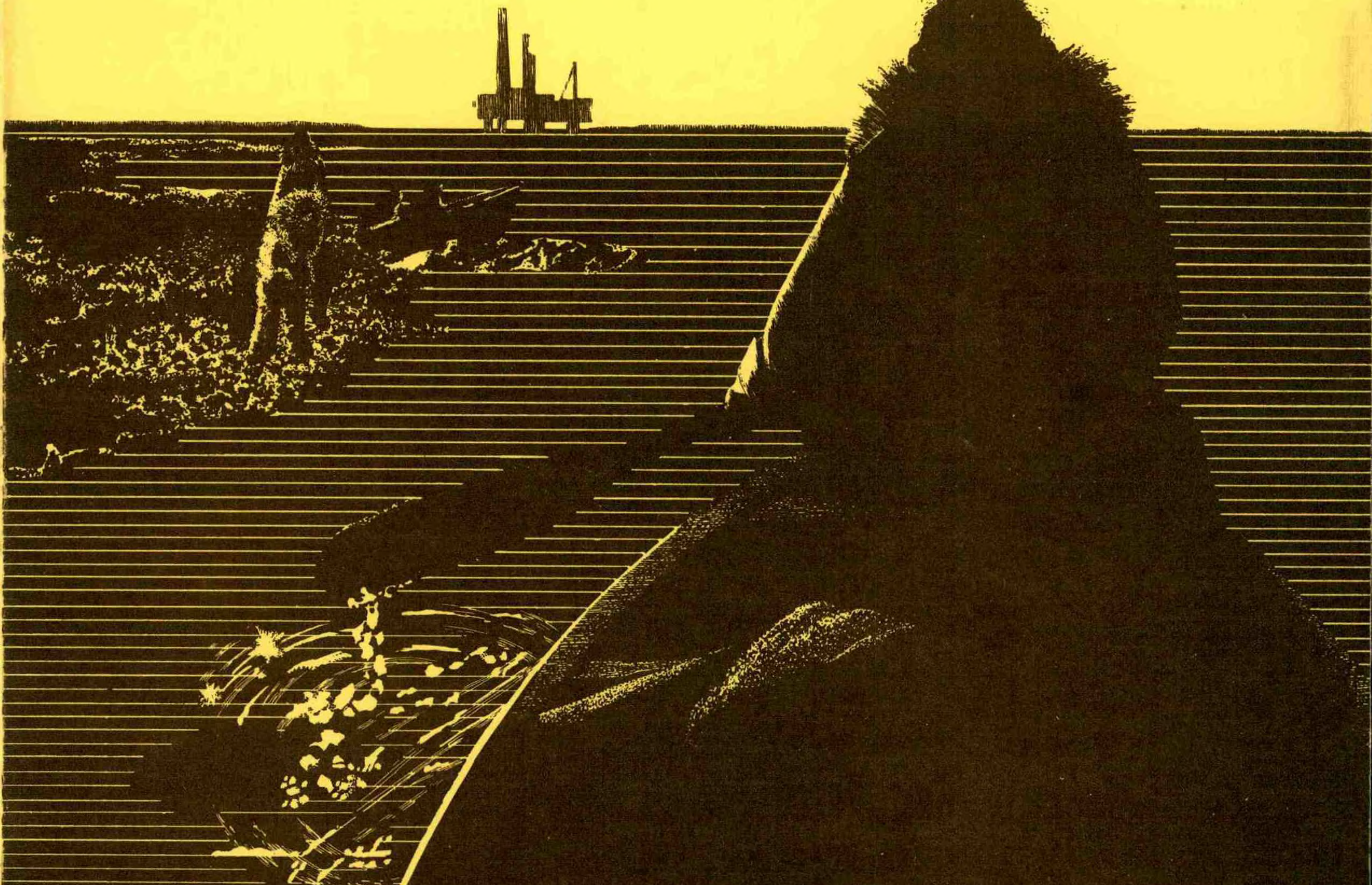
Outer Continental Shelf Environmental Assessment Program

Proceedings of a Synthesis Meeting:

The Barrow Arch Environment and Possible Consequences of [...]nned Offshore Oil and Gas Development

Girdwood, Alaska, 30 October–1 November 1983



U.S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF THE INTERIOR
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Proceedings of a Synthesis Meeting:

The Barrow Arch Environment and Possible Consequences of Planned Offshore Oil and Gas Development

Girdwood, Alaska, 30 October–1 November 1983

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Department of the Interior
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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 Bureau of Land Management (BLM), U.S. Department of the Interior, to conduct environmental research on Alaskan continental shelf areas identified by BLM for potential oil and gas development. Recently, through agency reorganization, the Minerals Management Service (MMS) of the Department of the Interior has assumed responsibility for offshore mineral leasing, and OCSEAP now functions through NOAA's National Ocean Service.

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 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 the proceedings of these meetings and include discussions of data presented during the meetings. Further presentations and data interpretations based on additional recent information may be included.

This synthesis report presents and evaluates available environmental data—transport and fate of pollutants, environmental hazards, biota and their food resources and habitats, and socioeconomic issues—related to potential petroleum development in the Barrow Arch OCS Planning Area. It is based to a great extent on information brought together at the first Barrow Arch Synthesis Meeting, held in Girdwood, Alaska, 31 October–2 November 1983. Information presented at the synthesis meeting has been complemented by extensive outside review to provide as complete a synthesis as possible.

It should be noted that certain information contained herein is specific to OCS Lease Sale 85 which was scheduled for February 1985. Subsequent to the synthesis meeting on which this report is based, this sale was deleted from the leasing schedule. Currently planned Sale 109 for the Barrow Arch is scheduled for February 1987. The new schedule affects only the timing of activities; other information in this report related to leasing remains pertinent.

Acknowledgments

This report was prepared with contributions and assistance from scientists of MMS and NOAA, other federal agencies, the state of Alaska, the petroleum industry, environmental consulting organizations, specific interest groups, and selected individuals. Special appreciation is extended to synthesis workshop organizers and chairpersons and to meeting participants who submitted written and graphic material for this synthesis report. The authors of the various chapters were patient and cooperative, and their efforts to maintain consistency among chapters are appreciated. We thank Jean Erwin for retyping edited versions of manuscripts, and Judy Landrum for preparing many of the illustrations. We gratefully acknowledge Catherine Mecklenburg and associates at Point Stephens Press, Auke Bay, Alaska for their professional efforts in the final production of the report.

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

Executive Summary

A portion of the continental shelf of the eastern Chukchi Sea between Point Hope and Point Barrow, Alaska, has been proposed for oil and gas lease sale (OCS Sale 85). The proposed sale area, called the Barrow Arch OCS Planning Area, extends from the 3-mile limit off the coast to approximately 375 km offshore. Over most of the area, the bottom topography is remarkably uniform and the water depth seldom exceeds 50 m.

In an effort to assemble, review, and interpret environmental data prior to lease sales, the Outer Continental Shelf Environmental Assessment Program convened a Barrow Arch Synthesis Meeting on 31 October–2 November 1983 in Girdwood, Alaska in anticipation of Sale 85. The purpose of this meeting was to bring together scientists and administrators so that the expected scenarios of oil and gas development, the hazards to development, and the biota and habitats at risk from such development could be identified.

This report summarizes the information assembled and discussed at this meeting, relying on additional outside information where necessary to provide a comprehensive synthesis of the Barrow Arch environment and possible consequences of petroleum development. It includes a brief description of the probable exploration and development activities, an evaluation of the transport and fate of pollutants that might be introduced by these activities, an analysis of the possible environmental hazards to the activities, descriptions of the status of biological and sociological conditions, and predictions of potential effects of oil and gas activities on the biota and on the local people. Significant points follow.

1) Probable activities following the lease sale include initial drilling during the open-water season only from ice-strengthened ships, and later drilling and production from floating or anchored steel-and-concrete structures that might be usable in the ice-covered season as well. Gravel islands are not expected to be feasible in most of the planning area, because the water is too deep. Oil would be piped to shore via subsea pipelines, or, less likely, transported south on icebreaking tankers.

2) Estimates of recoverable oil range from 0.52 billion barrels (most likely case) to 5.7 billion barrels (high case). Scenarios used for predicting activities in time and space assume 2.1 billion barrels of recoverable oil (mean case). Exploration is envisaged to begin in 1986; peak production would not be reached until about the year 2000.

3) Exploration and development may encounter such hazards as shifting sea floor sediments, moving sea ice, storms, and coastal erosion. There may be potential damages to the environment caused by releases of oil or drilling muds and cuttings, increased levels of human and industrial activity, and changes in biological, sociological, and economic conditions that result in human cultural change.

4) Prevailing winds in the Barrow Arch planning area are from the northeast for most of the year, but the major storms come from the southwest, in late summer and autumn. Surface components of oil slicks have predominantly wind-driven trajectories. Winds usually follow pressure gradients along the coast, but this relationship may not hold under certain regional weather patterns. Sea breezes may dominate inshore in summer when winds caused by regional pressure differences are minimal; this would occur over small portions of the Barrow Arch.

5) There are several components to circulation during the open-water season. Deeper waters generally move northeastward, driven by the movement of Bering Sea water into and through the Chukchi Sea. Eddies are common immediately north of the westward-extending promontories. A coastal jet of water, forced by the wind, may prevail nearest the coast. Upwelling along the coast may occur under strong northeasterly winds.

6) Major storms occur in late summer and fall, moving from the southwest. Tides are small (normally causing sea level changes of <15 cm) in comparison to wind-induced sea level changes at the coast (up to 3.5 m).

7) Ice covers the Chukchi Sea for about 8 months of the year. An open-water lead system commonly separates the shorefast ice from the moving pack ice in late winter and spring, extending the entire length of the planning area at about the 20-m depth contour. Occasionally in winter, large masses of nearshore ice move southward toward and through the Bering Strait, in response to northwesterly winds and the breakout of ice at the strait.

8) In most cases, given the scenarios evaluated, oil spilled in the nearshore environment would move seaward. Spilled oil would weather quickly in open water and would by natural forces be removed quickly should it reach high-energy beaches, but oil spilled under ice would dissipate very slowly until the ice melted. Oil spilled on lagoon beaches or other low-energy coastal environments would also persist for long periods.

9) In hypothetical cases considered at the meeting, only small fractions of sea bottom or coastline would be measurably affected by an oil spill. Oil spill cleanup at sea would be most difficult in ice-infested and stormy seas; it would be relatively easy in calm, open water.

10) Environmental effects of drilling mud and cuttings discharges are likely to be very small in space and level of adverse biological impact in comparison to effects of major oil spills. Relatively small areas would be affected by these drilling effluents, and most of the constituents discharged would be relatively innocuous in comparison to some frequently found in crude oil. However, little is known about cumulative or long-term effects of drilling muds and cuttings.

11) Hazards to oil and gas exploration and development include those presented by sea floor instability, sea ice movement, storm surge, and coastal erosion. Of these, sea ice appears to offer the greatest potential threat and the greatest impediment to exploration and development.

12) The main sea floor hazards are associated with sediment movement and sediment thinness. Migration of sandwaves and sand ridges is common in certain localities, and could potentially put stress on subsea pipes or expose them to ice gouging. Further, because sediments are relatively thin in most places, trenching into bedrock or placement of pipes in relict subsea channels may be required to avoid damage from ice gouging.

13) Ice hazards include possible intrusion into the planning area of large ice islands, normal movement of pack ice, and ice gouging of the sea floor. Movement of ice islands into the area could in theory be disastrous, but is historically uncommon. Ice breakout and other normal movements of sea ice in winter must be dealt with, as must the phenomenon of ice floes gouging the sea floor. The existence and dynamics of polynyas must also be considered in operations planning.

14) Coastal hazards are mainly a consequence of storm surge and the associated shoreline retreat. Coastal erosion rates and storm surge intrusions must be considered when placement of shore-based facilities is planned.

15) Storms may potentially be hazardous to drillships and other facilities in shelf waters. Storms are particularly hazardous when large amounts of sea ice are present.

16) Large numbers of marine mammals—walruses, spotted and bearded seals, belugas, gray whales, bowhead whales, and occasional fin whales—use the Barrow Arch as a migration corridor, summer feeding ground, or both. Ringed seals, polar bears, and some bearded seals are year-round residents. The seasonal movements and distribution patterns of these mammals are profoundly influenced by the seasonal cycle of sea ice, and are therefore generally predictable to the extent that ice conditions are predictable.

17) Vulnerabilities of marine mammals to hydrocarbon activities vary seasonally. In winter, only ringed seals and polar bears are common in the planning area, but because these animals are widely distributed populations of neither are particularly vulnerable. Two site-specific concerns in winter are development activities in the vicinities of bear dens and on-ice seismic activity near breeding seals. In spring, bowhead and beluga whales are vulnerable in the nearshore lead system; of less concern are walruses, bearded seals, and spotted seals in this lead system. In summer, lagoons and bays used by beluga whales and spotted seals, and a walrus haulout site near Cape Lisburne are coastal sites of vulnerability. Nearshore and offshore waters used by gray and fin whales, and offshore pack ice areas used by bearded and ringed seals, walruses, and polar bears are of less concern because the populations of these animals are distributed over larger areas. In fall no sites of acute vulnerability are identified; most mammals are distributed widely at this time.

18) Beluga whales when in confined areas such as spring leads or lagoons are potentially sensitive to noise and nearby activities of men and machines; they appear not to be particularly sensitive when not so restricted. Bowhead whales in general show considerable tolerance to ongoing noise from offshore drilling and dredging in open seas but react more strongly to rapidly changing situations such as approaching boats or aircraft. It is possible that stronger reactions would occur when bowheads are in more restricted situations such as the nearshore lead system during spring migration. Long-term responses of whales to noise and human activity have not been investigated. Little information is available about responses of other marine mammals to these kinds of disturbance.

19) Potential effects of oil on marine mammals vary among species. The most serious effects of oil on seals appear to occur through external contact; the level of adverse effect appears to vary with physical condition of the animal. The most serious observed effect of oil on polar bears has come through oil ingestion; in an experimental situation, oil consumed by polar bears grooming their oiled fur has caused death. Very few conclusions have been drawn about the effects of oil on whales. Dolphins, which are not found in the Barrow Arch, actively avoid aggregated oil slicks but not thin slicks. Some scientists speculate that bowhead whales may suffer adverse effects from oil on the baleen filtering system, oil adhering to external skin lesions or to tactile hairs around the blowhole and jaws, oil breathed in through the blowhole, or oil ingested.

20) Major information gaps related to the potential effects of oil and gas development activity on marine mammals include seasonal distribution status and population levels of several species in the Barrow Arch, as well as generic types of data gaps related to effects of noise, disturbance, and oil.

21) Birds that are seasonally abundant in the Barrow Arch planning area include waterfowl (primarily brant, common and king eiders, and oldsquaws), cliff-nesting alcids (primarily common and thick-billed murres), gulls (kittiwakes and glaucous gulls are most abundant), and shorebirds (primarily dunlins, red and red-necked phalaropes, and semipalmated and western sandpipers). Present in fewer numbers are loons, procellarids (fulmars and shearwaters), jaegars, arctic terns, and several alcids other than murres. The avifauna of the Barrow Arch differs from that of the Beaufort Sea mainly in its complement of colonial seabirds; the Beaufort Sea has almost none because the proper nesting habitat is lacking.

22) The primary uses birds make of the Barrow Arch are nesting (summer), foraging (spring to fall), migration (spring and fall), and staging and molting (summer and fall). Important nesting areas are the coastal cliffs near Cape Lisburne and the barrier islands at Kasegaluk Lagoon and Peard Bay. The nearshore lead system in spring is an important migration pathway for waterfowl. The open waters within 60–120 km of the cliff-nesting colonies and those of Ledyard Bay are primary foraging areas for seabirds. Coastal bays, lagoons, and salt marshes are important staging and molting areas for waterfowl and shorebirds.

23) The potential risks to bird populations from petroleum exploration and development include large oil spills, activities of men and machines, and loss of coastal habitat, in that order of importance. Areas and times where birds congregate to feed, molt, stage, or nest are where populations are most vulnerable. Such areas include Cape Lisburne and offshore and coastal areas within about 60 km of the cape (spring and fall); Kasegaluk Lagoon and vicinity (summer and fall); Peard Bay and vicinity (summer and fall); Point Hope and vicinity (summer and fall); and the lead system offshore of the fast ice (winter and spring). Bird populations most vulnerable to long-term effects are those with slow natural rates of reproduction (e.g., alcids).

24) Important additional research needs relative to birds include (a) surveys to determine distributional use patterns by major species in the ice leads in winter and spring, in Ledyard Bay and Kasegaluk Lagoon in summer and fall, and in the open-water season pelagic ecosystem in general; (b) investigations of natural mortality and recruitment patterns in alcids and other long-lived species; and (c) basic studies of life histories of marine prey (mainly forage fishes) of birds to determine spawning, rearing, and overwintering requirements.

25) The Barrow Arch fish fauna is a transition between Pacific Ocean and Arctic Ocean communities but more nearly resembles the Arctic Ocean fauna in its diversity and most common species. Both marine and anadromous fish communities have Pacific and Arctic components.

26) The marine fish community has large standing stocks of forage fishes (Arctic and saffron cods, capelin, sand lance) in comparison to marine communities of the Beaufort Sea. These forage fishes in turn support large populations of piscivorous birds and mammals.

