endeavors. Poorer families may become more dependent on transfer incomes but may still be able to participate in subsistence activities if they rely on species with lower effective unit costs.

Relying in part on earlier research (Hughes 1960; Bogojavlensky 1969), Ellanna (1980) concluded that the products of wage labor do not normally flow through traditional distribution networks in the Bering Sea area. Fienup-Riordan (1981) found, as have study team members in other parts of the state, that capital (but seldom cash) is widely shared through channels that function like traditional channels. Cash purchases are indeed one step removed from the cash itself, but this pattern of capital exchange and sharing is a persistent practice thoroughly grounded in tradition.

Ellanna (1983), in a study of ecology, population structure, and subsistence in Bering Strait island communities and at Wales, reached a number of conclusions about insular populations that hunt large sea mammals. She found in these communities a high ratio of males to females, high birth rates, an ecological base that may support both productive and dependent members, and high proportions of young to middle-aged males who exploit the greatest number of ecological niches. These conclusions reveal the importance of demographic characteristics and their potential relationship to volume and diversity of harvests. Ellanna (1983) argued that large populations with high ratios of able-bodied males were a prerequisite for specializing in hunting large marine mammals. Her evidence supports this contention. This population ratio may also benefit communities not specializing in the hunting of large sea mammals. For instance, a high ratio of young, able-bodied men and women might be essential to most demographic growth and economic adaptations. These traits seem to underlie many hunting and fishing adaptations throughout Alaska, and study team members witnessed this in areas with large land mammal and fishing emphasis in Unalakleet and in the NANA region. This population structure might also be a prerequisite for wage labor specializations.

The role of inflation in domestic economies is uncertain. Ellanna (1980: 31) reports that "inflation in the cash economy in the study area will increase the economic disparity between the 'haves' and the 'have nots'." In another OCS study, Porter (1980: 39) noted, "What is less commonly realized than the high level of Alaskan prices is their tendency to increase at a rate less than those of the United States." If both statements are valid, inflation may be less important than high prices, differential access to cash in various communities, and purchasing habits that distinguish the wealthy from the poor.

The following three sections contain descriptions and observations about three major topics of Norton Sound life: subsistence, technology, and mobility and household composition. General research findings and conclusions based on numerous studies concerning the subtleties, complexities, and flexibility of Eskimo responses to change in these areas are conveyed.

Subsistence

Subsistence hinges on a diverse range of species and products. In the face of increasing costs and impacts or disruptions in the system, it is possible that an optimization principle will encourage efficiency at the expense of diversity. Many subsistence products are very expensive, even if they are prized. These products may become more scarce, and available more often through luck or temporary financial good fortune. Or, these items may be accessible only for personal consumption and not for distribution and gifts. Less expensive items might become more commonly exchanged and thus attain a symbolic value that allows people to save money but still share (*cf.*, Fienup-Riordan 1983). In such cases the communities with the most conspicuous income differentials might become those most apt to harvest diverse resources.

In the event of changes in the distributions or numbers of individuals in species, the subsistence response would probably not match the scale of impact. The response might entail a "normal" harvest but at higher costs (since people might spend more time or travel farther afield), or a reduced harvest with proportionally lower costs. An optimization perspective (*i.e.*, a maximization of gain with minimization of risk and cost) could apply and a resolution pertinent to specific conditions would be achieved. These responses would vary dramatically within the Norton Basin since resource distributions and levels of reliance are not uniform. In the Yukon delta area, a decrease in numbers of salmon or moose would probably result in longer harvest periods and harvests close or equal to pre-impact levels. On the other hand, decreases in the numbers of bearded seal might discourage inland hunters from venturing to the coast at all, and decreases in the numbers of walrus or spotted seal might result in temporary harvest cessation (Fienup-Riordan 1983). Disruptions of these latter marine species at St. Lawrence Island probably would entail greater efforts to secure pre-impact harvest levels of these resources.

Domestic diets in Norton Basin communities are changing rapidly, primarily due to the influx and increased use of imported foods. Subsistence diets change from year to year within certain limits since availability and abundance of natural resources shift. As early as 1958, nutrition studies found that subsistence intakes were declining in some areas (Heller and Scott 1967). More recent studies (Knapp 1978) have suggested that diets of some persons in some villages are inadequate due to decreased protein intake and increases in the proportion of dense carbohydrates. Changes over this 20-year period point to specific increases in vitamins A and C, calcium, and carbohydrates, and decreases in thiamin, riboflavin, niacin, iron, calories, fat, and protein. Iron and calcium deficiencies may, however, be endemic to the Norton Basin region.

Young mothers, and women in general, followed by youngsters and elders, seem to be most likely to have dietary deficiencies but most of the population appears to be within acceptable nutritional limits. Accessibility of Western foods and the influences of school lunch programs seem helpful only for calcium supplements (Knapp 1978). The impact of Western foods is likely to increase in the future due to advertising and increased availability. Many youngsters, perhaps half the population of some villages, eat their primary meal of the day in the school cafeteria.

Unless food consumption habits change, these factors could diminish the positive nutritional effects of a subsistence diet, notwithstanding its cultural value to old and young alike.

Social, cultural, and economic identity in Eskimo society revolves around the same activities, and traditionally valued acts define people's identity. Events which alter subsistence harvests would directly affect social roles and elements of identity that hinge on those harvests. Women tend to carry out certain functions, men others, and youngsters and elders still other tasks which involve either actual harvests or preparation and distribution of harvest commodities. Discrete impacts on certain species or at certain seasons may "disenfranchise" certain population segments more than others. This could increase competition in the work force and in the sphere of traditional activities that by custom were not performed (Fienup-Riordan 1983). Stress could result if work force competition results in diminished opportunity, but such a situation may homogenize the work force and, therefore, memberships in traditional activities. This could lead to greater community-level adaptability and flexibility in responding to change.

Today, there is no long-term subsistence surplus; excess simply is shared and large excesses imply broader and more extensive sharing. In the event of harvest reductions, exchange networks would draw in on themselves. Though excess might become seen as a surplus that could be converted to cash or future gain, this is unlikely since it is so contrary to Eskimo values. Gifts do not imply a debt. However, subsistence foods sometimes are sold today, and such a pattern may become more common if the perceived value of subsistence foods increases. When subsistence foods are sold, the costs are often below the harvest cost. Salmon, for example, are frequently sold by commercial fishermen at rates below the market. It is also possible that communal or cooperative use of subsistence equipment (boats, reloaders, snowmachines, etc.), which has traditionally occurred between structured partnerships or kinship groups, would become in essence a form of exchange. Such capital exchanges do occur elsewhere among Eskimo groups (*e.g.*, in northwest Alaska) and represent short-term partnerships that entail the equal distribution of the harvest. In summary, pressures on domestic economic strategies might encourage changes to the pattern of exchange (Fienup-Riordan 1983). Eskimo society appears to contain traditional mechanisms for dealing with such changes.