27) The anadromous fish community has relatively low standing stocks, apparently because few productive natal streams discharge into the Barrow Arch. Cold-water barriers near the coast probably hinder large immigrations of anadromous fishes from elsewhere. In consequence of the scarcity of anadromous species, no commercial fisheries exist, although a few small subsistence fisheries depend on pink salmon and other anadromous species.

28) Most potential impacts to fish resources from oil and gas development are expected to be localized and short term in extent. Pink salmon are judged most susceptible to adverse impact; a large oil spill in estuarine nursery areas in summer might cause moderately extensive mortality in this species.

29) Benthic forms dominate among the invertebrates important in Chukchi Sea shelf food chains. The standing stock biomass of benthic infauna is generally higher in the southern and central Chukchi Sea than in the Bering and Beaufort seas. Within the Barrow Arch, benthic infaunal biomass is high in the southern areas, but diminishes with distance northward.

30) Among the benthic invertebrates of the deeper shelf waters, detritus feeders predominate. The infauna is dominated by North Pacific forms. The epifauna is less well known, but appears to be similar in many respects to that of the western Beaufort Sea. The major predators of the infauna are walruses and bearded seals; predation pressure in recent years may have caused reductions in standing stocks of bivalves. Major predators of epifauna are bearded and ringed seals, gray whales, and Arctic cod.

31) In the shallow waters shoreward of the 20-m depth contour, invertebrate communities appear similar in general composition, biomass, and diversity to those of the western Beaufort Sea, but different from those south of Point Hope in the Chukchi Sea. In these coastal shallows, vertebrate consumers (birds and fishes) probably eat mainly epifauna.

32) Zooplankton communities appear to be dominated by copepods, the individuals of which are small. They are thought to be inefficient grazers of the phytoplankton. Similar trophic inefficiency occurs in the Bering Sea, in contrast to that of the eastern Beaufort Sea, where copepods are large and relatively efficient grazers of phytoplankton. Correlated with this, perhaps, zooplankton consumers in the Beaufort Sea appear to be a far larger proportion of the vertebrate biomass than they are in the Chukchi Sea.

33) Macroalgal communities are more common in the Barrow Arch than they are in the Beaufort Sea, but phytoplankton is still the major provider of primary production to the food web. Most *in situ* phytoplankton production probably sinks before it is consumed. The Bering Sea is probably a major source of the detritus and nutrients that fuel Barrow Arch food webs.

34) Potential adverse effects of oil and gas development on nonvertebrate levels in the food web are almost certainly minor, because of the widespread distributions of the trophic components and the relatively small extent in space and time of conceivable disturbances. The chances for adverse effects on lower trophic levels to be important to higher trophic levels (vertebrates) are remote.

35) In the nearshore ecosystem of the Barrow Arch (within the 20-m isobath), vertebrates of concern to humans include bowhead, beluga, and gray whales; bearded, ringed, and spotted seals; walruses; several species each of seabirds, waterfowl, and shorebirds; and several species each of anadromous and marine fishes. Most of these use the area during the open-water period; only a few are year-round residents and a few are spring migrants only.

36) The major food base of vertebrates in the nearshore ecosystem is the epibenthos. A few species (walrus, bearded seal) feed on infauna, a few (shorebirds, forage fishes) feed on food derived from the water column, and one (brant) eats terrestrial plants. Locally, near seabird cliffs, the food web is mainly pelagic.

37) The distribution in time and space of many vertebrates in the nearshore zone is controlled by physical habitat factors—ice distribution and morphology, coastal morphology, water mass distribution and movement, and points of stream entry. Approximately 10 coastal localities have been identified as places where certain species are potentially sensitive to adverse impacts from oil and gas development activities.

38) The native communities that are dependent to some extent on subsistence harvests from the Barrow Arch planning area include Point Hope, Point Lay, Wainwright, Atqasuk, and Barrow. Subsistence activities as now practiced depend more on modern transportation equipment than they did previously. Species harvested are those that have been harvested traditionally, but patterns of use have altered with changes in local economies and with regulatory restrictions.

39) Currently, higher levels of local employment than occurred previously in native villages near the Barrow Arch have resulted in natives' dependence on snow machines, three-wheelers, and wooden or aluminum boats with outboard motors to harvest fish and wildlife. Free time is less available than formerly, and subsistence activities require rapid preparation and transportation for hunting and fishing forays. The increased efficiency provided by these modern methods of transport has allowed the natives to more or less maintain traditional levels of subsistence harvest despite decreases in free time, though some changes in target subsistence species have evolved as a consequence.

40) Subsistence land use and harvest patterns are sometimes different among villages because of differences in access to game and fish, size of village, and traditional patterns of use. For example, bowhead whales are generally accessible to hunters only at Point Hope, Wainwright, and Barrow; cliff-nesting seabirds and eggs are available only near Point Hope. Barrow is by far the largest village and thus individuals must sometimes travel farther to places where resources have not been depleted to some extent by subsistence use. Tradition may help determine which species residents pursue in their free time.

41) The animals commonly hunted by natives in the Barrow Arch are bowhead and beluga whales; walruses; bearded, ringed, and spotted seals; polar bears; anadromous and marine fishes; waterfowl; and seabirds. The species hunted by each village depend mainly on proximity of harvestable populations to each village and secondarily on harvest tradition.

42) The extent of potential impact of oil development on subsistence hunting will depend largely on the time of year that specific development activities occur, and the location. Subsistence activities are concentrated in time and space. Should oil development activities be coincident in time and space such that animals are frightened away, hunter access to the animals is hindered, or mortality of hunted resources results from oil pollution, the subsistence hunting effort may not provide the expected returns.

43) Not only may oil and gas development directly affect the ability of subsistence users to continue to make traditional levels of resource harvests, it will probably alter the existing employment patterns and the economic well-being of native villages near industrial activity centers. Given the mean case estimate of 2.1 billion barrels of recoverable reserves, the current North Slope Borough Capital Improvement Program activity is expected to decline by 60 percent, resulting in reduced local employment opportunities and delays in upgrading or completing community services. But the number of attractive jobs related to petroleum development may increase for residents of the region.

44) Should coastal development in support of offshore activities be concentrated at Point Belcher, employment opportunities and income for natives would increase within commuting distance of Wainwright, though constraints to Inupiat participation in petroleum-related opportunities would probably continue to exist.

45) Research needs concerning socioeconomic impacts are seen to be three. First, further research on the effects of noise, visual disturbance, and pollutants on subsistence species is needed. Second, a cooperative research effort with employers is needed to reduce uncertainties related to petroleum development and Inupiat employment. Finally, there is a need to collect better time-series baseline data from which to better predict socioeconomic impact and evaluate development effects as they occur.

Contents

Figures

Figure *Page*

Tables

1

Introduction

by Joe C. Truett

1.1 THE PROPOSED ACTION

Exploration for oil and gas on the Outer Continental Shelf of Alaska has accelerated in recent years. Most recent industry interest and government leasing programs have been on the Beaufort Sea; interest is now focusing west and south of the Beaufort. Lease Sale 85 in the Barrow Arch OCS Planning Area of the Chukchi Sea (Fig. 1.1) was scheduled for February 1985; it was recently superseded by Sale 107 scheduled for February 1987. This report is based on the proceedings of a synthesis meeting that focused on this region and its resources in view of OCS Sale 85.

The Barrow Arch planning area extends from the 3-mile geographical limit off the northwest coast of Alaska (10–20 m deep) to a maximum distance of about 375 km offshore. Over most of the planning area, water depth does not exceed 50 m, though the extreme northern edge of the area approaches the precipitous shelf break into the Arctic Ocean.

A scenario for petroleum development in the Barrow Arch has been developed by the U.S. Department of the Interior, Minerals Management Service (MMS) (McCrea and Roberts 1984). The scenario includes projections of amounts of recoverable oil discovered and methods of exploration for, and development, production, and transportation of the oil. Evaluations of the environmental consequences of Sale 85 in the Barrow Arch are based on this scenario. The timing of activities as proposed by the National Petroleum Council and estimated by MMS is shown in Figure 1.2. The scenario descriptions that follow are based on MMS schedules and scenarios.

The primary units for drilling the exploration and delineation wells will initially be ice-strengthened drillships, a proven technology. They will be able to operate about 90 consecutive days, from breakup to freeze-up (or perhaps a shorter time if restrictions on operations during bowhead migration and gray whale feeding times are applied). A drillship would normally be able to drill and test one well per year.

By the third or fourth year, drilling units would be used that have the capability of extending the drilling season into all or part of the winter, thus more wells per year could be drilled. Types of units potentially used include a floating, circular-shaped Conical Drilling Unit (CDU), cassion-type structures ballasted with sea water, monocone-type structures, and steel or concrete islands. Artificial gravel islands will probably not be used because the water in nearly all lease units is too deep.

Drillship operations would be supported during the open-water season by barges towed into the area from southern ports. Year-round drilling from other structures would require support by helicopters, icebreaking work-supply boats, or perhaps air-cushioned vehicles. Air support would originate from airports at Barrow, Wainwright, or possibly Kotzebue.

The scenario envisages that 2.1 billion bbl of recoverable oil (mean case estimate) would be discovered in the Barrow Arch (Fig. 1.3). The oil would be produced from three platforms resting on the sea floor. Monocone or concrete-and-steel structures towed to the sites would serve as platforms.

Oil produced would be carried by subsea pipeline to Point Belcher on the coast, and from there by overland pipeline to the Trans-Alaska Pipeline System (TAPS). About 320 km of subsea pipeline and 425 km of overland pipeline would be required. Two pump stations would be required onshore.

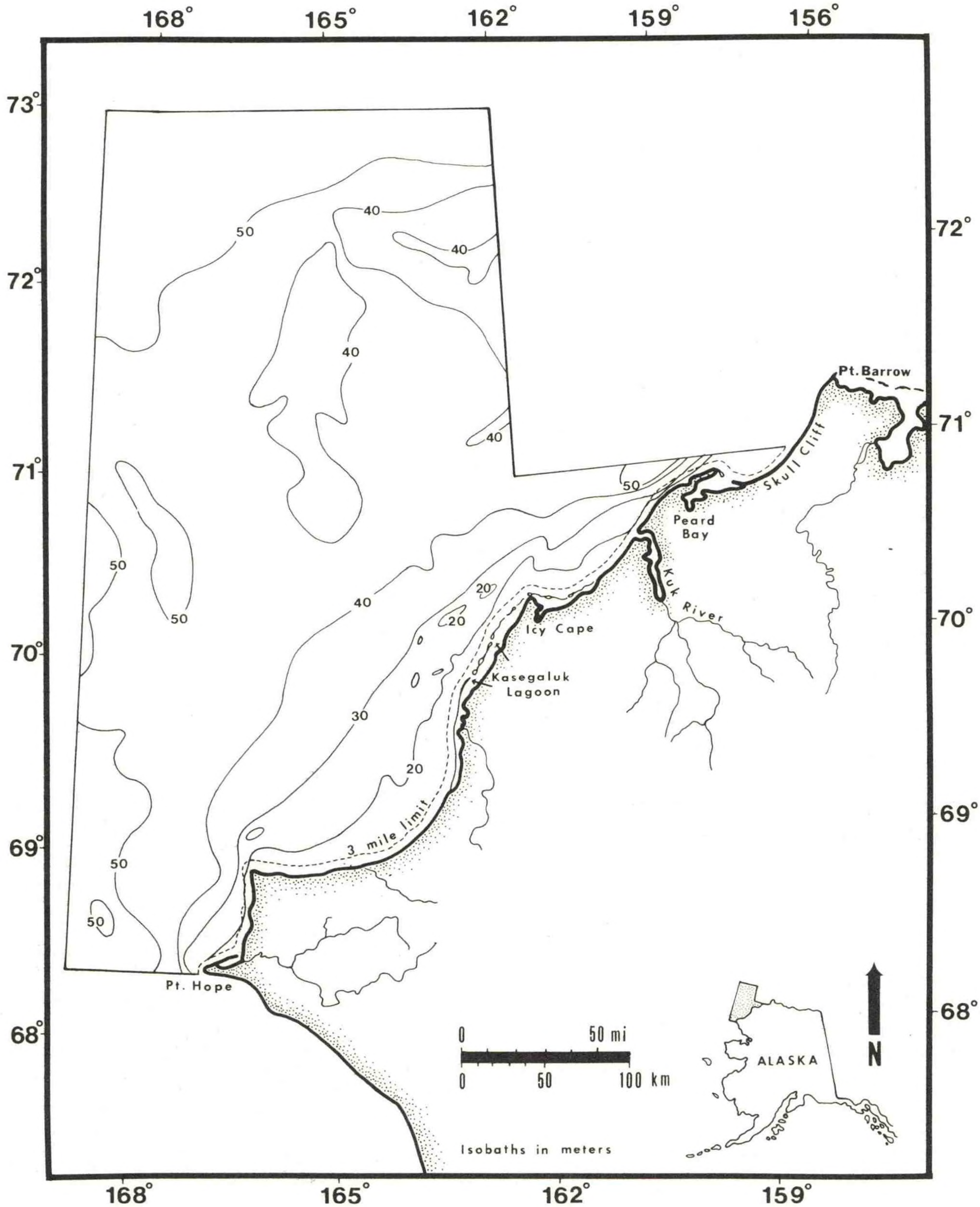

FIGURE 1.1—The Barrow Arch Outer Continental Shelf Planning Area (OCS Sale 85), eastern Chukchi Sea.

An alternative method for transporting oil from production platforms to southern markets would be icebreaking tankers. Tankers would be more likely if smaller quantities of oil than projected were found, or if significant technological advances in tanker transport occurred during the next several years.

Alternative estimates of recoverable reserves include a most-likely-case estimate (0.52 billion bbl) and a high-case estimate (5.7 billion bbl). Scenario differences for these alternatives are summarized in Figure 1.3 and Table 1.1. Regardless of the resource estimate, the technologies for exploration, development, and transportation would remain generally the same as described above.

1.2 NATURAL HAZARDS TO OCS STRUCTURES AND ACTIVITIES

Hazards to the exploration and development of the Barrow Arch for petroleum are probably similar to those of many other shallow Arctic continental shelf areas. Geological hazards such as migrating sandwaves on the sea floor and gas-charged sediments may be expected. Ridging of sea ice and movement of ice islands and other multi-year ice could pose hazards to ships, drilling platforms, and subsea pipelines. Storm-induced wave action may offer threats to coastal facilities and subsea pipelines. Coastal retreat, caused mostly by storm surge erosion, may further threaten shore-based facilities. Seismic and volcanic activity are probably unlikely to occur in the region.

1.3 ENVIRONMENTAL IMPLICATIONS OF THE PROPOSED ACTION

Potential consequences of OCS oil and gas exploration and development in the Barrow Arch include (1) effects of pollutants, particularly oil, on vertebrates and their food chains; (2) effects of increased human activity and boat and air traffic on birds and mammals; (3) changes in lifestyles of local people and consequent changes in harvest levels of mammals, birds, and fish; and (4) socioeconomic changes with regional and statewide implications.

In any petroleum exploration and development sequence in marine waters, unavoidable and accidental releases of oil are of concern. Large accidental oil spills are probably the greatest concern, but also, chronic releases of relatively small amounts of oil may have adverse local effects.

Oil spills may be particularly hazardous to marine mammals and birds. Bowhead whales, belugas, and eiders migrate through the Barrow Arch in early spring, at which time the only open water available to them may be the lead system that persists southwest of Barrow. Oil in this lead system could have large adverse effects on these animals. Fish are of less concern; most adults could readily avoid oil and concentrated populations of juveniles are smaller here than in more southerly OCS areas (Kotzebue Sound, Norton Sound, southeastern Bering Sea). Oil in food chains of valued species may be less of a problem than direct effects of oil on the animals themselves.

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 bactericides 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.

Petroleum exploration and development will invariably cause increased numbers of people to occupy the area, and boat and aircraft traffic to increase. Disturbance to migrating whales and birds is a concern, particularly if such activities occur at a time and place whereby these animals are displaced from potentially critical habitat. Activities that occur in or near polynya systems in spring could be especially detrimental. Increased activity near beluga calving areas, walrus haulout areas, or seabird nesting cliffs offers other potential adverse effects.

Invariably, when exploration and development activities occur in areas remote from large human population centers, drastic changes in the lifestyles of residents may be expected. Increased per capita income, mobility, and other changes frequently cause

TABLE 1.1—Activity levels (number of facilities) predicted for three alternative estimates of recoverable resources (mean = 2.1 billion bbl; low = 0.52 billion bbl; high = 5.7 billion bbl).

	Mean	Low	High
Exploration wells	22	10	44
Delineation wells	9	3	18
Production platforms	3	1	6
Production and service wells	114	22	309
Offshore pipelines (miles)	200	25	250
Shore terminals	1	1	1
Production (billions of barrels)	2.1	0.52	5.7

SOURCE: McCrea and Roberts 1984.