Eskimo culture differs from Western models in that Eskimo people tend not to sell or commoditize their labor for the highest profit, nor do they accrue assets for potential gains in the distant future, nor compartmentalize their social and economic roles (*e.g.*, as "homemaker" and "father" as opposed to "professional" or "entrepreneur"). However, they exercise great caution in cost-benefit analysis and seek to optimize their domestic conditions in balance with many noneconomic practices and values. Optimization leads to patterns of seasonal mobility and may lead to relocation and altered economic strategies, as noted above. Optimization, however, does present the Eskimo people with serious conflicts that may increase in importance if economic opportunities change.

Unproductive or prolonged subsistence activities, especially in summer, increase the need for cash. This greater need may coincide with diminished access to cash if wage opportunities are bypassed in order to hunt and fish. Subsistence capitalization requirements are not constant and tend to demand uneven and sometimes abrupt needs for cash. If these needs cannot be satisfied, subsistence activities may be curtailed. This curtailment drains available cash since substitutes must be sought and the likelihood of subsistence recovery becomes dimmer in the short run. Poorer families may be less able to engage in subsistence and thus be more reliant on substitutes or may be able to capitalize only less expensive activities. Natural conditions may change, making certain species less accessible, which in turn makes them more expensive and potentially less attractive to pursue.

Technology

Some of the most obvious double binds are evident in the area of technology. Eskimo people have traditionally been quick to grasp and use new technology, but optimization has always underlain these decisions. New forms of technology (especially sophisticated utilities) may be abandoned if local people must support costly maintenance and operation with diminishing revenues. Many newer forms of technology represent only incremental increases in efficiency at very high costs. If these forms of technology are nonetheless necessary, a great conflict will arise from the optimization perspective.

Snow machines, for instance, have been in use for about 15 years. Newer models, however, are only marginally "better" now than they were some years ago. However, because they are not likely to be abandoned, it is possible that their incremental cost increases will not be matched by equivalent increases in value. A dangerous downward spiral of higher costs for less and less value is already on the horizon. With limited options and little opportunity to recycle parts and maintain machines in harsh environments, technological binds like this are apt to increase.

Mobility and Household Composition

Current village compositions will not change greatly if current services in villages remain accessible and necessary, local institutions continue to fulfill their roles, subsistence resources are distributed as they are today, harvest pressures and competition do not greatly exceed current levels, natural habitat conditions remain as they are, and, finally, cash opportunities do not greatly diminish or improve. These conditions, however, are subject to great change due to chance, legislative or administrative action, and economic and population trends. If any or several of these factors change, changes in domestic mobility and household structure are likely. There could be an increase in nuclear family households, less interhousehold interaction, increased mobility to sea ice and employment centers, and more frequent trips to and from fishing, hunting, and collecting sites, depending on the specific character and magnitude of change.

6.2.2 Potential Consequences of Subsistence Disruption

Economic Effects of Low- to Medium-Level Resource Disruptions: Yukon Delta

A recent study (Frank Orth and Associates 1983) sponsored by Nunam Kitlutsisti and the Alaska Department of Community and Regional Affairs sought to describe the potential economic impacts of major oil accidents on the Yukon delta. This study sought to assess the value of subsistence goods through the calculation of replacement costs of estimated subsistence harvests. Once such calculations were completed, the authors then evaluated the impact of designated reductions in subsistence harvests in terms of their dollar values.

Based on data contained in secondary literature (Wolfe 1981; Fienup-Riordan 1983) and field investigations, the authors attempted to arrive at adjusted harvest volume estimates in several species categories. After performing many other calculations of estimated life of capital goods, replacement costs of subsistence technology, local commodity costs, and a variety of wage and transfer income inputs to the domestic economy, the authors determined replacement costs for households and villages of all subsistence species. The adjusted harvest estimates (in dressed pounds) per household and replacement costs (at $4.73/lb) per household and per village are listed in Table 6.1.

The cash replacement values were then compared with other sources of regional cash income, combined with projected commercial fisheries incomes, and the resulting proportions of cash-value income by source were used to calculate how regional income dependencies would shift if subsistence harvests were reduced. The authors assumed 5%, 10%, and 50% subsistence harvest reductions (aggregated across all species) and projected dollar-equivalent losses to the study area of $520,758 in the 5% scenario, $1,041,515 in the 10% scenario, and $5,207,575 in the 50% scenario over a one-year period. Since subsistence activities depend on regular sources of cash for capital purchases and maintenance, reductions in the subsistence harvest may be exacerbated by increased dependence on, but limited access to, sources of cash income. Thus, if subsistence reductions are matched by increasing dependence on other sources of income, that dependence, if unsatisfied, may further hamper subsistence efforts.

Impacts to species may result in numerous subsistence responses which vary on the basis of localized environmental conditions and individual circumstances. The vast range of potential responses can be illustrated by assessing only two variables: capital limitations and time limitations. Subsistence users with high capital limitations but few time limitations might be inclined to engage in labor-intensive harvests that require only very limited capital expenditures. For instance, such a user might simply spend more

TABLE 6.1—Resource harvests and replacement costs of harvested resources in Yukon delta villages.

Village	Resource Harvest (pounds)	Replacement Cost per Household (dollars)	Replacement Cost per Village (dollars)
St. Marys	3,168	14,985	959,017
Pitkas Point	3,236	15,306	336,738
Mountain Village	2,840	13,433	1,182,121
Emmonak	2,122	10,037	1,073,965
Alakanuk	2,870	13,575	1,248,909
Kotlik	3,278	15,505	806,257
Sheldon Point	5,168	24,443	415,530
Total	22,682		6,022,539

SOURCE: Braund, in Frank Orth and Associates (1983).

time in order to harvest an acceptable volume of the affected species. Users with high capital and high time limitations might harvest a lower-than-average volume of the affected species, or might choose to divert both time and capital to other harvests altogether (thereby terminating harvests of affected species). Users with high time limitations but low capital limitations might opt for a capital-intensive strategy, such as more mobile pursuit or interception techniques, capitalization of team harvests geared toward the same or other species, or capitalization of higher-cost but high-gain harvests of entirely different species.

These few examples illustrate the potential range of responses, but ignore important considerations such as weather and environmental conditions, individual diet habits, and sociocultural values associated with particular harvest activities. Typical responses can result in either high or low harvest levels of affected species, termination of harvests for affected species, and diversion of time and capital to other species harvests. It is impossible to predict, however, which response type will be dominant.