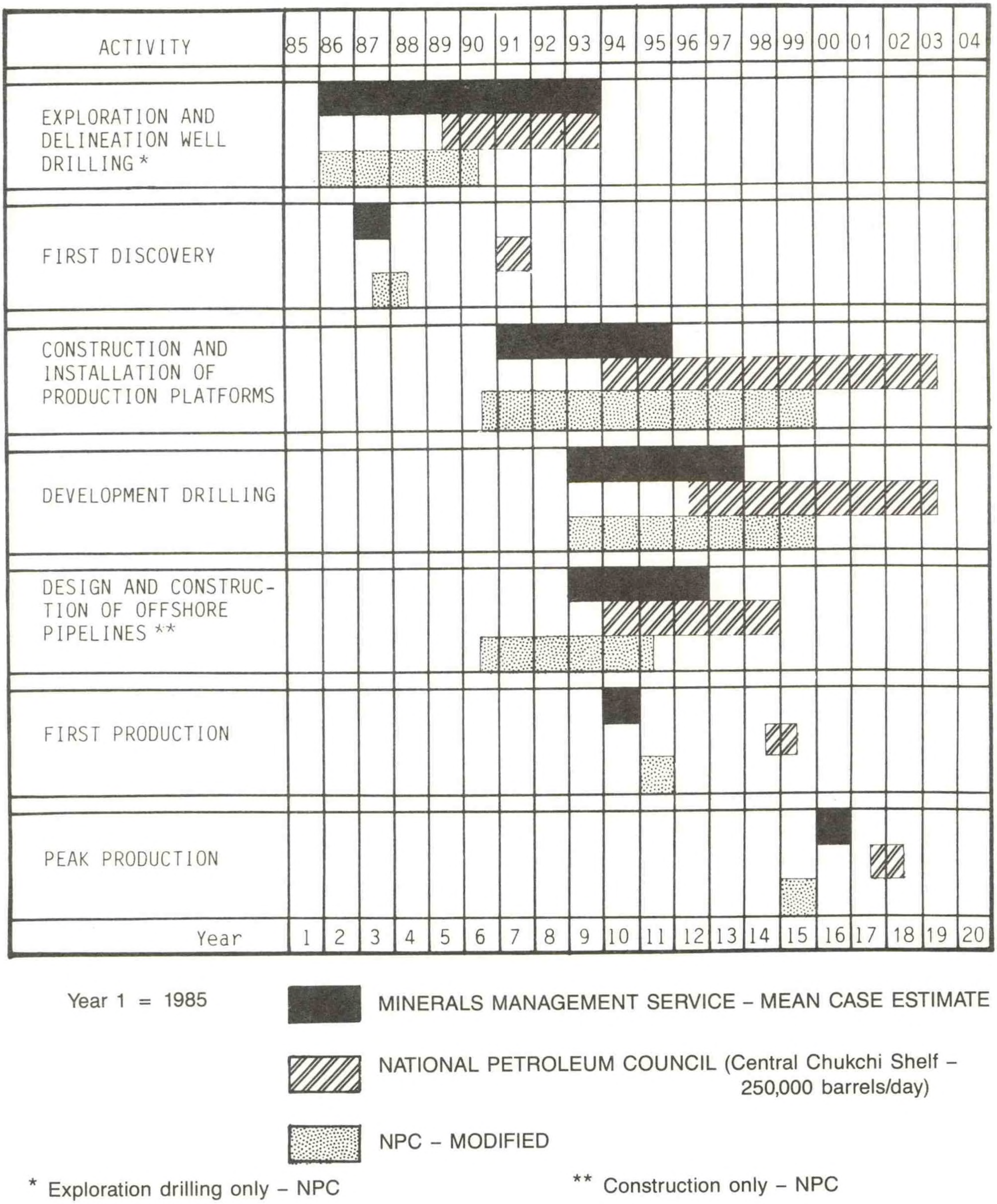

FIGURE 1.2—Comparison of Barrow Arch Sale 85 oil development scenarios of the Minerals Management Service and the National Petroleum Council.

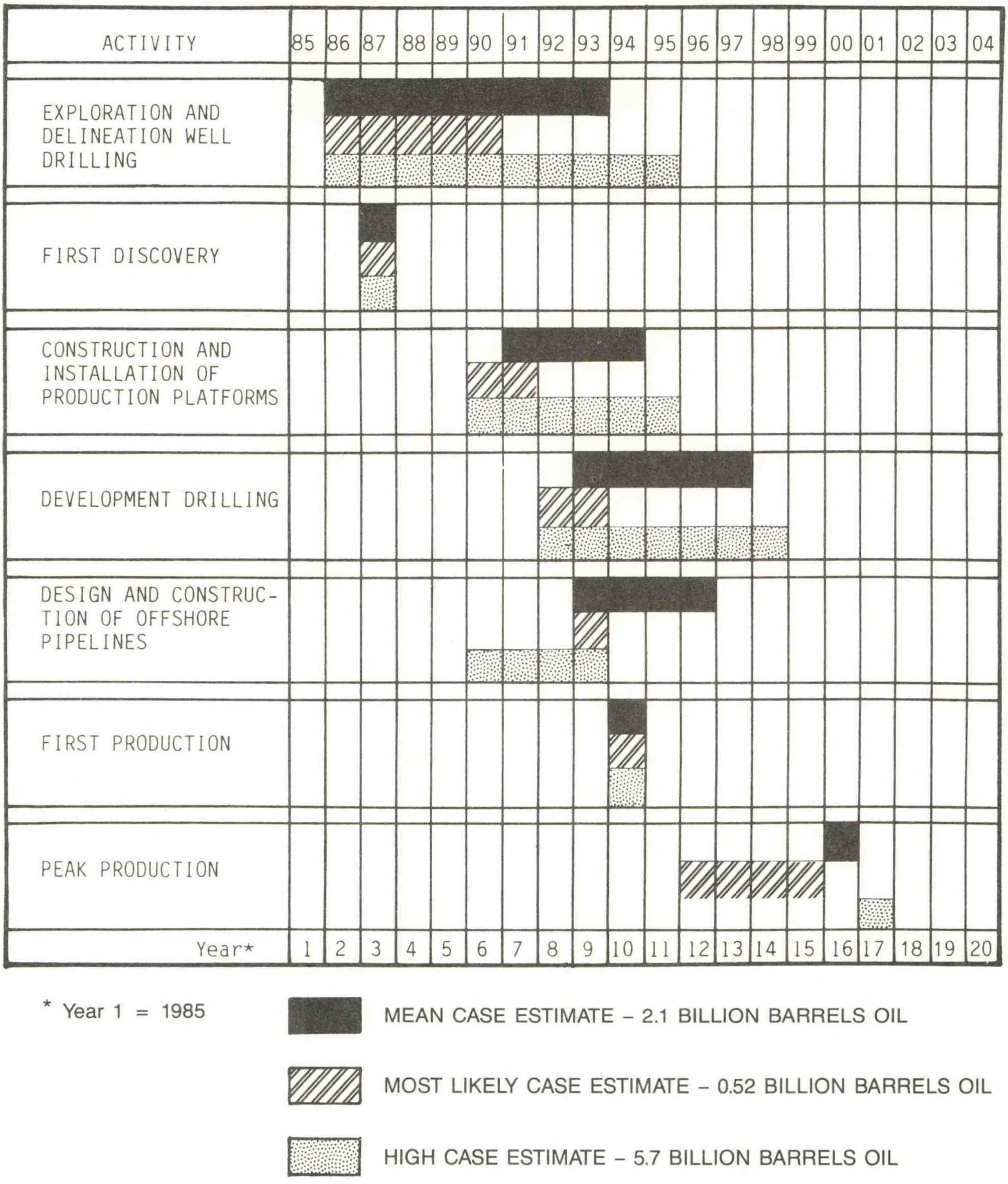

FIGURE 1.3—Barrow Arch oil development scenarios for three alternatives in resource recovery estimates. (After McCrea and Roberts 1984.)

changes in resource use patterns. For example, increased cash income and mobility generate the potential for greater efficiency in subsistence harvest of mammals, birds, and fish. On the other hand, increased income may cause a decreased desire in hunters to harvest resources, or cause patterns of harvest to change.

Because exploration for and development of oil and gas generate tremendous increases in cash flow, local and regional economies are drastically affected. Cash income per capita frequently increases at the local level, and the patterns of cash flow in more distant localities change as well. These changes frequently alter lifestyles and social values and are accompanied by increased social problems such as loss of community traditions, increases in crime, and dissatisfaction with current employment patterns. Specific socioeconomic changes anticipated to result from Sale 85 are not precisely predictable, but will probably parallel those that have occurred in other places such as the North Slope, where onshore petroleum development has continued for many years and where OCS activities have recently accelerated.

1.4 BARROW ARCH SYNTHESIS MEETING

In response to information needs made obvious by the proposed lease sale, OCSEAP convened a meeting of OCSEAP investigators, other researchers, and resource managers in Girdwood, Alaska, 31 October through 2 November 1983. The purpose of this meeting was to assemble and review the most up-to-date information related to potential OCS activities in the Barrow Arch, the hazards to petroleum development there, and the vulnerabilities of biological and human resources that might be affected by such activities. Topics addressed at the meeting were as follows:

1. Descriptions of scenarios of OCS oil and gas development
2. Transport and fate of oil and other pollutants
3. Environmental hazards to oil and gas exploration and development
4. Use of the area by marine mammals and potential effects of OCS oil and gas development activities on these animals
5. Use of the area by birds and the expected responses of birds to OCS-related activities
6. The status of finfish resources in the area and the potential effects on these resources of OCS-related activities
7. The coastal ecosystem, its important components and processes, and its sensitivities to oil and gas exploration and development
8. The existing subsistence and socioeconomic patterns expected to be affected by OCS activities, and the nature of the expected changes

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

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2

Transport and Fate of Spilled Oil

by George S. Lewbel and Benny J. Gallaway

With contributions from K. Aagaard, W. Benjey, R. Colony, M. Cronin, B. Galen, W. Gusey, L. E. Hachmeister, J. R. Harper, B. E. Kirstein, Z. Kowalik, S.-K. Liu, J. Loncar, J.R. Payne, R. Pitman, R. Prentki, Q. Robe, W.M. Sackinger, W.B. Samuels, P. Schneider, W. J. Stringer, L. K. Thorsteinson, and D. E. Wilson. Meeting Chairman: M. J. Pelto.

The question of where oil spilled in the Barrow Arch might go and what might eventually happen to it is addressed in this chapter. Descriptions of the physical environment are presented as background. Predictions of oil transport are based upon known physical data, including wind and current directions and intensities, and upon modeling results. Three hypothetical oil spill scenarios are evaluated. Predictions of fate are based upon experimental field and laboratory oil spills, and upon extrapolation from other geographic areas.

2.1 THE PHYSICAL ENVIRONMENT

2.1.1 Coastal Geomorphology

Nearly half the length of the Barrow Arch coast is "open," or exposed to the sea; the other half is protected to some extent by spits, points of land, or barrier islands. About a third of the coast is backed by either high or low tundra cliffs, and a twentieth by rock cliffs. There are also a few wetlands and mud flats, especially at river mouths or deltas.

The coast can be divided for convenience into three major segments. The northern segment, between Point Barrow and Icy Cape (Fig. 1.1), is primarily high tundra cliffs averaging 10–14 m in height, with two large, relatively deep estuaries (Peard Bay and Kuk River). The high tundra cliffs consist mostly of unconsolidated sediment, and contain much less ice than low tundra cliffs. Cretaceous bedrock is often exposed in the lower portions of many of the high tundra cliffs. Skull Cliff north of Peard Bay exemplifies this type of coastline. High tundra cliffs occur in other coastal segments, too, but they are more common to the north.

The central coastal segment, between Icy Cape and the southern end of Kasegaluk Lagoon, is a long, narrow, shallow lagoon with few tidal passes, and is backed by a low tundra cliff 3 m or less high. The cliffs typically are often fronted by fringing gravel beaches varying in width from about 10 to 100 m. Some lagoon locations are backed by mud flats, and at the mouths of small streams there are often small estuaries, deltas, and marshes. On the seaward side of the lagoon are relatively stable barrier islands and spits. The more stable islands have dunes on them.

Some of these low-lying coastal features such as bars, barrier islands, and channels show extensive movement. Low-profile barrier islands and spits seem to be migrating landward at rates of 1–2 m/yr. There is also evidence of northward movement of the barrier islands. For example, the Seahorse Islands and the entire entrance channel to Peard Bay are apparently moving northward. Seaward of the barrier islands lies an ever-changing set of moving, parallel sand and gravel bars and sandwave fields.

The southern segment, from southern Kasegaluk Lagoon to Point Hope, is an area of high relief, with tall cliffs of Permian and Triassic sandstone and shale bedrock near the coast. The cliffs increase in height toward the south, reaching an elevation of approximately 300 m at Cape Lisburne.

2.1.2 Coastal Meteorology

Wind conditions along the coast of the Barrow Arch reflect two major classes of factors: areawide pressure system effects and local thermal effects (sea breeze). The prevailing winds along the coast during most seasons are primarily from the northeast (northeasterly) and secondarily from the southwest (southwesterly) (Brower *et al.* 1977). The major storm winds in summer and fall blow from the southwest, a direction giving them maximum fetch during the open-water season (Wiseman and Rouse 1980).

Wind direction along the coast has been correlated with measured atmospheric pressure at Point Barrow and Cape Lisburne (Wilson *et al.* 1981). When pressures at Point Barrow exceed those at Lisburne, wind is predicted to blow from the northeast, and vice versa (Fig. 2.1). During periods of measurement (Wilson *et al.* 1981) this thesis has been validated. Under normal summer arctic conditions, the positions of the Siberian High and Aleutian Low create pressure patterns that produce the correlation between pressure difference and wind direction along the coast.

However, under certain circumstances this correlation does not hold. With a low positioned as in Figure 2.2, with its isobars parallel to the coast of the Barrow Arch, coastal winds will be northeasterly (counterclockwise around a low) despite the lack of pressure differences between Point Barrow and Cape Lisburne. Furthermore, in some years, a strong pressure gradient declining from Point Barrow to Cape Lisburne has been associated with southwesterly winds, the opposite of those that would have been predicted from the model of Wilson *et al.* (1981) (T. Kozo, pers. comm.).

Surface pressure values from three points have been described as yielding more reliable predictions. NOAA's Office of Marine Pollution Assessment and the Minerals Management Service have used three-point grids (Fig. 2.3) successfully since August 1981 (T. Kozo, pers. comm.) to generate predictions of wind direction and velocity. Kozo (*In prep.*) indicates that measured surface velocity is equal to about 55% of predicted geostrophic velocity, and that surface direction is equal to predicted geostrophic direction minus 37.5°.

When winds due to areawide pressure systems such as storms are minimal, the thermal contrast between the coast and the ocean during summer results in the development of onshore winds, or sea breezes (T. Kozo, pers. comm.). As air over the land becomes warm compared to air over the sea, it rises and is replaced by cooler air from off the water. During August, the sea breeze is present an average of 18% of the time, and reaches a maximum velocity of 5–6 m/s, usually when pressure gradients are low. This breeze could present problems of forecasting in case of an oil spill near shore, in that the direction of movement would be toward the nearest coast during sea breeze occurrences, despite otherwise relatively calm conditions (Kozo 1982).

A comparison of wind data from a variety of sites along the Bering, Beaufort, and Chukchi coasts has revealed that sites less than 100 km apart are usually very similar in wind direction and velocity (cross-correlation index greater than 0.8) (Kozo *In prep.*). Consequently, it is reasonable to extrapolate some kinds of data to new sites from long-existing meteorological stations, at least within this distance.

Wind direction and velocity are strong determinants of the movement patterns of waterborne pollutants. A floating pollutant such as the bouyant fraction of crude oil is particularly responsive to surface wind stress. Moreover, movement of shallow coastal water throughout the water column is generally with the wind (Wiseman and Rouse 1980; Wilson *et al.* 1981). Values derived from using the three-point grid system to predict wind direction and velocity may be particularly applicable to predicting trajectories of oil on or in the water. For example, currents within 5 km of the coast at Wainwright are more closely correlated with geostrophic winds calculated from the B, C, D pressure triangle (Fig. 2.3) than with the pressure difference between Point Barrow and Cape Lisburne (T. Kozo, pers. comm.).

2.1.3 Currents, Storm Surges, and Tides

Nearly all of the available information on water circulation and tides is based on studies in the open-water season. At this time, there is a general movement of water in the Chukchi Sea toward the north, from the Bering Strait into the Beaufort Sea (Fig. 2.4). The main forcing function for this broad-scale northward movement is the difference in sea level between the Pacific and Arctic oceans (Coachman *et al.* 1975), which is probably caused by the regional distribution of wind stress. Though the net transport through the Bering Strait and Chukchi Sea is northerly (Coachman and Aagaard 1981), even against moderate northerly winds, the flow may temporarily reverse to southerly under strong northerly, northeasterly, or easterly winds.

Currents

There appear to be several components to circulation in the Barrow Arch during the open-water period (July through October). Two distinct and large water masses—Bering Sea Water and Alaskan Coastal Water—dominate the circulation patterns over most of the shelf, beyond depths of 20–30 m. Nearer shore, eddies occur downstream from major points of land, and a coastal jet, following bathymetric contours, appears adjacent to the coast in at least some locations. Also, upwelling at the coast is common under certain meteorological conditions.