Effects on Resource Harvests of Low- to Moderate-Level Resource Disruptions: Yukon Delta

The following discussion details plausible subsistence impacts on the Yukon delta based on a recent study (Woodward-Clyde 1984) of the potential impacts of a moderate oil spill in Norton Sound. This study in one sense underestimates the likely impacts since it introduces quantitative estimates of species disruption for salmon alone, which are assumed to suffer a direct 3.5% mortality (55,000 fish). Other effects are generally ranked (*e.g.*, impacts on herring and waterfowl are said to be "high"). Results of this study are summarized below. Land mammals and vegetable products in any location would be little affected and are by and large dismissed from the analysis.

The areas and periods of greatest sensitivity to an oil spill are probably nearshore subtidal and intertidal areas in late spring and early summer and intertidal and estuarine areas in summer, fall, and winter. The presence of waterfowl alone in late spring and fall in the intertidal and estuary-river mouth locations makes these sites of considerable concern. Though waterfowl represent only a small proportion of the subsistence harvest, their subjective value is high. Reliance on herring at Scammon Bay in late spring and early summer also draws attention to the subtidal and intertidal locales. Although the offshore and subtidal areas are important in both spring and fall for sea mammals (and their harvest), these species are perhaps less susceptible than waterfowl to potential spills since they may be more likely to avoid contamination. Periods of greatest oil spill cleanup difficulty (freeze-up and breakup) are also those times people are least likely to be hunting these species. However, because of their importance to subsistence users, these species might suffer impacts that are psychologically more stressful to the users than are impacts to other species.

Because fish species (1) are relatively vulnerable, (2) are necessary for subsistence in all areas and in all seasons, and (3) comprise critical alternates to other species if a spill should occur, they figure prominently in this analysis. Herring, for example, are most important in the southwestern section of the delta and to a lesser extent in the northeast. If only this resource were affected by a spill incident, the main impact would be on Scammon Bay residents. Because herring are a basic resource here, and because they can be harvested with a relatively low cost per unit (Fienup-Riordan [1983] calculated costs of close to $0.10 per pound), use of substitutes could be a significant burden on the human population. Salmon also can be harvested at moderate costs per unit and are important resources in all communities. They would be particularly susceptible to damage during several periods of the year and during more than one life cycle stage. Whitefish and sheefish are important in fall and winter in most areas and are also traditional backups that are harvested intensively when summer harvests are insufficient (Wolfe 1981; Fienup-Riordan 1983).

In summary, critical primary resources with very high subjective values are at risk in late spring and summer (waterfowl, sea mammals, herring, salmon); a mix of critical resources that often have high subjective values are at risk in fall (waterfowl, sea mammals, some salmon, whitefish, sheefish); and critical backup species are at risk in fall and winter (whitefish, sheefish).

Table 6.2 depicts proportions of subsistence harvests by village in major resource categories for two different years. Data for 1981 reflect a selected sample of highly productive harvesters, whereas the 1983 data represent a broader range of harvesters.

Most of these subsistence harvesters take large numbers of salmon and other fishes (primarily whitefish, sheefish, burbot, pike, blackfish). However, the experts (first column) may harvest fewer "other" fish. Harvests of sea mammals, land mammals, and fowl are important but secondary to fish species. Both sets of data show a similar pattern for land mammal and fowl harvests, whereas the experts obviously harvest more sea mammals relative to their overall harvest.

Scammon Bay and Sheldon Point may be more at risk for subsistence impacts than are other communities because (1) they have relatively large proportions of fish in harvests, (2) they are off the main channels and thus have less flexibility in intercepting migrating salmon, and (3) they are near the coast and thus are

TABLE 6.2—Percentages of various resource categories in subsistence harvests at selected Yukon delta villages.

	Salmon		Other Fishes		Sea Mammals		Land Mammals		Fowl	
Village	1981	1983	1981	1983	1981	1983	1981	1983	1981	1983
Alakanuk	27	24	38	50	18	4	10	13	7	8
Emmonak	37	—	33	—	15	—	9	—	5	—
Sheldon Point	48	50	30	36	15	3	5	4	3	6
Scammon Bay	—	42	—	36	—	9	—	5	—	7
Kotlik	28	—	30	—	21	—	14	—	8	—
Mountain Village	31	—	48	—	3	—	16	—	2	—

SOURCE: Wolfe 1981; Fienup-Riordan 1983.

relatively susceptible to oil spill impacts. On a village-by-village basis, relative vulnerabilities of subsistence harvests to oil spill impact, and factors determining the vulnerability rating, are as follows:

Sheldon Point and Scammon Bay (highest vulnerability): These villages (1) have high proportions of fish in their harvests and (2) are less able to exercise flexibility in intercepting salmon, and thus possibly are more subject to impacts of localized spills. Scammon Bay fisheries, for instance, harvest salmon mainly at Black River. Further, Scammon Bay relies on herring, which could sustain greater impacts than those noted for salmon. However, salmon losses would have less influence on cash income in these communities because commercial fishing is less important than in other Yukon delta communities.

Emmonak, Alakanuk, and Kotlik (medium vulnerability): These villages (1) require more cash to engage in a more mobile interception of salmon so harvest levels would reflect changes in cash income; (2) are more active in expensive sea mammal harvests; and (3) are more subject to secondary impacts on sea mammal harvests, including reductions of sea mammals in the immediate area due to their greater sensitivity to human impacts (*e.g.*, clean-up operations) or to reductions in their foods (fish). These vulnerabilities to impact could be offset by the ability of the villages to (1) divert more cash into lower-cost-per-unit harvest activities and reduce expensive activities, and (2) divert cash into more mobile pursuits away from the contamination zone.

St. Marys, Mountain Village, and Pitkas Point (low vulnerability): These communities are least susceptible to impacts since they engage in fewer high-cost-per-unit harvests, use more of the low-cost-per-unit backup fish species that are probably not subject to impact this far upstream, and do not need to exercise interception techniques (*i.e.*, salmon that are not harvested downriver will eventually be accessible to these communities).

Minor losses to low-cost-per-unit species that are relatively abundant (fish) are likely to result in minor or negligible reductions in harvests. When harvest impacts occur, they can be compensated for by increased harvests of low-cost-per-unit species at other times of the year. For instance, a salmon loss might be balanced by more intensive whitefish, sheefish, burbot, blackfish, and pike harvests in fall and winter. Minor impacts to some species could result in abandonment of all or most harvests, especially if the species do not have high subjective values or are expensive to procure. Fienup-Riordan (1983) noted that impacts to spotted seals could result in no hunting of them at all since few are harvested anyway and other sea mammals are more highly valued.