The major water masses flowing through the Barrow Arch originate in the Bering Sea. As Bering Sea Water flows northward through the Bering Strait, there are three water masses (from east to west: Alaskan Coastal, Bering Shelf, Anadyr) differentiable

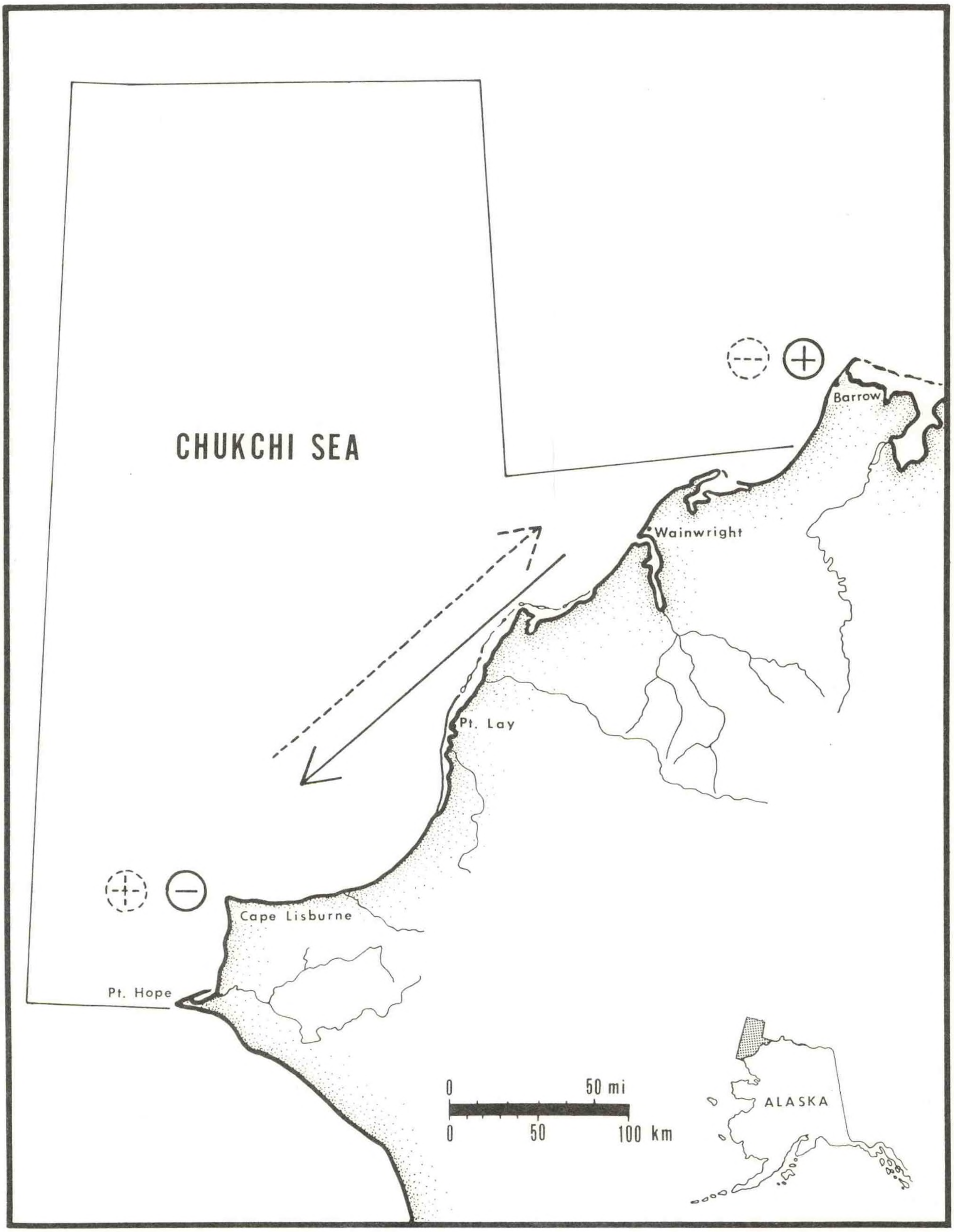

FIGURE 2.1—Wind direction in the Barrow Arch as a function of atmospheric pressure differences. ⊕ = high pressure; ⊖ = low pressure.

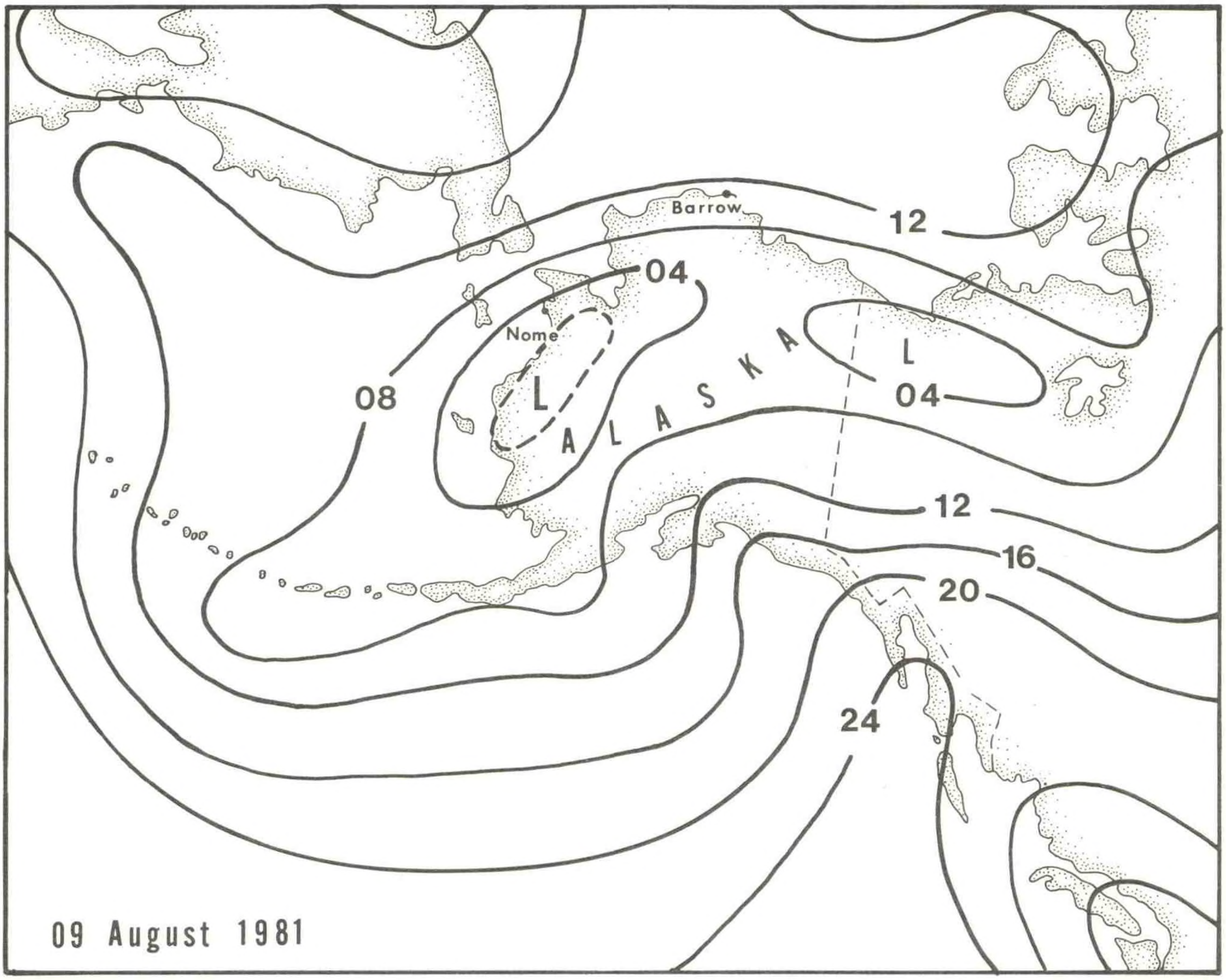

FIGURE 2.2—Example of a weather system that would generate winds from the northeast in the Barrow Arch despite similar atmospheric pressures at all coastal localities. L = low pressure center; isobars shown in mb pressure. (Provided by T. Kozo.)

on the basis of salinity. Within a short distance north of the strait the water masses reduce to two (through combination of the Anadyr and Bering Shelf waters). These two have been named Bering Sea Water (resulting from the merging of Anadyr and Bering Shelf waters) and Alaskan Coastal Water (Coachman *et al.* 1975).

Bering Sea Water has higher salinities (32.2 to 33 ppt) and lower temperatures in summer (near 0°C) than Alaskan Coastal Water. South of Point Hope, Bering Sea Water dominates the central and western areas of the Chukchi Sea, but in this southerly area, Alaskan Coastal Water (salinity usually somewhat less than 32 ppt, temperature as high as 10–15°C) dominates the surface waters within about the eastern third of the Chukchi. Alaskan Coastal Water is characterized by lateral gradation from a relatively cold and saline fraction on the west, to a warm and less saline one close to the coast (Coachman *et al.* 1975). Because of its lower density, it is largely contained in the upper ocean layers, but near the coast may extend to near the bottom (Coachman *et al.* 1975; Wiseman and Rouse 1980).

At Point Hope, at the southern edge of the Barrow Arch, the flow of Alaskan Coastal Water bifurcates, one part moving northwestward along the south side of Herald Shoal (and thus bypassing the Barrow Arch) and the other part diverging northeastward along the Alaskan shore (Fig. 2.5). Existing data suggest that the flow of Bering Sea Water bifurcates here also, the less saline part veering northeastward with the Alaskan Coastal Water, but at depth. This northeasterly stream (at least the Alaskan Coastal Water portion) diverges from the coast north of Cape

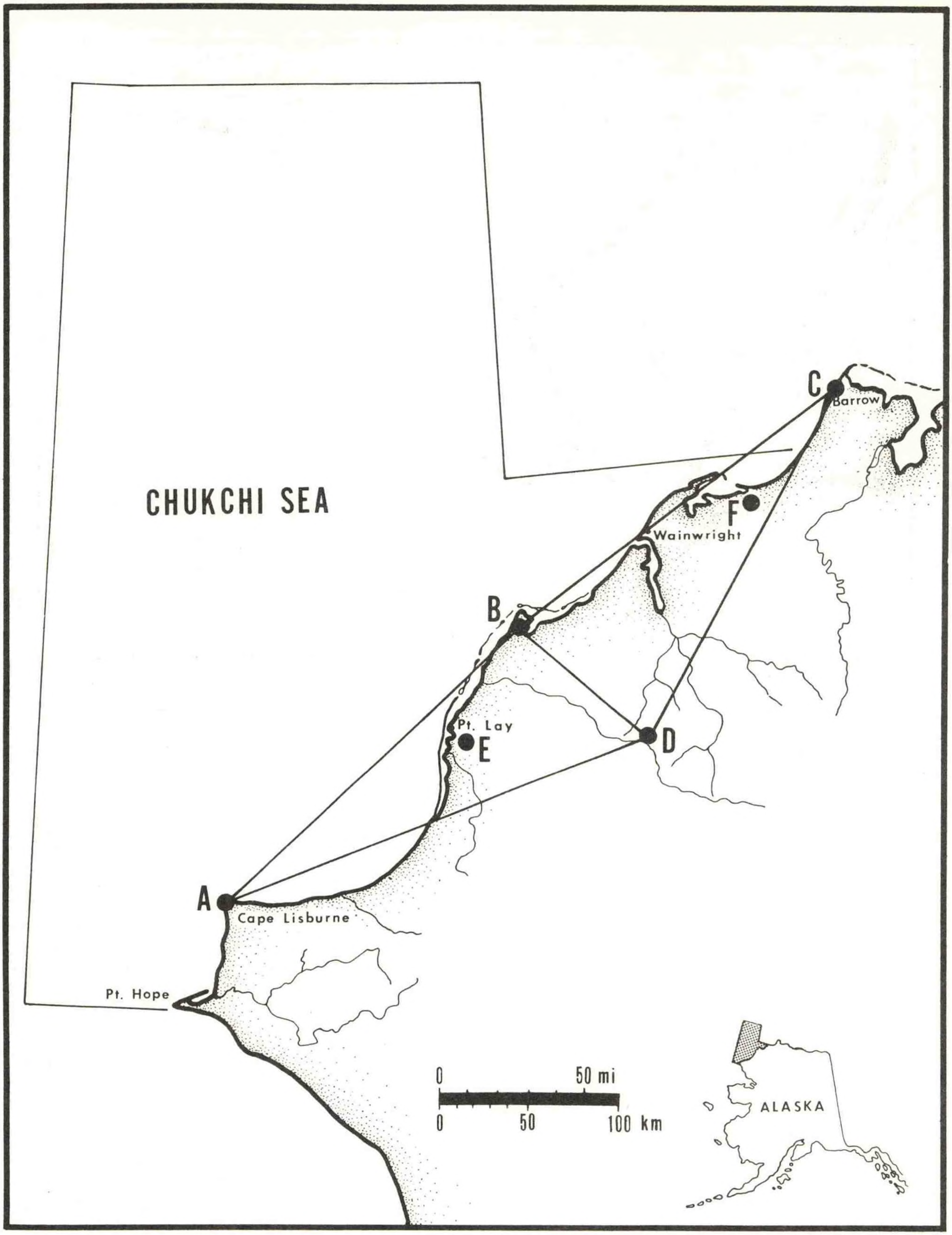

FIGURE 2.3—Positions of surface atmospheric pressure stations (ABCD) and mechanical weather stations (EBF) used by Kozo (1984) to evaluate the usefulness of pressure triangles in predicting coastal winds in the Barrow Arch. (Provided by T. Kozo.)

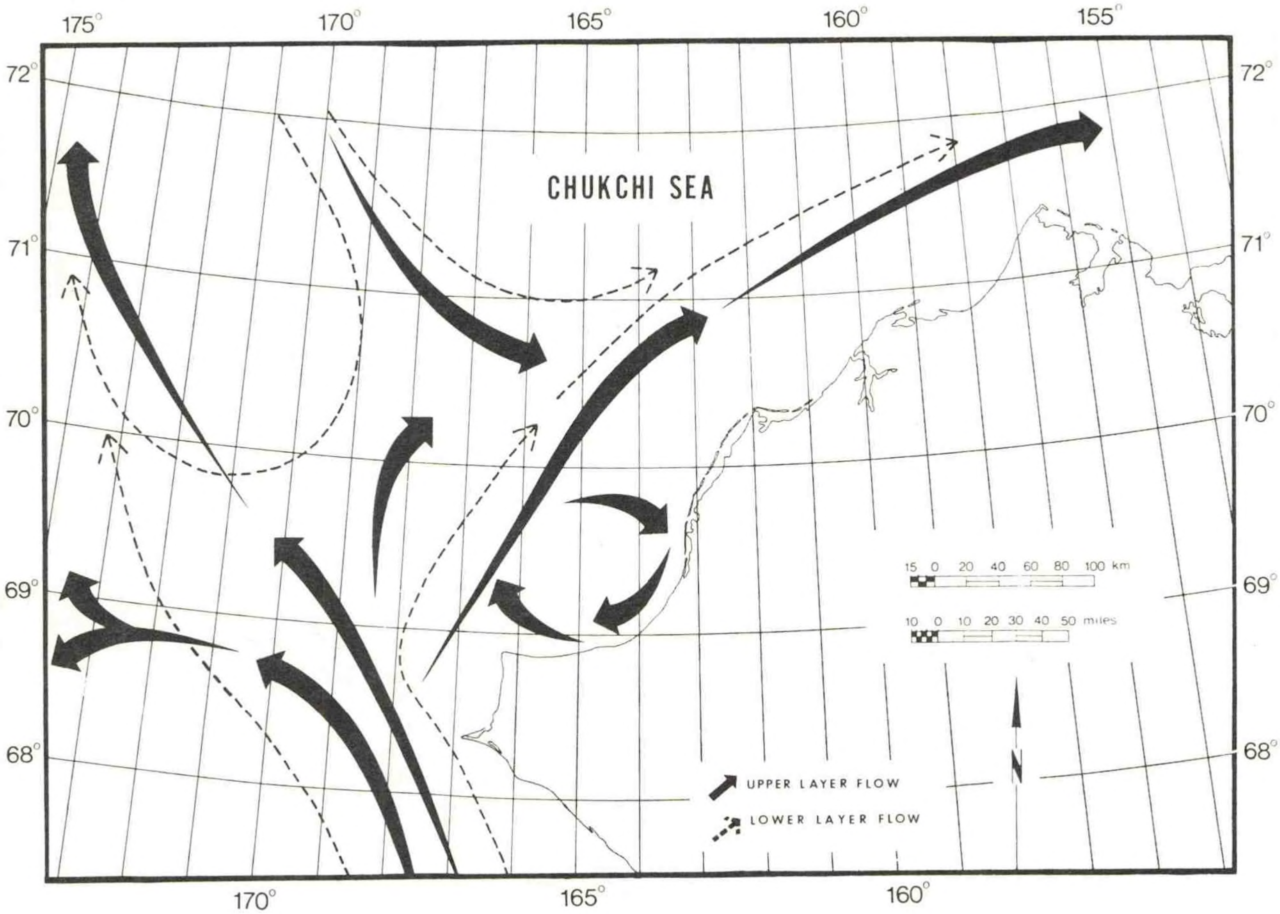

FIGURE 2.4—General water mass movement patterns in the eastern Chukchi Sea during the open-water period. (After Coachman *et al.* 1975.)

Lisburne (bypassing Ledyard Bay) but returns to near the coast at Icy Cape (Coachman *et al.* 1975). From thence it more or less parallels the coast until it rounds Point Barrow.

The core of the Alaskan Coastal Current may be as far as 100 km or more offshore in the coastal region between Cape Lisburne and Icy Cape, but as close to the shore as 20–30 km in coastal areas north of there. In Barrow Canyon southwest of Barrow, and in an area northwest of Icy Cape, intrusions of Arctic Ocean Water have been detected in the lower part of the water column (Coachman *et al.* 1975; Mountain *et al.* 1976); this water is less widespread than water from the Bering Sea. Thus in the Barrow Arch region, marine waters may be pictured as dominated by water from the Bering Sea. That portion called Bering Sea Water occurs at depth and westward. In the eastern parts is a north-moving stream of Alaskan Coastal Water, which is normally above the pycnocline but reaches near bottom in shallow areas. Arctic Ocean Water intrudes locally.

Nearer the shore, clockwise eddies appear as recurring features of circulation northward of points of land such as Cape Lisburne, Icy Cape, and Point Franklin (Fleming and Heggarty 1966; Sharma 1979; Hachmeister 1983) (Fig. 2.5). These have been observed when nearshore (Alaskan Coastal) currents are north-flowing (Fleming and Heggarty 1966; Hachmeister 1983). They are apparently caused by deflection of the currents by capes and points, which causes separation of the current and consequent formation of eddies downstream of the protruding landform (Sharma 1979).

Further, the Chukchi Sea presents a physical environment that appears conducive to the formation of nearshore baroclinic coastal jets. Wiseman and Rouse (1980) have documented one to occur near Point Lay. The coastal jet measured occurred very near the coast (far inshore from the Alaskan Coastal Water and inshore from the Cape Lisburne eddy; Fig. 2.5), and was observed when regional shelf flow was generally northward. The observed flow followed

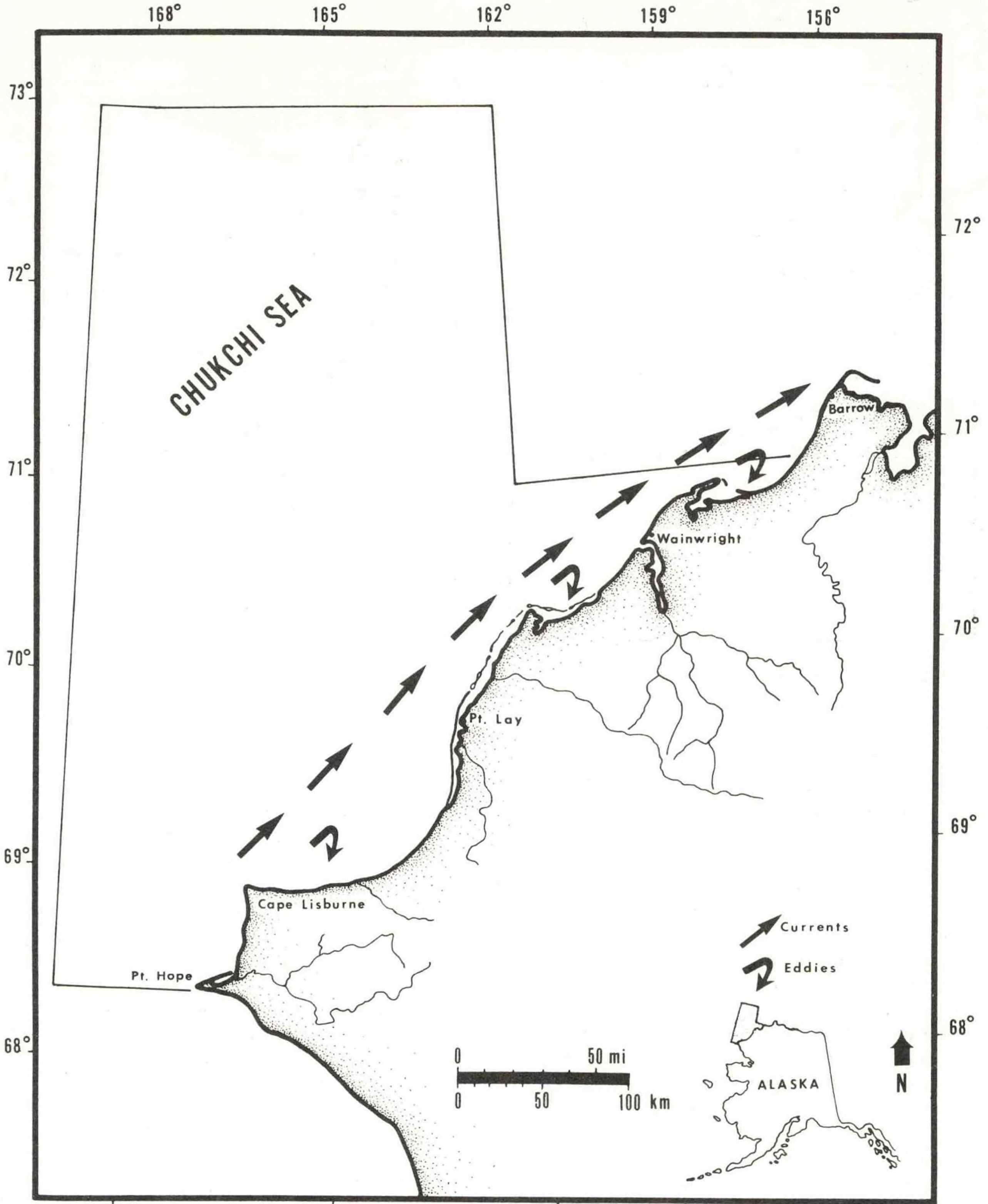

FIGURE 2.5—General water movement patterns in the nearshore environment of the Barrow Arch showing the persistent northeastward Alaskan Coastal Current and characteristic eddies behind points of land. (Surface flow may respond to changing wind stress and thus frequently vary from this pattern.) (After Coachman *et al.* 1975; Sharma 1979; Wiseman and Rouse 1980; Hachmeister 1983.)

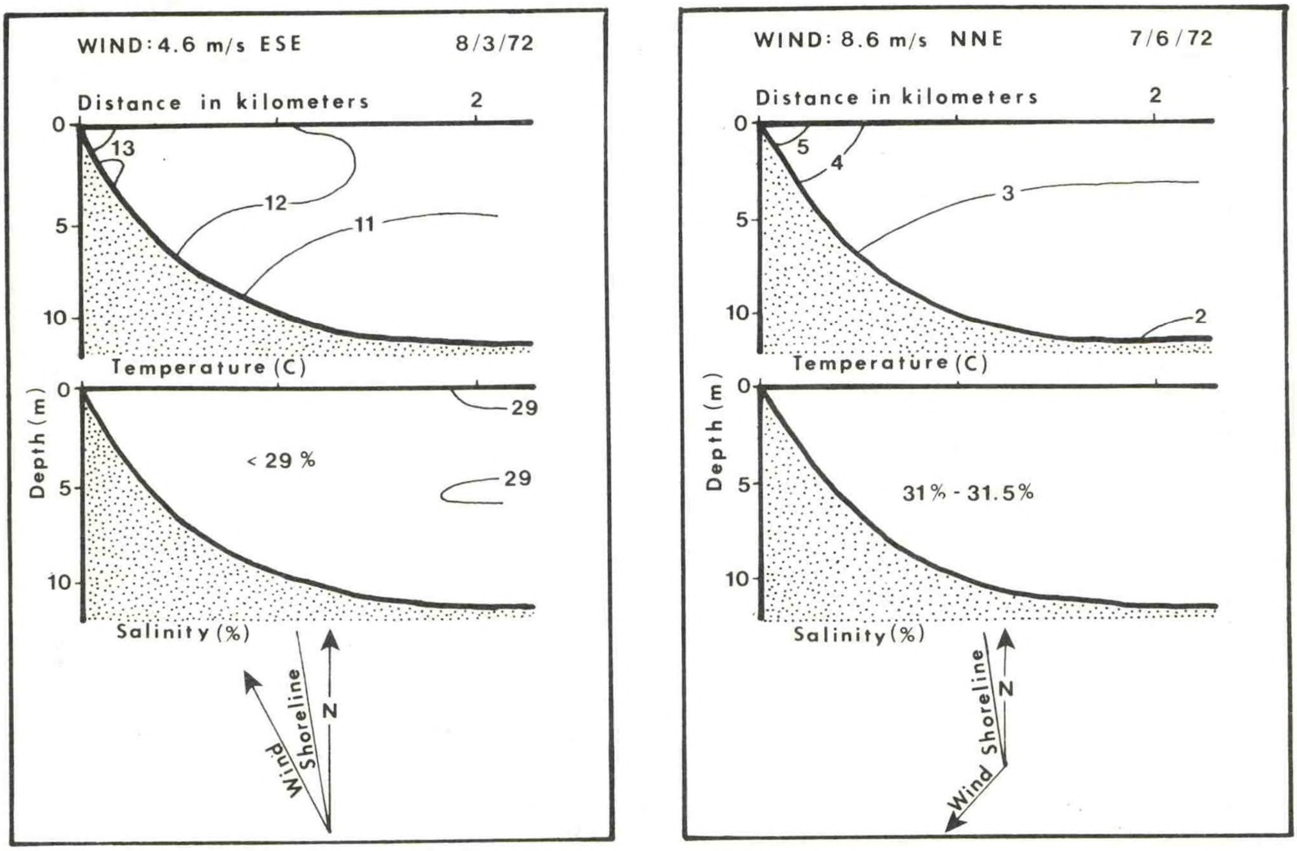

FIGURE 2.6—Differences in temperature and salinity regimes in coastal waters near Point Lay under two different wind regimes. (After Wiseman and Rouse 1980.)

the wind component parallel to shore and responded rapidly (within a few hours) to changing wind stress. The alongshore flow was as high as 70 cm/s and commonly near 40 cm/s. These authors note that current data suggesting the existence of a coastal jet have also been taken near Point Franklin in the Chukchi Sea, and at locations in the Beaufort Sea.

Upwelling appears to be a common phenomenon in summer very near shore in the Barrow Arch (Wiseman and Rouse 1980; Hachmeister 1983). This is due to the frequency of strong northeasterly winds, which are ideal for causing upwelling. During periods of southerly or light northeasterly winds, warm, low-salinity waters lie near the coast; surface waters flow northward. But during strong northeasterly winds, these warm, brackish waters move offshore (at the surface) with Ekman drift; colder, saltier waters upwell along the coast; and nearshore surface waters move generally southward (Wiseman and Rouse 1980).

Wiseman and Rouse (1980) documented upwelling near Point Lay (Fig. 2.6) and Hachmeister (1983) observed it at Point Franklin (Fig. 2.7). Relatively rapid exchange of nearshore waters with lagoon waters may be expected (Hachmeister 1983) to maintain marine-like conditions in at least the open lagoons. Should upwelling events commonly occur throughout the coastal region of the Barrow Arch, and it appears probable that they do (Wiseman and Rouse 1980), there are important implications with respect to habitat quality of the nearshore and lagoon areas for invertebrates, fishes, and mammals that use these areas.

During the winter, both northerly and southerly current flows are common beneath the ice, although northerly flow prevails most of the time. Average velocities measured at six stations off Point Lisburne were low, seldom higher than 10 cm/s (Coachman and Aagaard 1981). Highest monthly average values have been recorded in December (maximum about 18 cm/s). Seven-month averages are in the range of 1-5 cm/s, but the low average values reflect in part the high variability in direction; instantaneous transport rates are somewhat higher.

Storms

Storms in the summer often generate winds to the northeast, further reinforcing the general current flow

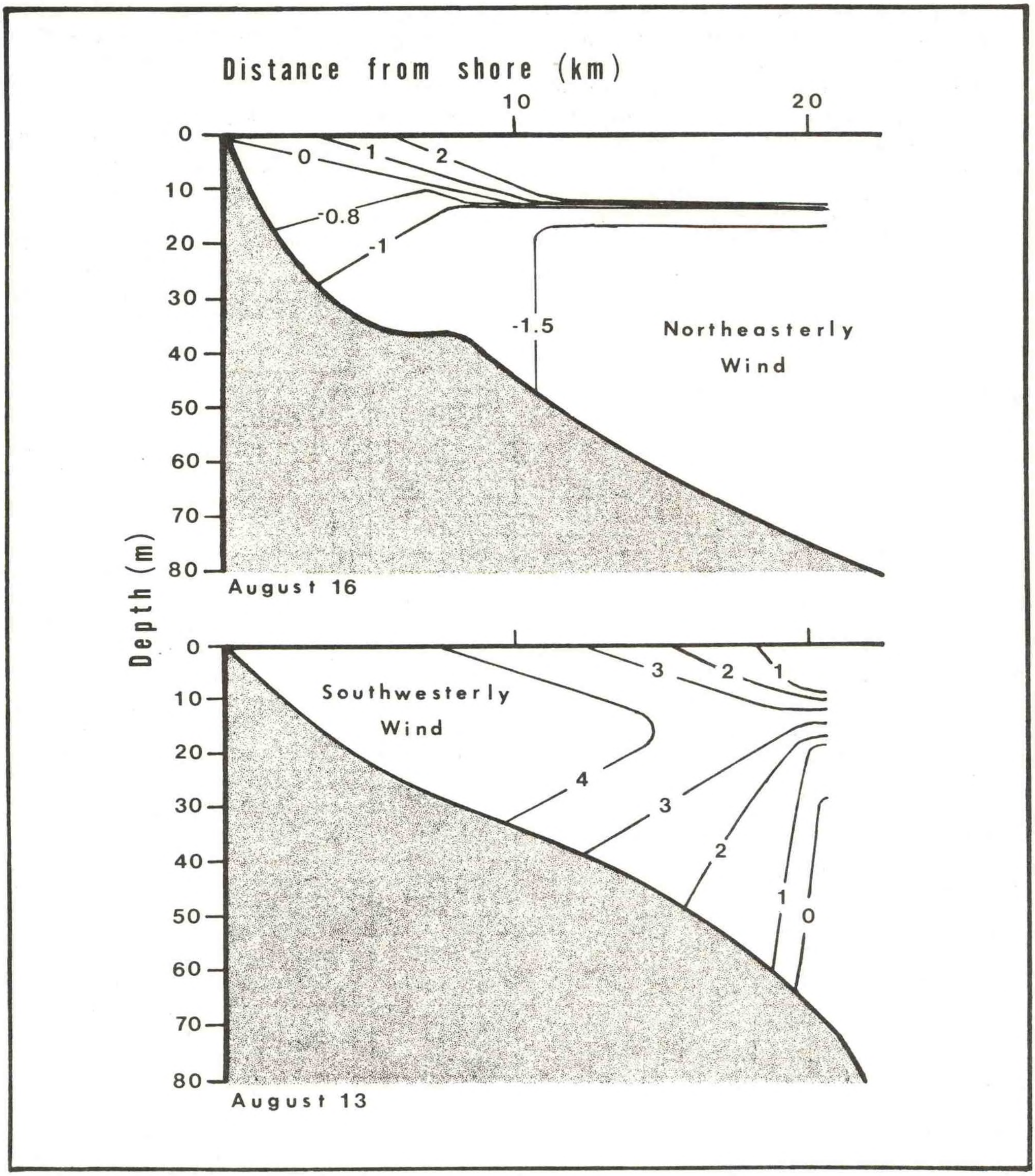

FIGURE 2.7—Differences in temperature profiles (°C) in the nearshore environment near Point Franklin under two different wind regimes. (After Hachmeister 1983.)

in that direction. During storms, high longshore surface flow rates are common in the region dominated by the Alaskan Coastal Current, ranging up to about 200 cm/s, but more typical velocities seem to be in the range of 50–80 cm/s (Hufford 1977). Subsurface rates are also relatively high. Velocities of about 60–75 cm/s have been recorded at depths of 10–54 m off Icy Cape and Point Franklin.

The first records of storm surges in the Chukchi Sea were made by Hunkins (1964) when Ice Island

T-3 was aground. For 6 weeks, sea level was recorded. A positive storm surge (40 cm) was related to the passage of a low-pressure system, and a negative surge to passage of a high-pressure system.

Since there are no permanent tide gauges along U.S. Arctic coasts, storm surge statistics can be inferred from a Canadian gauge in Tuktoyaktuk (Henry 1974). During the period 1962–73, surge amplitudes ranged from −1.10 to +1.89 m. The +1.89 m surge occurred on 4 October 1963, when a 3- to 3.5-m rise in sea level occurred at Barrow and produced the equivalent of 20 years of normal sediment transport.

Estimates of tides, sea level, and currents during storm surges have been derived from equations of motion and continuity for water and ice (Kowalik and Matthews 1982), driven by wind calculated from the pressure distributions available through the Arctic Ocean Buoy Program (Thorndike *et al.* 1982). The surge model has been tested against measured data from Tuktoyaktuk with good agreement. The data also indicate that ice cover slightly damps the amplitude of surges.

Typical maximum storm surge elevations in the Barrow Arch are on the order of 3–4 m, based on observations of coastal driftwood lines. At the northern edge of the region, if the 1963 storm surge at Barrow (3.5 m) is assumed to recur only once every 125 years on the average, then a storm surge of 2–3 m may recur on the average once every 10 years (Z. Kowalik, pers. comm.).