People might feel the effects of subsistence losses in several ways. The poor would be more profoundly affected. They might rely more heavily on low-cost-per-unit foods, for which there might be more competition. They might have less access to gifts of higher-cost-per-unit foods if such foods are in short supply. Richer residents might have to spend more to harvest the same quantities of foods and thus might have fewer remaining assets for subsequent pursuits or be less able to share capital equipment with others. Having less cash could make people far less able to harvest high-cost-per-unit foods, which could influence regionwide sharing patterns of scarce goods. Direct competition among individuals for lower-cost-per-unit foods could introduce social problems with friends and kin.

If response options focus on harvests of lower-cost-per-unit foods, harvest pressures could influence subsistence patterns if affected residents range beyond their traditional hunting and fishing grounds. For example, coastal residents might use inland sites known for their fall and winter fishing more than would normally be the case; since these sites may also be used by upriver residents, these upriver residents may experience impacts due to increased hunting pressure even if they are not directly affected by a spill.

In the event of serious subsistence disruptions, other responses are plausible. Due to reductions in resources, people might use cash for store purchases rather than for subsistence capitalization, with resulting financial deficits. Families and individuals may consolidate their households to reduce high fixed costs. People may migrate to escape localized impacts or to seek cash opportunities, or combine these strategies by consolidating households in other Yukon delta villages. Thus affected communities may not experience a net population decline, since relatives in nearby and equally affected villages may relocate to another delta village, not to escape the habitat impact but to consolidate households and save money. Changes in exchange patterns, traditional roles, and socialization of subsistence skills may rapidly accelerate.

Effects of High-Level Resource Disruptions: Unalakleet

High-level resource disruption in the Unalakleet area could cause serious problems (Jorgensen *et al.* 1984). Disruptions to four dominant staples and to secondary food sources during each season for a year would cause severe and protracted consequences to the village population, its institutions, its solvency, its neighboring villages, and the regional corporations. Large federal transfers would be required. Substantial outmigration would occur. Other impacts specified for medium-level disruptions such as rapid depletion of stored food, the pursuit of less abundant and less preferred resources, less safety and efficiency in harvesting and resulting higher costs, the purchase of substitutes and consequent capital drain, the exhaustion of lines of credit, the implementation or advocacy of emergency programs and relief projects, increasing pressure on redistribution and exchange channels, and consolidation of households would all likely occur.

Effects of High-Level Resource Disruptions: St. Lawrence Island

Serious disruptions to four key subsistence resources of St. Lawrence Island communities could cause the following sequence of events (Little and Robbins 1984):

1) Crews of hunters and collectors and patricians would draw down stored foods and would soon exhaust these reserves (frozen fish, walrus and seal meat, and birds). Alternative naturally occurring species would be sought to compensate for affected food sources.

2) Without a steady supply of some naturally occurring food sources, families, households, patricians, friendships, and intervillage cooperative networks would share whatever resources could be obtained until the variety and abundance of diverse resources were restored. The severity of the shortages would depend on the magnitude of impacts, which are presently unpredictable.

If resource depletion persisted, many aspects of the unique cultural characteristics of the Yupik speakers of the island would be lost. The numerous social interrelations and subsistence cooperative networks for all subsistence activities would be eliminated. The social system and its manifold ethics of sharing, mutual concern, community solidarity, and pride in self-sufficiency, physical prowess, training in subsistence pursuits for youngsters, and the quest for cash largely based on cottage industries, would be removed from daily life.

6.3 POTENTIAL ECONOMIC IMPACT OF OCS DEVELOPMENT

This section discusses several plausible avenues of OCS development influences on the regional economy and identifies the most likely economic impacts. Impacts are described qualitatively rather than quantitatively. Information from this and earlier chapters is synthesized to describe plausible consequences of OCS-related impacts in terms of vulnerabilities and sensitivities of human subsistence and sociocultural systems.

6.3.1 Employment

The main potential for direct economic interaction between OCS development and the community and regional economies in the Norton Basin area might be through resident participation in the OCS work force. Of the Norton Basin communities, only Nome seems able to assume some limited support functions for the offshore industry.

Since most job openings would likely be away from settlements, intraregional transportation services would affect the access of interested residents to OCS employment opportunities. If Nome were to be the dispatch point to offshore work sites, then the quality of air service between Nome and the various communities would become critical. Unalakleet is the only study community with mainline jet service to Nome. The others are served by small aircraft only. Approximate air distances to Nome for a selection of communities are: Golovin—75 miles, Emmonak—120 miles, Alakanuk—130 miles, Unalakleet—150 miles, and Savoonga—135 miles. At present levels of service and cost, transportation barriers may inhibit the ability of residents in outlying communities to work regularly on a rotating shift basis at OCS employment.

All of the study communities have a relatively large pool of unemployed adults in the prime working ages who are potential candidates for employment in OCS industries. Table 6.3 lists a sample of these communities. Official unemployment rates throughout the region are high, but by report of the Alaska Department of Labor the official rates seriously understate

TABLE 6.3—Potential OCS work force in selected communities in the Norton Basin area.

Community	Potential Work Force[1]
Alakanuk	146
Emmonak	196
Golovin	31
Nome	965[2]
Savoonga	195
Unalakleet	241

SOURCE: U.S. Census 1980.
[1] Defined as total population between 20 and 44 years of age.
[2] Due to undercounting on the 1980 census, this figure is probably too low.

effective unemployment rates for a number of technical reasons. Job skills and work experience of the resident work force might not be well matched to the job requirements of the OCS industry, and if so, this would impair the short-term employability of the resident labor force. Job training programs could help overcome these handicaps.

Some sketchy data suggest that household and work force mobility are generally low, which might inhibit resident participation in the OCS job market. According to 1980 census data, the percentages of residents then 5 years or older who lived in the same census division as in 1975 were: Nome—71%, Unalakleet—83%, Savoonga—91%, Emmonak—91%, Golovin—96%, and Alakanuk—97%. These data indicate that resident populations are relatively stable, especially in the more remote communities. Perhaps this indicates a reluctance in many households to relocate just for better access to employment opportunities.

Demographic data that illustrate return migration suggest that relocation is often temporary (John Muir Institute 1984). Unemployment and underemployment are chronic in most regional communities. Section 6.1.1 summarized Norton Basin economic trends and showed that employment growth over the last decade outstripped population growth by a factor of about 10. However, substantial growth in the Nome labor area trade and service sectors was concentrated in the city of Nome. Nonetheless, the stability of village populations suggests that village residents may not respond quickly nor proportionally to increases in employment opportunities in even a fairly accessible regional center.