Tides

Tide enters the Chukchi Sea from the east Siberian Sea. In comparison to tidal amplitudes found on the Bering Sea shelf, those of the Chukchi Sea and the Barrow Arch are small, with correspondingly small tidal velocities (Liu and Leendertse 1984).

Sharma (1979, quoting Creagor 1963 and Wiseman *et al.* 1973) reported the tides to be semidiurnal. Wiseman and Rouse (1980) reported semidiurnal tides up to 15 cm in height between Cape Lisburne and Icy Cape. Three-dimensional models by Liu and Leendertse (1984) show the semidiurnal component to dominate, and the sea level variations due to tides to be rather small, about 10 cm or less (Fig. 2.8).

Simulations by Liu and Leendertse (1984) indicate that the propagation of tides is dominated by bathymetry. These authors state that circulation and transport associated with tidal propagation constitute one of the most important driving mechanisms in coastal waters.

Tides were measured in Peard Bay in the Barrow Arch area during August 1983 at three stations (W. Galen, pers. comm.). Peard Bay is about 6–7 m deep. Current velocities in the bay were tied closely to tidal fluxes. Tidal ranges were quite limited; the maximum tidal ranges observed were about 80 cm. Occasional storm surges probably provide much higher flushing rates than do tides in such semi-enclosed coastal areas as Peard Bay.

Peard Bay showed a mixed diurnal-semidiurnal tide. At locations near Point Franklin and in the center of the bay, velocities were usually 15 cm/s or less. Currents were stronger on flood tides than on ebb tides; farther from the coast, at the entrance to Kugrua Bay, tidal velocities sometimes reached 60 cm/s. Wiseman and Rouse (1980) noted that the tide period is close to the inertial period along the Barrow Arch coast, which would theoretically give large tidal currents for small tidal ranges, but they found small tidal currents near shore.

2.1.4 Ice

Several aspects of ice distribution and characteristics in the Barrow Arch are important in evaluating distribution and abundance of biota and transport and fate of pollutants. These are discussed briefly here. The subject of ice dynamics in relation to environmental hazards is given more detailed consideration in Chapter 3.

During most of the year the waters of the Barrow Arch are covered by first-year ice and perennial (polar pack) ice. First-year ice usually begins to form in the northern Chukchi Sea in October and its southward growth proceeds rapidly. Ice thickness continues to increase until April. Breakup occurs about mid-June in the southern Chukchi Sea and ice soon begins to recede northward (Sharma 1979). By early July the ice edge may have retreated up to a few hundred kilometers offshore in the Barrow Arch area, and by early September most of the area may be ice free (Colony 1979) (Fig. 2.9). The southern edge of the polar pack ice is normally not far south of the shelf break at any time.

The coastal regions are covered with shorefast ice for about 8 months. Generally, August and September are the months with the least sea ice in this nearshore zone. The extent of open water along the coast during summer is dependent to some extent on the wind field. Easterly and southerly winds keep ice pushed back from the coast once it has broken away (Sharma 1979); northerly or westerly winds bring ice to the coast.

Ice may sometimes act as an important agent of transport of pollutants that are on or just beneath the ice. Potentially of special importance in the Barrow Arch is the phenomenon of ice breakout, in which the ice occasionally moves rapidly southward in the nearshore shelf areas. About four times a year on average, southward-moving ice blocks Bering Strait, then "breaks out" as the ice arch plugging the strait fails. During these breakouts ice may move south-

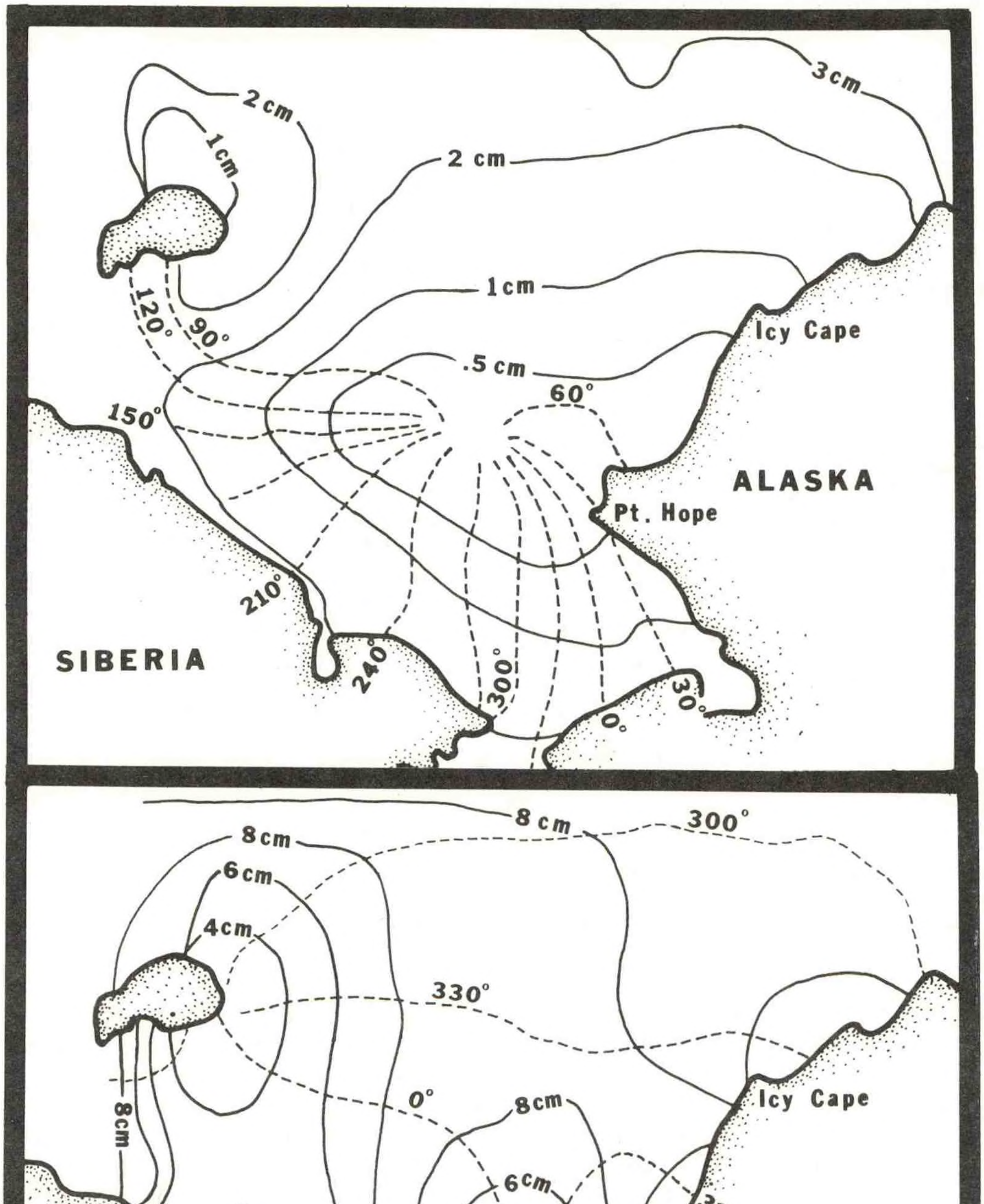

FIGURE 2.8—Computed co-tidal charts for the diurnal (upper map) and semidiurnal (lower map) tidal components in the Chukchi Sea, using the three-dimensional model of the Bering and Chukchi seas. (After Liu and Leendertse 1984.)

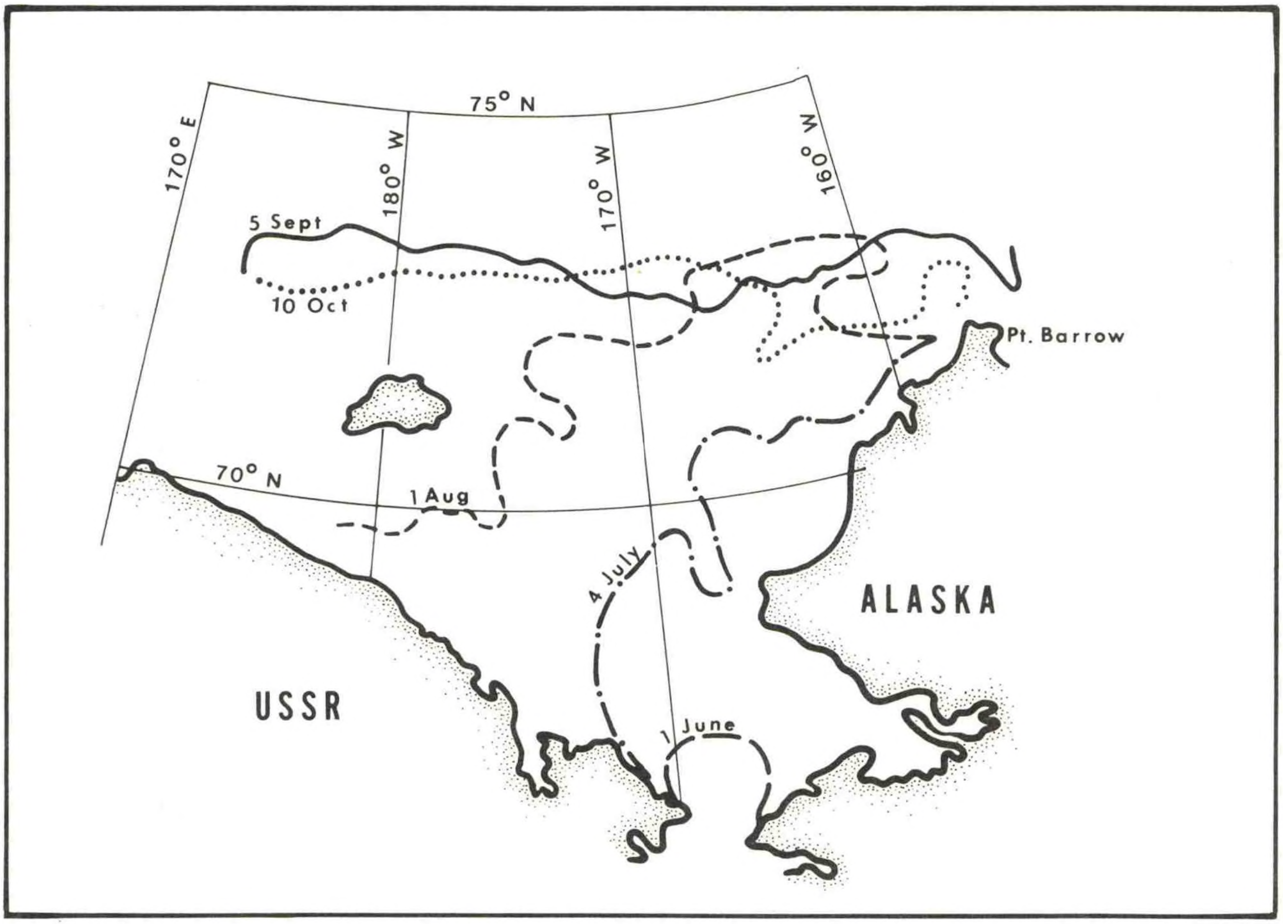

FIGURE 2.9—Ice edge margin in the Chukchi Sea, summer 1978. (From Colony 1979.)

ward from as far north as Barrow. It creates both a hazard to development and a transport mechanism for floating oil (M. Pelto, pers. comm.).

Another important ice phenomenon, with respect to its effects on the transport, fate, and effects of pollutants, is the annually recurring polynya near the coast in the Barrow Arch. In late winter and spring, easterly winds move ice offshore of the fast ice and a polynya forms parallel to shore between Cape Lisburne and Barrow (W. Sackinger, pers. comm.). In addition to forming a potential trap for floating pollutants (e.g., oil) in spring, this polynya system is used in spring, before other areas are free of ice, by important populations of sea ducks and bowhead and beluga whales. (The physical details of this polynya system and its importance to biota are discussed in Chapters 3–5.)

2.2 TRANSPORT OF SPILLED OIL

2.2.1 Hypothetical Trajectories

At the Barrow Arch Synthesis Meeting, transport of oil that could potentially be spilled at sea was evaluated by examining trajectories of oil spilled at selected sites. Trajectories were based on the Rand Corporation models (Liu and Leendertse 1984).

The modeling system used to simulate oil trajectories has a three-dimensional hydrodynamic model as one of the more important models. 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 finite grid. The vertical momentum, mass, heat, and turbulent energy exchange coefficients are computed from the turbulent energy, thus the model contains a turbulent closure computation. Turbulent energy dissipation due to mixing of heavier water with lighter water is accounted for in the turbulence closure. 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 the simulation of oil spill trajectories. The weather model is a stochastic model that contains a storm-track model component; it is based on synoptic weather analyses and storm-track statistics. It has been described in some detail by Liu and Leendertse (1984).

In addition to the hydrodynamics and weather models, models predicting the gravity-wave (Stokes drift) component and dimensions of the spilled oil are included. Details of these models have been described by Schumacher (1981) and Liu and Leendertse (1984).

At the meeting, hypothetical oil trajectories were launched at three sites in the Barrow Arch. Launch sites selected were near Peard Bay, Point Hope, and Point Belcher. The scenarios were discussed by L. Thorsteinson, S. Liu, B. Kirstein, and W. Samuels.

Scenario 1

In Scenario 1, it was assumed that a subsea pipeline rupture occurred in late summer near Peard Bay in 20 m of water. The ruptured line was shut down within a day, but not until 5,000 bbl of oil had been released. It was assumed that the wind persisted for 5 days between 30° and 90° at speeds between 10 and 15 knots.

In the scenario analysis, it was determined that the assumed winds were realistic, and that they would generate alongshore currents of 20–30 cm/s from the northeast, at least during the time the given conditions persisted. There would be approximately a 61% chance of oil reaching land within 30 days after the spill. Potential landfalls were all between Point Franklin and Point Barrow. Figure 2.10 shows 30-day trajectories for 40 launch points as predicted by the Rand model.

It was estimated that, within 30 days, 40% of the oil would still be at the surface, 40% would be dispersed in the water column, and 20% would have evaporated (assuming no landfall). After 30 days, the area that would be covered by a surface plume of 1 ppb concentration or greater of oil in the top 2 cm would be about 50 by 120 nmi at maximum. Surface concentrations would range from 2.3 ppm after 1 day to about 0.13 ppm after 30 days.

Scenario 2

Scenario 2 assumed that a subsea pipeline rupture occurred near Point Belcher on 1 March, and discharged 500 bbl of oil per day for 100 days. The rupture was assumed to occur 2 km offshore in a water depth of 5 m.

In the scenario analysis, it was recognized that sea ice is still thickening at this time and that ice cover would persist for essentially the entire 100-day period. Open water might sometimes exist in the region because of the configuration of the Chukchi Polynya or because of an ice breakout. Ice overlying the rupture, however, would likely be shorefast ice (about 1 m thick at the time of the spill) not likely to be opened by polynya formation or ice breakout. Only a 10–15% chance exists that the spilled oil would reach open water before breakup.

The under-ice layer of oil formed by the spill would reach 1–10 cm in thickness and eventually cover an area 150–500 m in diameter. The oil would be frozen in place within 2 weeks after it reached the undersurface of the ice. An estimated 98–99% of the original mass of the oil would still be present at the time the ice melted and the oil was released into open water.

The oiled ice could move in any of several directions depending on oceanographic and meteorologic events. It is possible that by June it would have been caught up in the general regional ice drift (Thorndike and Colony 1980) and moved as far as 300–500 nmi northwestward from the release site. If a breakout should occur and entrain the oiled ice, the ice would move southwestward toward Bering Strait, but the probability of the oiled ice reaching the strait would be less than 1%. (Chances would be greater should the oil be released earlier in winter than 1 March.) Chances of some of the oiled ice coming ashore to melt are relatively high—12% chance in 3 days after breakup, and 61% within 10 days.

If oil should be released in summer at this site (instead of spring), a hypothetical picture of the daily envelopes of oil for a 30-day period would look very much like that shown in Fig. 2.11, in which oil was assumed to be released near Peard Bay.

Scenario 3

In Scenario 3, it was assumed that a blowout occurred at the wellhead under a drillship in 36 m of water about halfway between Point Hope and Cape Lisburne. The blowout occurred in late June after an early breakup, with 1,000 bbl of oil per day released for 75 days before the blowout was controlled by a relief well.

It was further assumed that, at some time during the 75-day period, a constant 10-knot wind blew for 72 h from the west. Thermocline depth at this time was at 10 m, and alongshore currents were to the north at 0.5 knots. Under these conditions, oil from the release site reached shore near Cape Dyer (between Cape Lisburne and Point Hope) in about 33 h.

Given this scenario and what is known about regional oceanography and meteorology, it was predicted that the chances of oil coming ashore between Point Hope and Cape Lisburne would be 4% within 10 days and 27% within 30 days. An estimated 1,200 bbl of oil would come ashore given the winds described in the assumptions.