6.3.2 Economic Opportunity

The resident economy can provide or perform three general functions for the offshore industry: upland facility sites, commercial and industrial goods and services, and labor services. (Section 6.3.1 discussed labor services.) With the exception of the southwestern coast of the Seward Peninsula and St. Lawrence Island, the Norton Basin region is not a likely candidate to provide sites for onshore industrial facilities. Thus, with those exceptions, provision of industrial facility sites and related construction activities would probably have little economic impact on the region. Provision of commercial and industrial goods and services in support of offshore development would depend on what the communities in the region can offer and under what conditions demand for these goods and services might arise. Only the economic structure of the Nome area has strong trade and service sectors. Local goods and services of importance to the offshore industries would likely be quite limited. The Wade Hampton regional economy is very weak in trade and services and, as noted earlier, the Yukon delta communities are poorly located for providing any kind of support for offshore operations.

Logistical arrangements and construction of onshore facilities and operations would determine the level of demand for local goods and services. The transportation system for offshore personnel to and from the offshore work stations would likely require a combined jetport/heliport facility within flying range of offshore work sites. Nome is the only locality with aviation and related support facilities for transients needed during the exploration phase. Similarly, Nome is a likely transit station for air shipment of light industrial goods, perishables, and other supplies to offshore platforms. Because of limitations on natural harbor and port facilities, no community in the region is equipped to serve as a marine support base to receive, warehouse, and dispatch bulk supplies such as fuels and lubricants, drillpipe and other drilling supplies, drillwater and potable water, etc., to platform sites. The region will not be attractive to oil service industries until it has a medium-draft port facility.

6.3.3 Inflation

Local inflation is often an unwelcome companion of rapid economic growth and increases in income. The communities of the region seem prone to rapid inflation caused by OCS development. These communities have few enterprises and entrepreneurs, a narrow range of locally available goods and services, and long, unreliable supply lines. Such essentials as housing stock and public facilities are in short supply and expensive to expand. Capital is scarce, and entrepreneurs are slow to react to uncertain new opportunities. Under these conditions any sudden infusion of new purchasing power could cause inflation. A lag between supply and demand would be likely.

In small, emerging market economies, a sustained rise in consumer purchasing power and demand can eventually stimulate economies of scale, promote new business formation, help upgrade the assortment of locally provided goods and services, and raise the general level of economic well-being. Even where such a local inflationary cycle proves beneficial to many short-term local residents, persons and households with fixed incomes or at the fringe of the cash economy are hit hardest—typically the elderly, the unemployed, and those dependent on income assistance. On the other hand, merchants, property owners, and those who supply goods and services in high demand and short supply may fare well economically during periods of demand-driven inflation, as may chain operations and regional banks.

6.3.4 Norton Basin Path Model

Figure 6.2 represents the socioeconomic-sociocultural path model developed for the Norton Basin. The subsystems in the model are identified with abbreviated labels that correspond to the variable names. The variables are described on the left below, and the subsystem labels representing these variables in the model graphics are listed on the right.

VARIABLES	SUBSYSTEM LABELS
Exogenous Subsystems:	
Employment	EMPLOYMENT
Economic Opportunity	ECONOMY
Inflation	INFLATION
Independent Subsystems:	
Sex ratio	sex ratio
Dependency ratio	dependency
Income stability and predictability	income stability
Age of household head	age
Dependent Subsystems:	
Village size	village size
Single person households, percent of total	single
Institutional coordination and cooperation	institutions
Household size	household size
Sodality memberships	sodalities
Income and labor strategies	income strategies
Proportion of harvested protein in diet	protein
Diversity of subsistence harvests	harvests
Subsistence harvest expenses	expenses
Household income	income
Political participation	political roles

This path model uses beta weights (standardized regression coefficients) to represent the strength of causal relations found between variables in a recent socioeconomic study of Norton Sound (John Muir Institute 1984). The solid lines represent patterns of effects postulated between these subsystems. The dotted lines represent direct influences from the three key independent variables. This model has not been validated and should be interpreted as a provisional explanation.

We have argued that the most likely economic impact of OCS development would be on local labor participation. Although other modes of economic intervention (such as OCS-induced inflation, provision of shoreside facilities, expansion of services sectors) are possible, they do not seem very likely. Even direct labor participation is apt to be marginal because of the poor fit between necessary job skills in exploration, development, and production tasks and local job skills and background. In addition, local workers may hesitate to take jobs that they associate with development activities that are perceived to be disruptive to local habitats or that demand seasonal or temporary relocation.

The path model evaluates the economic variables and proposes that the main and immediate effects of increased labor participation would be on community dependency ratios, village size, and income stability and predictability (bottom of Fig. 6.2). All things being equal (*i.e.*, holding all other socioeconomic trends static), such an increase in employment would depress dependency ratios (*i.e.*, the population would "age" demographically through in-migration of mature adults seeking employment), elevate village (population) size for the same reason, and enhance the predictability, and possibly the stability, of personal incomes. These effects would then percolate through the path system, influencing a variety of other socioeconomic subsystems. These effects could play upon one another in numerous ways. For instance, the immediate effect of reduction of the dependency ratio would be to increase village size, as the path to village size from the dependency subsystem shows. (This path has a weight of −0.54, thus a decrease in the dependency ratio entails an increase in village size.) This influence is complemented by the direct effects on village size itself, a feature that makes the increase in village size a significant and very likely result of this OCS impact. Other results could follow in a similar fashion.

In summary, the logic of the path model suggests that increases in employment levels as a result of OCS activity would cause or coincide with the following subsidiary changes: an increase in village size; a decrease in the dependency ratio; an increase in the predictability, and possibly the stability, of income; an increase in coordination and decrease in cooperation between local institutions; an increase in the percentage of single person households; a possible decrease in household sizes; an increase in the number of sodality memberships in households; a modest increase in household income; an increase in the number of political roles in households; and ambiguous

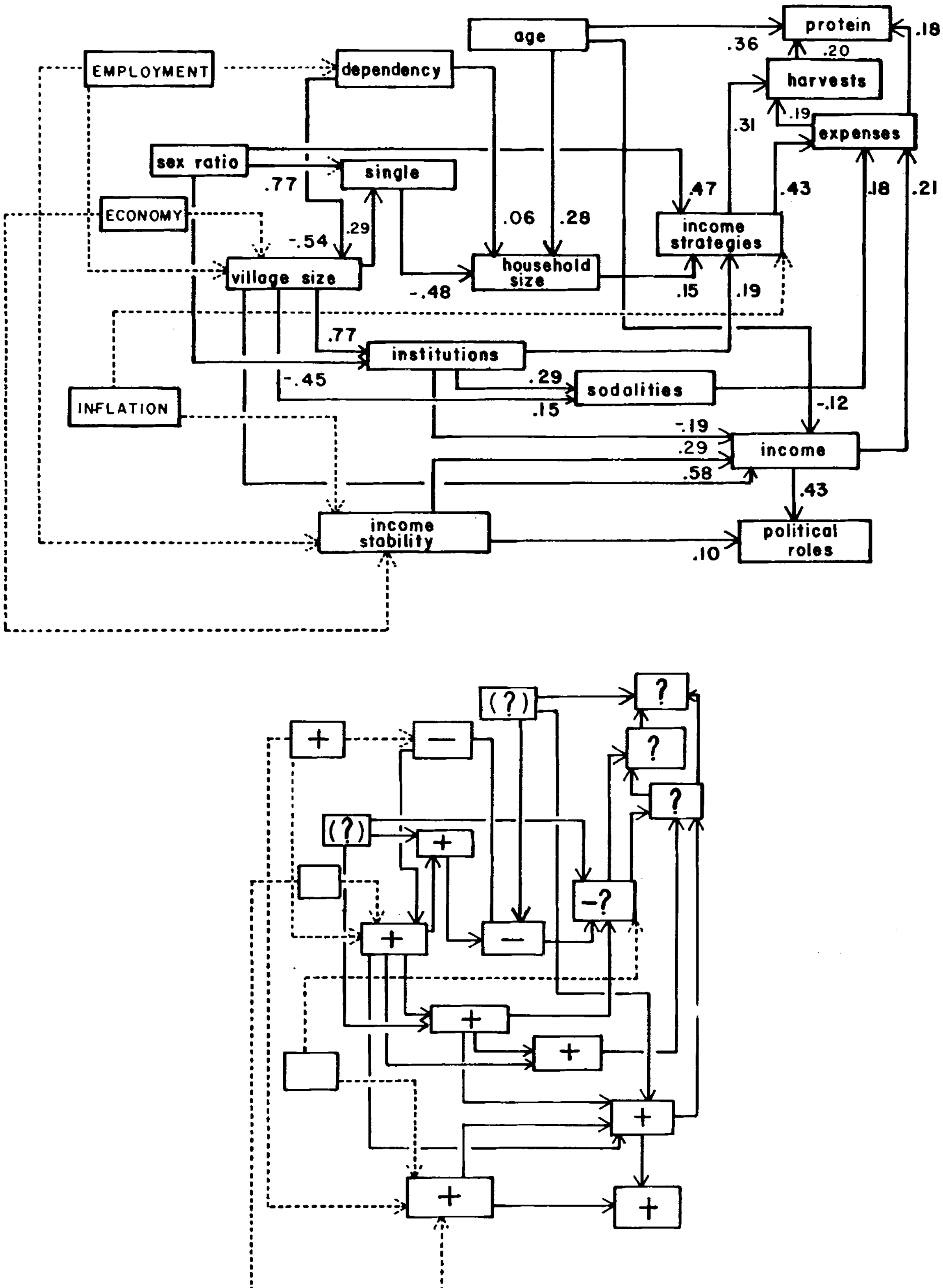

FIGURE 6.2—Norton Basin socioeconomic-sociocultural path model.

changes to income and labor strategies, subsistence expenses, ranges of harvests, and levels of subsistence protein in diets. The influences of the age and sex ratio subsystems are logically independent of probable OCS effects, but exert very strong and important influences on other key subsystems. Both the sex ratio and age of household heads yield independent effects in this path system that may act to strongly complement, counteract, or hold static several of the important influences on the subsistence subsystems. Thus, changes to subsistence are much harder to anticipate than are the other institutional and domestic subsystem changes that are already designated.

Changes to subsystems generated by local employment participation may create impacts in three categories: sociocultural systems; subsistence patterns; and state, regional, or community economics. If the assumption of low employment participation is valid, impact susceptibility is likely to be low in these categories. If this assumption is invalid, and high levels of employment participation are likely, then more substantial changes in several subsystems would reveal medium impact susceptibilities in all three categories listed above. The changes would be caused by differential intraregional migration and by pressures on local infrastructures, on subsistence resources, and on the institutions that relate to them. If the changes are substantial enough to significantly influence all subsystems, thus causing important changes in economic well-being, community and regional economic impact susceptibilities could be high.

Specific economic issues raised at the Norton Basin Synthesis Meeting cannot be fully assessed but deserve comment since highly specific changes might have unique and significant results. Job training, recruitment, and placement programs could mitigate the employment obstacles noted earlier. If oil industries undertake such programs, the programs would, if successful, displace existing programs for employment training and placement that are operated within existing institutions. The circumstances would establish high impact susceptibilities for sociocultural systems. If such programs are instead coordinated through existing institutions, the programs would, if successful, require changes in local and regional government policies and plans, and would influence economic wellbeing, yielding medium to high impact susceptibilities.

6.4 POTENTIAL SUBSISTENCE AND SOCIOCULTURAL IMPACT OF OCS DEVELOPMENT

The biological and habitat assessments that precede this chapter address regional and population-wide risks. Human uses of these habitats and species, however, are localized. Key subsistence sites or zones tend to comprise dense, overlapping distributions of several species. Altering these distributions or densities may result in subsistence impacts that are more serious than are population-level species impacts. Access to resources is also conditioned by technological, social, and economic factors that are independent of resource distributions. Hence, resource presence is not equivalent to resourceavailability.

The following discussions outline localized sociocultural and subsistence vulnerabilities. Impacts are summarized at the close of the section. It should be noted at the outset that harvest fluctuations are common, and that impacts similar to to those evaluated here have occurred in the past and will undoubtedly occur in the future independently of OCS intervention. It must be emphasized that no conclusive predictions about OCS-related risks and impacts can be made at this time.

6.4.1 Yukon River Delta

Based on volume of harvests and diversity of uses as well as biological sensitivity, the major use areas at risk are:

1) Cape Romanzof to Scammon Bay
2) Yukon delta coastline from the Black River mouth to Pastol Bay
3) Pastol Bay to Point Romanof

Although these areas represent a nearly unbroken stretch of coastline in and near the Yukon delta, different subsistence strategies and resource concentrations justify this arrangement. Subsistence impacts in any area would affect users in all areas, though unequally, because exchange networks crosscut these areas. For instance, Scammon Bay fishermen transport herring to the north and Pastol Bay hunters move belukha to the south. Impacts on exchanged commodities may potentially influence users at each exchange node.