As the oil came ashore, concentrations of 5–7 ppb in the water column would be expected. In the surf zone (assuming it to be 20 m wide) about 0.50 kg

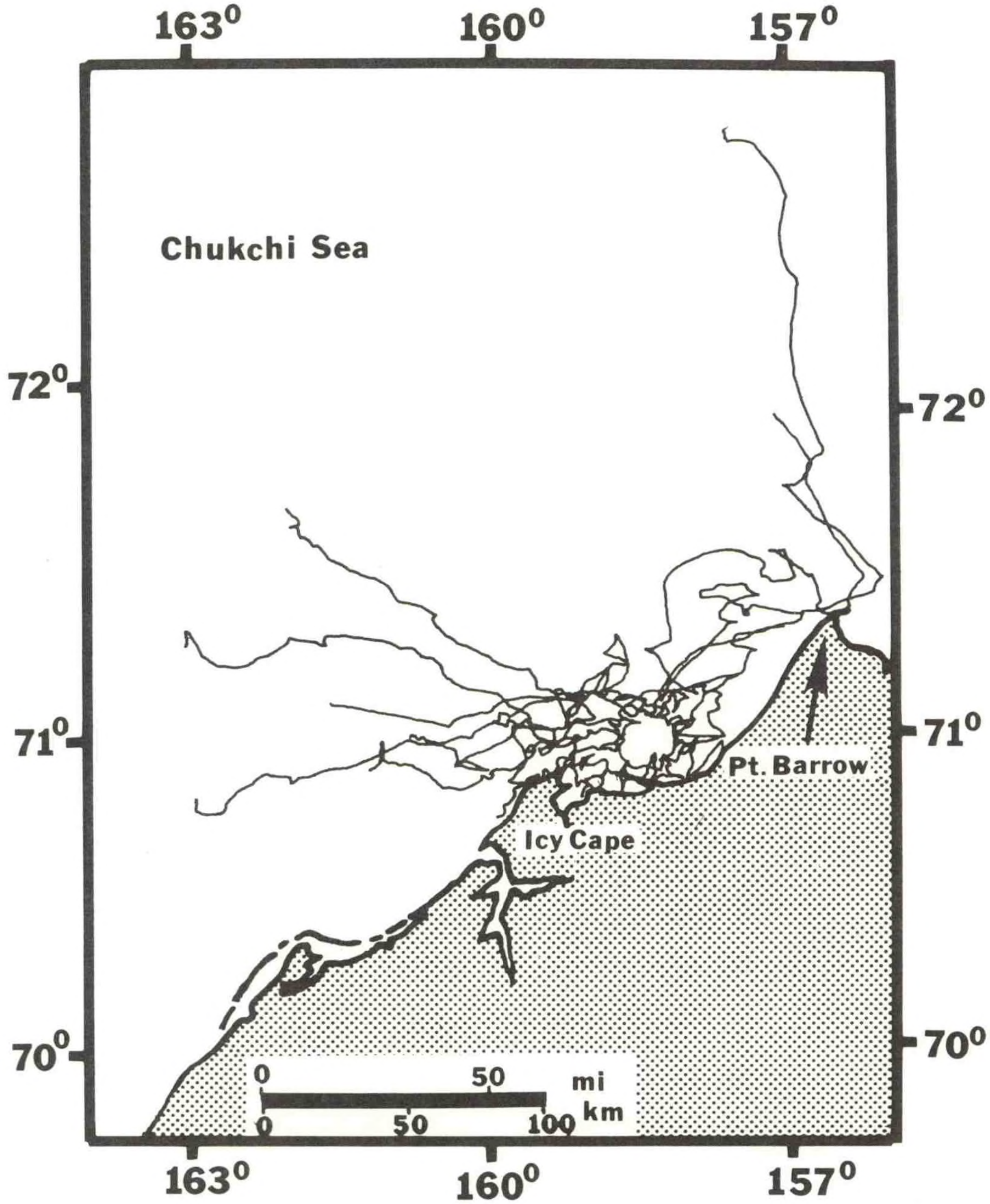

FIGURE 2.10—Thirty-day trajectories launched near Peard Bay during the summer oceanic period. (Provided by S.-K. Liu, Rand Corporation.)

of oil/m² would be deposited. Concentrations on the beach, assuming oil penetration to 10 cm, would be about 5.4 kg of oil/m³ in the 10-cm layer (equivalent to 0.0025 weight fraction).

Under most expected conditions, the oil would be transported seaward (Fig. 2.12). The most likely transport direction over the 75-day period would be northwestward, and by the end of the 75 days, oil would have traveled 220 nmi. Figure 2.13 shows, for this release site, predicted daily envelopes and paths, over 30 days, of an oil plume of <1 ppb surface concentration.

Assuming the conditions of water-column turbulence and net motion to be similar to those in Bristol Bay (for which more data are available), oil concentrations at the surface, in the water column, and in benthic substrates were predicted. Within the surface 2 cm, 2 ppm after 75 days had passed would be expected. In the water column (assuming a 10-m depth), there would be about 0.64 ppb total hydrocarbons after 75 days. Surface and water-column concentrations in the Point Hope–Cape Lisburne area would

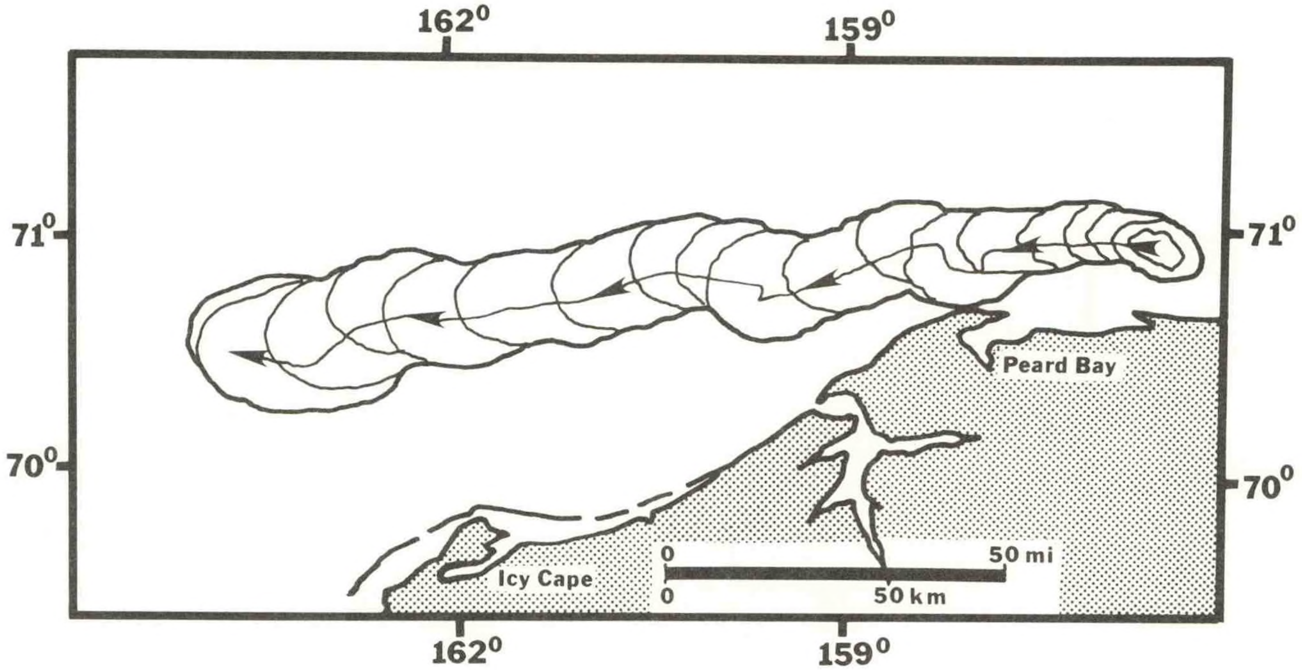

FIGURE 2.11—Daily envelope of 1 ppb surface concentration contour of a hypothetical spill of 500 bbl per day near Peard Bay under summer oceanic conditions. (Provided by S.-K. Liu, Rand Corporation.)

be expected to differ somewhat from those in Bristol Bay, because this part of the Chukchi Sea has more variability in drift pattern, smaller tides, and less turbulence than does Bristol Bay.

Concentrations expected to occur in benthic environments would vary from place to place and with time after blowout commencement. After 75 days, approximately 5–10 km² of sea bottom would be expected to be affected. Within this area, quantities of oil expected to occur in the benthos, and the area over which they would occur after 1, 2, and 3 days, were estimated (Table 2.1). In general, the areal extent of benthos affected would increase daily, but the concentration of oil in benthic environments would not.

2.2.2 Oil Spill Containment and Cleanup

The temporal and spatial effects of spilled oil are influenced by the timeliness and effectiveness of oil spill containment and cleanup. The scenarios just described assume that no oil containment and cleanup measures are brought to bear, and in this sense their predicted effects might be unrealistic. To put the potential effects of these scenarios in a more realistic context, it is appropriate to highlight a few points about oil spill cleanup technology.

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 without ice, 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 presented by spills on water containing ice, especially in rough seas. Figure 2.14 illustrates a summary of containment, recovery, and disposal techniques believed by industry to be feasible depending on surface conditions (Industry Task Group 1983a). Most of the emphasis is placed upon *in situ* burning of spilled oil during heavy ice periods, with oil recovery becoming more important in open-water season.

There is a great deal of controversy about the

TABLE 2.1—Quantities of oil expected to be found in benthic environments after 1, 2, and 3 days of a 1,000-bbl per day spill off Cape Dyer.

Quantity (g/m^2)	Areal Extent (m^2) Day 1	Day 2	Day 3
20	250	0	0
2	100	210	480
0.2	100	210	450
0.02	50	330	320

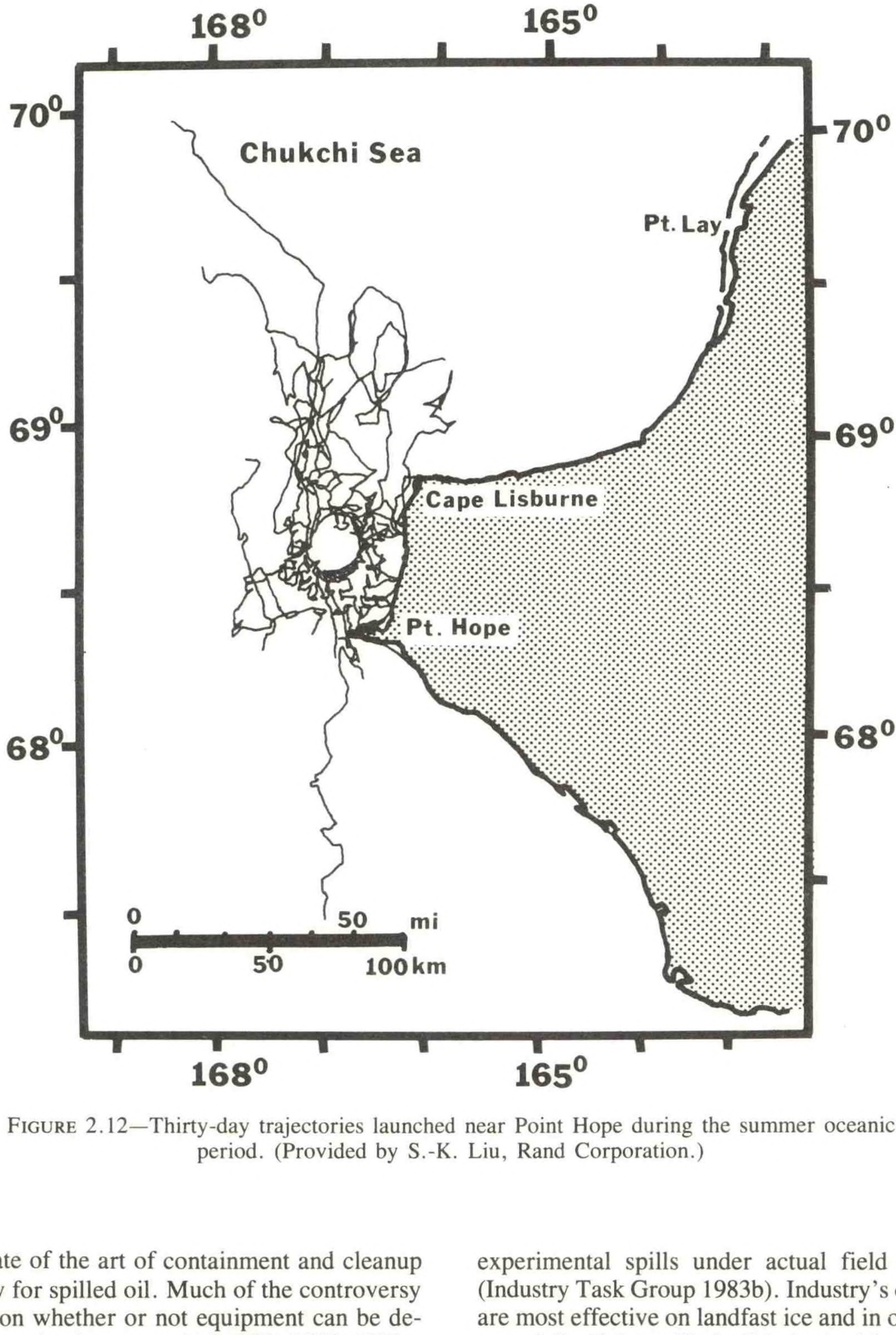

FIGURE 2.12—Thirty-day trajectories launched near Point Hope during the summer oceanic period. (Provided by S.-K. Liu, Rand Corporation.)

present state of the art of containment and cleanup technology for spilled oil. Much of the controversy centers upon whether or not equipment can be deployed where ice is present (ADEC/ADNR 1983a, 1983b). Concerns include availability and maneuverability of vehicles and vessels, residues and pollutants resulting from ignited oil, effectiveness of booming and skimming, and related issues.

Industry has demonstrated its abilities to mobilize equipment preparatory to containing and cleaning up experimental spills under actual field conditions (Industry Task Group 1983b). Industry's capabilities are most effective on landfast ice and in open water, especially if the spilled oil is ignited immediately. Spills in broken ice are more difficult to handle; the greatest success is had when the spill is contained within a small area close to its source. When a spill is dispersed far from its source or when ice is moving, containment and cleanup are most difficult (S. L. Ross Environmental Research Ltd. 1983).

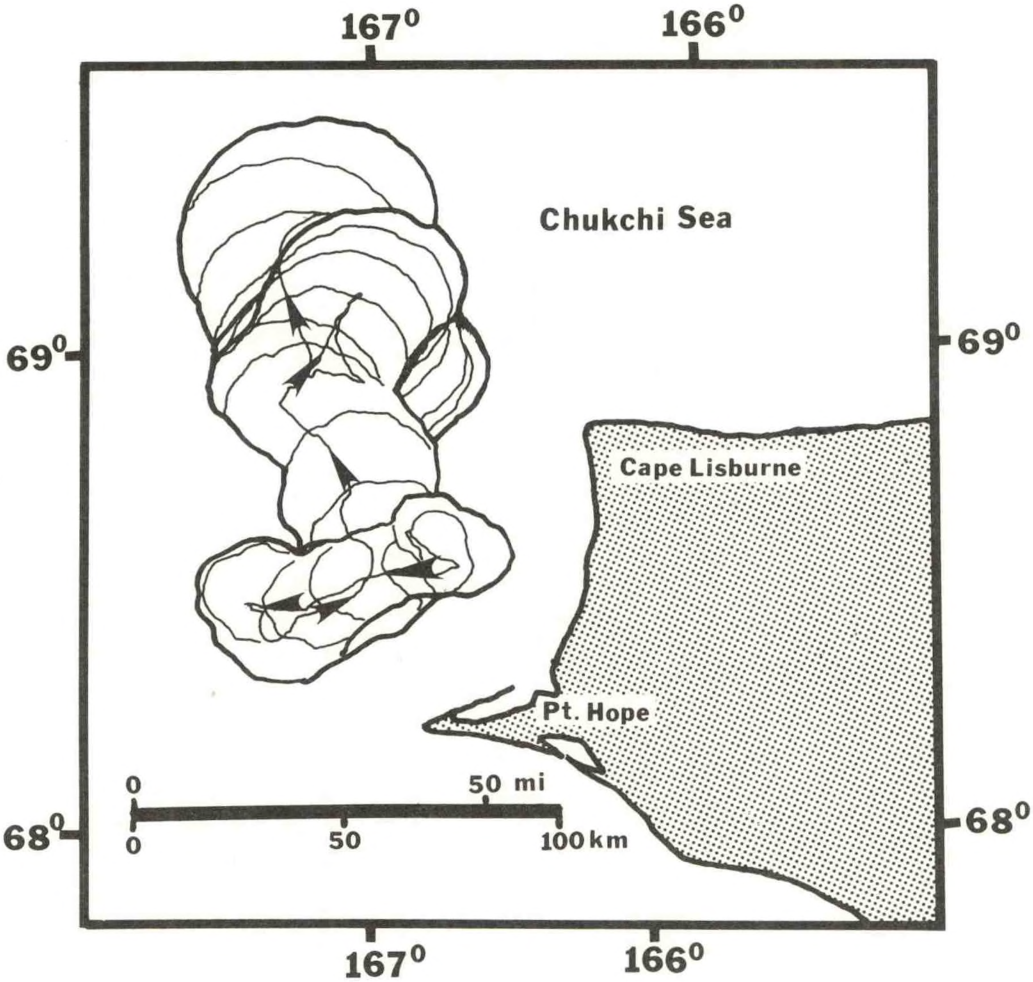

FIGURE 2.13—Daily envelope of 1 ppb concentration contour of a hypothetical 30-day continuous spill near Point Hope. Also illustrated is the centerline of the path reflecting the stochastic weather process compounded with nearshore circulation components. (Provided by S.-K. Liu, Rand Corporation.)