In terms of sensitivity, birds and fish are the subsistence resource classes most at risk (see Section 4.7). Virtually all of the shorebird and waterfowl species common to Norton Sound are abundant in these areas, nearly all are used as secondary food resources, and most have a moderate to high or very high sensitivity to disturbance. The key subsistence fish species are salmon, herring, (Scammon Bay), whitefish, Bering cisco, and sheefish. Arctic char, sculpin, smelt, burbot, grayling, tomcod, pike, halibut, and blackfish are important secondary resources at some times and for certain population segments. Salmon and herring are primary resources; the rest are secondary, but they may become primary if salmon and herring are disrupted. These resources have a moderate sensitivity to oil spills, and the salmon may be subject to harvest pressures which entail high risk. The two primary resources are also commercially harvested. Mammals are subject to lower risk, and other high-risk classes (such as invertebrates) are rarely used.

Risks to subsistence patterns entail risks to sociocultural organizations (U.S. Department of the Interior 1985). Many indigenous sociocultural organizations revolve around subsistence harvests. Harvest teams, networks of kindred and friends with whom resources are exchanged, and ceremonial and ideological dimensions of resource consumption are based on access to and use of these resources. Since the overall diversity of species harvested in the delta may be lower than that in the remainder of the Norton Basin, delta areas may be subject to somewhat higher risks to both subsistence species access and sociocultural organizations.

Analyses of oil spill dispersion patterns suggest that the probabilities of oil reaching habitats within the delta (see Section 2.2) are relatively remote. Probabilities of oil reaching the offshore delta area are comparatively high during the 3-day interval following a spill, in which spilled oil will have weathered very little (see Section 1.3.1). The number, diversity, and sensitivities of birds using the delta and adjacent waters create notable and unique vulnerabilities to this subsistence resource.

6.4.2 Norton Bay–Seward Peninsula

The major use areas at risk in the eastern Norton Sound, Norton Bay, and southern Seward Peninsula region are:

1) Diomede Island
2) Cape Prince of Wales–Lopp Lagoon
3) Sledge Island and King Island
4) Brevig Lagoon–Grantley Harbor–Port Clarence
5) Woolley Lagoon
6) Safety Sound
7) Bluff Cliffs
8) Golovnin Bay
9) Moses Point
10) Koyuk River mouth–northeast Norton Bay
11) Cape Denbigh
12) Egavik Creek–Unalakleet River mouths
13) Cape Stephens–Stuart Island

Numerous prehistoric, historic, and contemporary village sites at or near these locations provide evidence of their longstanding harvest potentials. Although the residents in the southernmost area are Yupik speakers, they are best classed with the other Norton Sound Inupiat due to their institutional ties in this area.

Subsistence harvest diversity is probably higher here than in the Yukon delta because of more diverse and often larger harvests of marine mammals and large land mammals. Invertebrate harvests are also larger in these locales. Since mammals are generally less susceptible to impacts than fish and birds and since invertebrates are low-volume secondary food resources, fish and birds are again the key risk categories despite the high impact susceptibility associated with invertebrates. Salmon, herring, and whitefish are the fish species most at risk. Salmon species are primary resources and herring, although more widely available than in the delta, are most likely a secondary subsistence resource (as are whitefish and sheefish in some locations). This generalization does not overlook the fact that herring are critical resources in some locations. Arctic char, sculpin, smelt, burbot, grayling, tomcod, pike, and halibut are also important resources at some times and for certain population segments. Seabirds are important in this area, mainly to the west, and other birds are both less diverse and less abundant than in the Yukon delta. The fish and birds noted have moderate to very high sensitivities to direct oil disturbance (see Section 4.7). Two varieties of king crab and Tanner crab also are harvested commercially, as are salmon and herring; we suggest that these species are subject to moderate to high sport or commercial harvest pressures.

Fishing dominates a subsistence economy that is combined with coastal and inland hunting from Stuart Island to about Safety Sound. The commercial fishery is robust here, though not as strong as in the Yukon delta region. These fishery-based activities gradually blend with increasingly strong emphasis on small (and at King and Diomede islands and Wales, large) sea mammals. In the large sea mammal hunting communities (King and Diomede islands and Wales), sea mammals become important primary resources. Walruses are most important in terms of both dietary significance and cash potential. Birds are important but secondary resources throughout the area. Despite the increasing reliance on sea mammals in the western reaches, fish are important resources everywhere. Oil spill analyses suggest that the area west of about Golovnin Bay is more at risk for direct oil disturbance than are areas farther east. Since Nome is also apt to be the locus of many noise, traffic, and human disturbances, this western zone is probably more at risk than is the eastern zone, even though fish are more dominant resources in the east.

Impact susceptibilities of sociocultural organizations are similar to those described for the Yukon delta (U.S. Department of the Interior 1985). Although resource diversity may mitigate potential subsistence and sociocultural impacts, the placement of Nome in this region expands the range of potential disturbances. The middle portion of the region may have a high relative probability of oil contact in the 30-day scenario (see Section 1.3.1). Thus, though eastern Norton Bay is vulnerable, it appears relatively immune to direct disturbance in these scenarios. However, the transportation and institutional infrastructure at Unalakleet could attract some shore-based support services or traffic which could introduce indirect disturbances in eastern locales.

6.4.3 St. Lawrence Island

Based on diversity of subsistence use and volume of harvests, as well as biological sensitivity, the key risk areas are:

1) Koozata Lagoon
2) Meruwtu Point
3) Powooliak Bay
4) Niyrakpak Lagoon
5) Kitnepaluk locale
6) Eewak Point
7) Kialegak Point
8) Ataakas Camp
9) Alngeeyak locale
10) Camp Kalowiye

Since Gambell and Savoonga residents engage in exchange and mutual assistance networks that are at least as dense and consistent as those between any two communities in the Norton Basin, if not more so, impacts on any species important to subsistence would affect residents in both villages in a similar manner.

The subsistence species classes most at risk by virtue of dietary and cash significance as well as sensitivity are sea mammals and birds. At certain times of the year, however, numerous fishes, invertebrates, and land mammals are critical for many people. The dietary volume and cash significance of sea mammals (especially walrus), the cultural importance of the bowhead, and the biological sensitivities of seabirds, though, are indisputable. Spotted and ringed seal meat and oil are eaten almost daily by most residents. The dietary significance of walrus is even more important, and earned income from ivory carving represents an important source of cash. Walrus hides provide crucial materials for clothing and boat construction, as do nonfood products from other species. Bowhead hunting carries idiomatic cultural meanings that are central to St. Lawrence Yupik belief systems. Although seabirds represent secondary resources in terms of dietary volume, their nutritional contribution is important and their impact susceptibilities are high.

As a rule, harvest diversity is somewhat lower here than in central Norton Sound but greater than in the Yukon delta area. The mitigative potential of diverse harvest alternatives is somewhat counteracted by the relatively high disturbance potential at or near St. Lawrence Island. Walruses may have a high sensitivity to oil spills during only a single season, but primary walrus foods are consistently sensitive (though not likely to be drastically depleted). Bowhead whales have a low to moderate sensitivity to oil spills, but are currently subject to high harvest pressures. Other marine mammals have lower sensitivity ratings. All local seabirds have high sensitivities to pollutants and moderate vulnerabilities to traffic disturbances.

Virtually all local sociocultural organizations, including formal and nonformal exchange and mutual assistance networks, patriclans, and clan-segments, operate so as to produce, distribute, or consume renewable resources. Although these are not their exclusive functions, they are primary ones. Formal institutions of governance and leadership are directly influenced by patriclan systems, hence impacts to subsistence species have the potential to influence numerous sociocultural organizations. In the event of serious impacts to subsistence species, local sociocultural organizational functions could be displaced by outside formal institutions if local, alternative economic options are not available. Because St. Lawrence Island is geographically remote and the local economy so narrow, few local mitigative options are available.

6.5 SUMMARY

People living in the Norton Basin area acquire a large portion of their food and cash income from mammals, fish, and, to some extent, birds, harvested for subsistence. The Yukon delta residents rely largely on salmon and other anadromous fishes, and secondarily on marine fishes and mammals. Communities elsewhere at the perimeter of Norton Sound and the Seward Peninsula harvest a broad array of species—fish and shellfish, seals and other sea mammals, caribou, birds—but salmon is still probably overall the key subsistence item. St. Lawrence Islanders depend on marine mammals (walrus; ringed, spotted, and bearded seals; bowhead whale), secondarily on marine and anadromous fishes, and also on birds. Harvesting activities are essential elements of the social and cultural lives of these people.

Recent socioeconomic studies suggest that direct economic impacts of OCS activities on Norton Basin communities (*e.g.*, local increases in support or supply industries, employment, and inflation) are likely to be small. The main potential for economic change may be through the participation of individual residents in the OCS work force. However, OCS development could result in economic change in communities by changing employment patterns and economic opportunities in the communities and by causing local inflation in prices of goods. If large-scale economic changes occurred, impacts to subsistence and sociocultural systems are likely to be more substantial than those identified herein.

Attitudes about OCS development vary among communities. St. Lawrence Island Native corporations are apparently not now interested in having OCS industrial activities come to the island. Most Norton Sound residents and institutions appear opposed to development, fearing environmental and social disruption. Nome residents show less opposition than most, viewing development as inevitable and perhaps beneficial in some respects.

The potential that environmental change brought about by OCS development would affect subsistence harvests cannot be measured with any accuracy. Decreases in animal populations viewed as possible by some investigators might result in more effort being required for normal harvest levels, diversion of time and effort to other activities, or perhaps decreased harvests of fish and wildlife by some communities or some population segments. Changes in subsistence activities and in community economic and social patterns could result. With existing data, it is not possible to predict with any confidence that any of these changes would occur.

A socioeconomic/sociocultural path model has been developed for the Norton Basin planning area to help predict socioeconomic consequences of OCS development. The model is based on existing data about apparent trends in economic, cultural, and social characteristics of Norton Basin communities. No validation of the model has yet been made, so the reliability of its predictions is not known. The model predicts that changes to economic, sociocultural, and subsistence systems due to OCS-induced economic changes are possible. However, changes to subsistence systems are difficult to predict since the model focuses on key economic variables and omits ecological variables.

Oil spill trajectory, weathering, and probability analyses presented elsewhere in this volume suggest that the western portion of the Norton Basin is most at risk for direct oil disturbances. However, the dominance of fisheries in both the cash and subsistence economies in the eastern portion, the plausibility of indirect or secondary disturbances at Unalakleet, and sensitivity of Yukon delta habitats may suggest a greater vulnerability of subsistence resources in eastern Norton Sound.

Species vulnerability ratings developed in earlier chapters are based on population distributions. Low ratings usually imply that distributions are extensive. However, since subsistence harvests are extremely localized, low species impacts may coincide with higher subsistence impacts for selected villages. For this reason, the sensitivity ratings are most useful for inferring impacts on subsistence availability.

Because subsistence impacts are defined on the basis of impacts on any one species, a minimal test for subsistence impacts can be achieved by assessing a single resource class. Many of the birds in the Norton Basin are subsistence species. Birds commonly cited in the subsistence literature include all geese, black brant, pintail, mallard, all eiders, oldsquaw, sandhill crane, all auklets, and all murres. Several of these have moderate to high sensitivity to spills and discharges (*i.e.*, black brant, cackling Canada goose, pintail, spectacled eider, auklets, and murres), and the ducks, geese, and seabirds have moderate to high vulnerability to traffic disturbances. These ratings imply susceptibility to a variety of impacts with a duration in excess of one generation. Because a duration of one year is a key threshhold feature of moderate and major impacts on subsistence species availability, and since the ratings above suggest impact durations of one year or more, subsistence impact susceptibility is apt to be medium to high in the Norton Basin as a whole. Moderate subsistence impacts do not exceed one year in duration, while major impacts do. Impacts, however, would not be uniform across the Norton Basin. Since subsistence species availability is localized and conditioned by numerous abiological influences, impact probabilities are impossible to calculate. Realistic impact levels could be lower if these abiological influences mitigate the impact, but such mitigation would involve greater harvest expense and effort.

If subsistence users mitigate localized impacts by substituting alternative economic practices for disrupted harvests, seek out alternative harvest partnerships or exchange networks, or use other harvest territories to compensate for localized shortfalls (all of which are plausible), these practices would lead to de facto disruptions of existing sociocultural organizations (which comprise existing exchange networks and harvest teams, among others). Mitigative arrangements could displace existing arrangements in the short term. Displacement is a characteristic of major sociocultural impacts, while short-term disruption (less than 5 years) characterizes minor impacts.

Since it is impossible to stipulate a most-plausible combination of disruption and displacement, a balanced susceptibility rating would be medium for sociocultural organizations. In the absence of displacement, impact susceptibility would be low. If disruption persisted for 5 years, impact susceptibility would be medium to high. Such impacts, were they to occur, would probably not affect all sociocultural organizations in any location, nor would all population segments be equally affected.

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