2.3 FATE OF SPILLED OIL

This section examines the probable fate of spilled oil. Field and laboratory data are evaluated and predictions are made of the probable fates of oil should it be spilled in the Barrow Arch planning area.

2.3.1 Field Results

The best available information on the fate of petroleum on arctic coastlines is that derived from the Baffin Island Oil Spill (BIOS) project, which spilled crude oil on a variety of beaches in a controlled field experiment (Owens *et al.* 1983). Results of the BIOS project indicate that wave energy is the major factor influencing the rate of loss of spilled petroleum from arctic beaches. After 1 year following experimental beach spills, a reduction in oil of at least an order of magnitude may be expected in sites exposed to intensive wave action. After 2 years, petroleum may not be detectable on high-energy beaches, and another order of magnitude in reduction may occur even on low-energy beaches. In sheltered bays, however, oil stranded in the intertidal zone may remain for many years. Virtually all evaporative processes appear complete within the first few weeks following a spill, and countermeasures such as the use of dispersants or forced flushing of sediments may not be any more effective in oil removal than are natural processes.

2.3.2 Laboratory Results

Research (Payne *et al.* 1983) on spilled oil in seawater wave tanks (0–38°C) indicates that the behavior of spilled petroleum (including evaporation, fractionation, adsorption onto suspended materials, dissolution, slick spreading rate, rate of bacterial

APPLICABILITY OF ARCTIC OIL SPILL RESPONSE TECHNIQUES

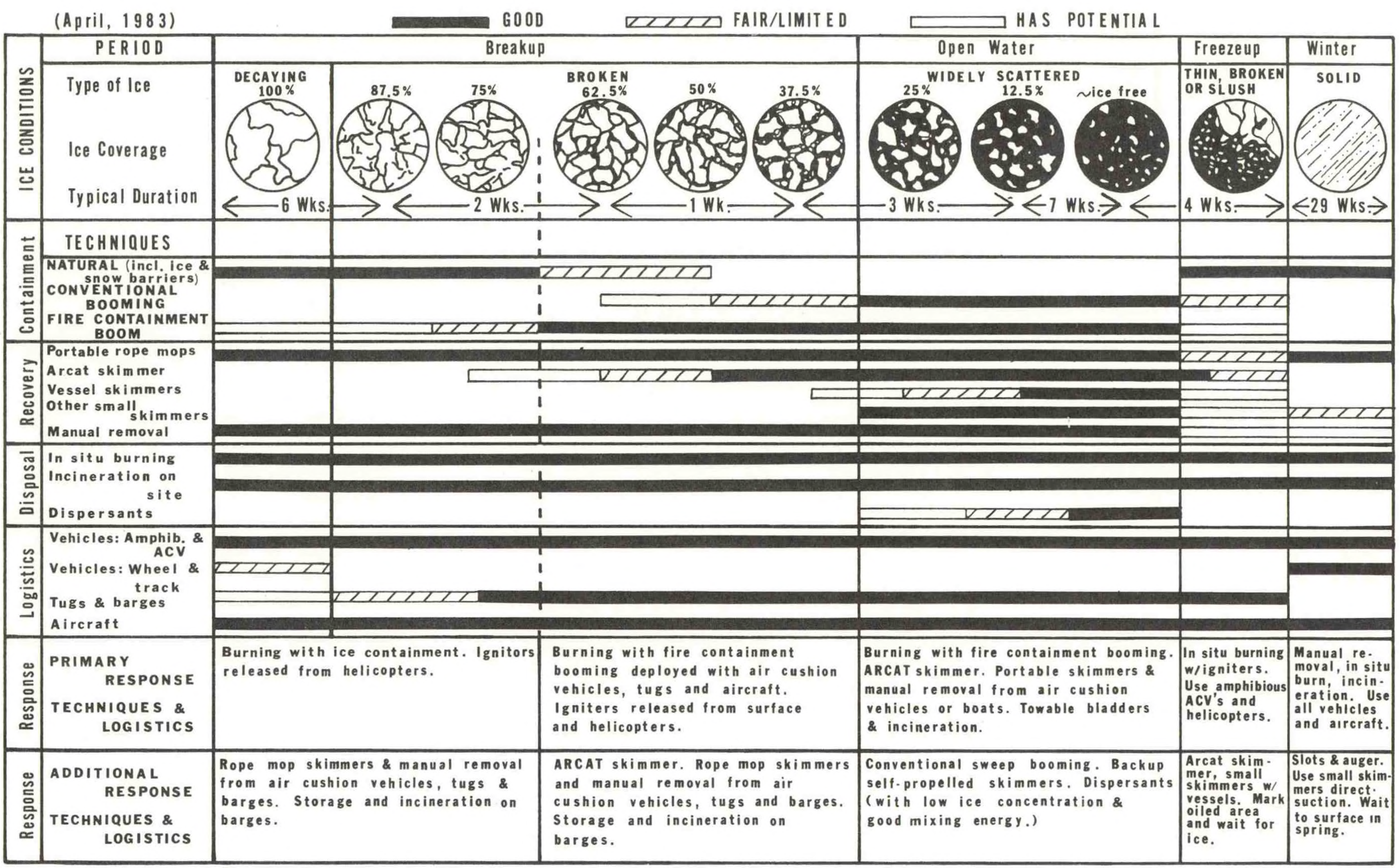

FIGURE 2.14—Summary of state-of-the-art oil spill response techniques in Arctic waters. (From Industry Task Group 1983a.)

degradation, etc.) can be predicted in arctic and subarctic environments. In general, weathering includes a loss of lower molecular weight fractions, dissolution and dilution of aromatics and other water-soluble compounds, an increase in viscosity and cohesion of slick components, and an increase in water content of emulsified fractions. Most of these processes reach nearly steady-state values in a few weeks or months, the time depending upon the type of oil spilled and the environmental conditions to which the oil is exposed after release.

Experimental results indicate that, with continuous agitation under low temperatures, most spilled petroleum components reach near equilibrium concentration values in the water column beneath slicks within a few days (Fig. 2.15). Rates of change in many characteristics of weathering oil in water (e.g., density, percentage water incorporated in oil, interfacial tension) rapidly decline within several days (Fig. 2.16). Ice conditions strongly affect the weathering process. Tar balls undergo bacterially mediated degradation, and may continue to release sheen for longer periods of time as their surface layers are solubilized. The nature and composition of the slick are thus very dependent upon the time and distance between release and impact points. At points downstream, slick characteristics are also dependent to some extent upon ice cover and weather en route, and original composition.

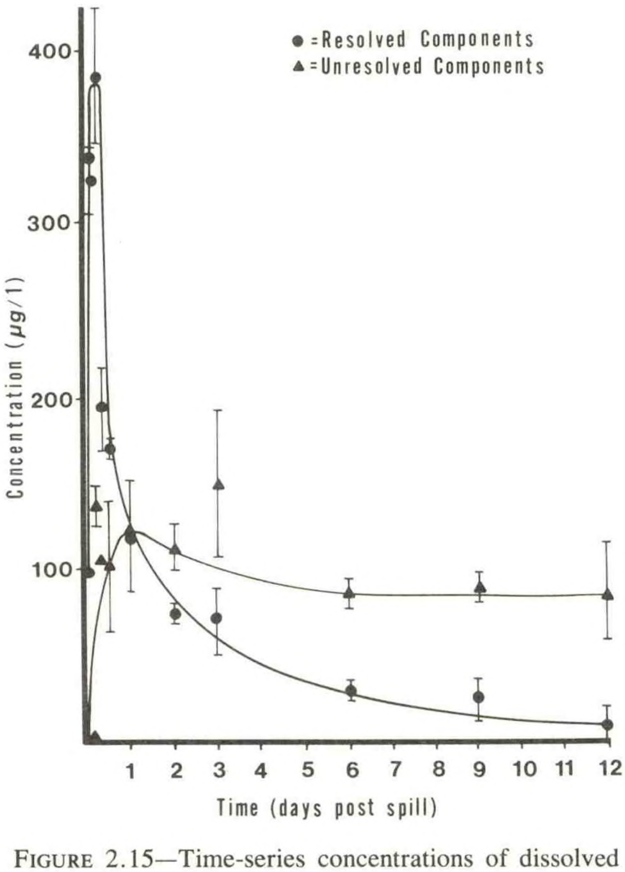

FIGURE 2.15—Time-series concentrations of dissolved hydrocarbons in the water column as determined by the total resolved components and unresolved complex mixtures present in chromatograms of seawater extracts. Values are means of measurements from three experimental wave tanks. (From Payne *et al.* 1983.)

2.3.3 Predictions for the Barrow Arch

Hypothetical trajectories and depositional fates of oil under three scenarios were discussed in Section 2.2. A summary of some of the possibilities for deposition follows, along with brief conclusions about the fate of oil once it is deposited.

If a petroleum spill should occur near shore during the winter in the Barrow Arch, the oil might become incorporated within the new ice forming at the edge of the coastal polynya, advected within the polynya, or incorporated into ridges when the polynya closes (Stringer 1982). Depending upon which way the ice is moving at the time, the oil could either be moved offshore (most likely) with the ice, or transported onshore and released at breakup.

The relative exposure of various portions of the Barrow Arch coastline to spilled petroleum will depend on the precise site of a spill, and on the weather at the time of the spill. Open coastal areas will be more likely to be exposed to contamination by oil spills than those areas protected by barrier islands. The seaward sides of barrier islands, obviously, will be exposed to the same degree as other open coasts.

Approximately 50% of the Barrow Arch coastline consists of barrier island–lagoon or wetland habitats (J. Harper, pers. comm.). (A precise breakdown of lagoon and wetland types and their relative vulnerabilities to contamination by oil was not available for this report.) Since some lagoons have few and small inlets, there are not many places for oil to get behind the barrier islands from the outside ocean. Further, many wetlands may be well above normal high tides. These habitats may be somewhat insulated from offshore spills. In addition, it may under most circumstances be possible to protect some of the lagoons (e.g., with booms). But other lagoons (e.g., Peard Bay) are less well protected by spits and islands, and may be difficult to protect from oil spilled in the adjacent ocean.

Much of the Barrow Arch outer coast will probably clean itself of any spilled oil relatively rapidly during the open-water season, due to wave action. Of chief concern are the lagoon systems inshore of the barrier islands, and the wetlands in low-energy environments, which may be slower to purge. If spilled petroleum did get into protected lagoons, or wetlands, it might remain for many years. The retention time would probably be closely related to weather, with

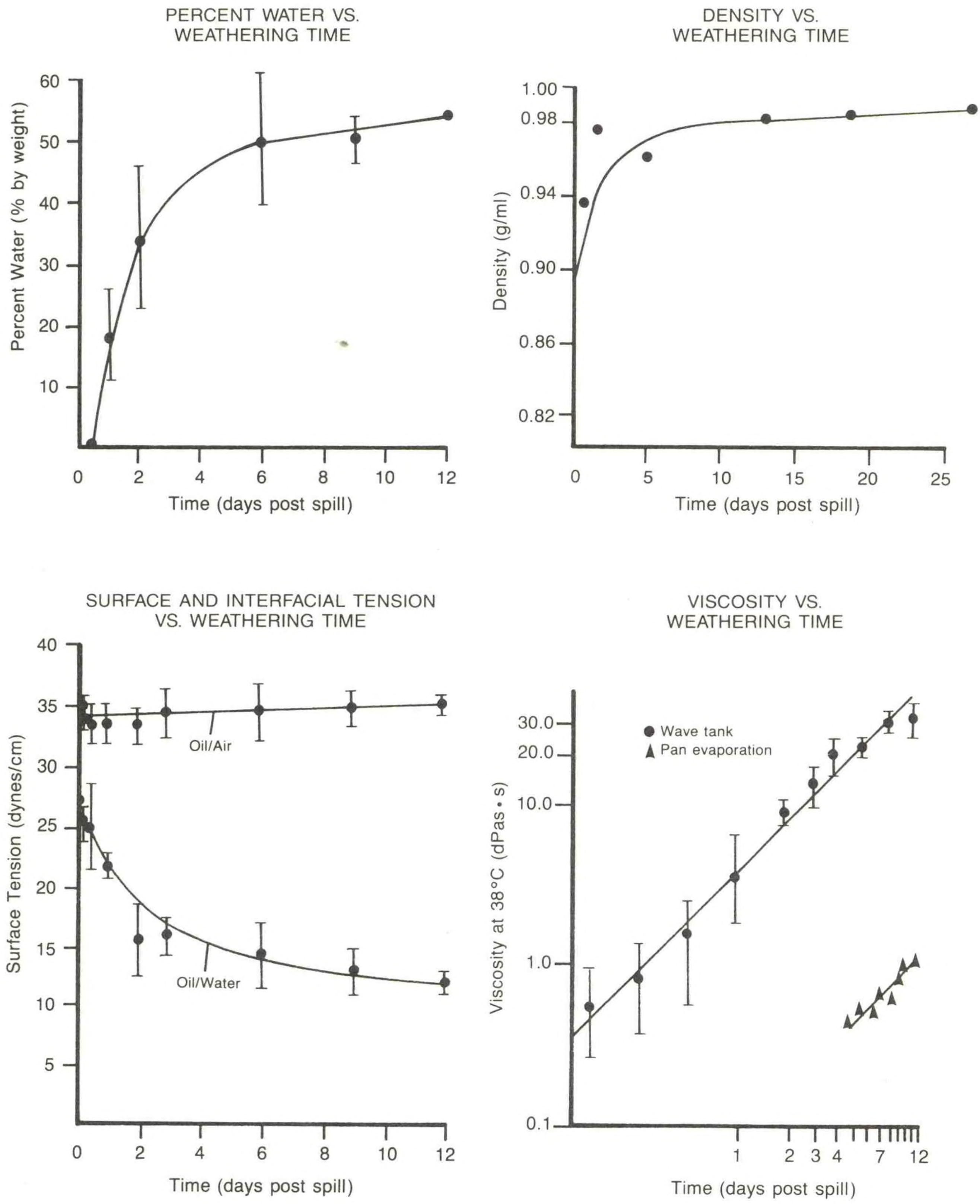

FIGURE 2.16—Patterns of change through time in rheological properties of Prudhoe Bay crude oil as determined in experimental wave tank systems. Values are means from three tanks ±1 standard deviation. (After Payne *et al.* 1983.)

calm periods favoring retention and rough weather favoring oil removal. During storms, flushing of protected lagoons has been observed, with water flowing northeastward through the lagoons and out over the northern barrier islands.

2.4 TRANSPORT AND FATE OF DRILLING FLUIDS AND CUTTINGS

Discharges of drilling muds and cuttings differ from releases of oil in that the quantity and quality of drilling muds and cuttings that will be released is predictable and subject to permitting. Once the lease sale has been held, even the locations of these releases are somewhat predictable, and thus their transport can be described on a site-specific basis. During the initial stages of exploration at least, the transport directions and magnitudes will be determined by currents in the vicinity of drillships during the open-water season.

Two types of discharges normally occur: the mud and cuttings released during drilling, and bulk discharges from storage tanks at the end of drilling (Schumacher 1982). Quantities of daily discharges of mud and cuttings range from 100 to 300 bbl per day. Typically 5–15 bulk discharges of 50–200 bbl will occur per well, with a final 500–2,000 bbl of bulk discharge.

Discharges contain both particulates that settle and solutes or collodial material that spread 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 200–500 m from the drill site (Meek and Ray 1980). Plume dimensions and attenuations of concentrations in the horizontally spreading plume depend on current velocity and rate of discharge. A typical detectable plume would be 100–200 m wide and 2–4 km long, and would therefore cover an area less than 1 km^2 (Schumacher 1982).

It is clear that effects of drilling fluid and cuttings discharges are much more limited in space than effects of moderate to large oil spills. Further, because regulations generally prescribe biologically innocuous materials in drilling fluids, only slight biological effects from these discharges are expected. Most long-term effects will be in benthic environments, where discharges may accumulate locally around the drill site.

2.5 SUMMARY

This chapter describes (1) those aspects of the physical environment of the Barrow Arch that could potentially influence the transport and fate of pollutants discharged at sea, (2) transport of spilled oil under three hypothetical trajectory scenarios, and (3) the probable fates of oil and drilling muds and cuttings.

Nearly half the length of the Barrow Arch coast is exposed to the sea; the other half is sheltered from the open sea to some extent by spits, points of land, or barrier islands. Northerly reaches of this coast are backed primarily by high tundra cliffs, much of the middle region is fronted by low-lying barrier islands, and the southern coasts have high topographic relief with cliffs up to 300 m above sea level.

Prevailing meteorological conditions at the coast are controlled by two main factors: areawide pressure systems and sea breezes. In most seasons, prevailing winds are northeasterly but the major storms in summer and fall come from the southwest. Winds usually follow coastal pressure gradients. When summer winds caused by pressure systems are minimal, the thermal contrast between the land and the sea causes onshore sea breezes.

There are several major components to open-water circulation. Beyond depths of 20–30 m, the predominant direction of water movement is northeastward (forced mainly by Bering Sea Water influx) and parallel to depth contours. Clockwise eddies typically form downstream of points of land—Cape Lisburne, Icy Cape, Point Franklin. In shallow water inshore from the Cape Lisburne eddy, and perhaps adjacent to other stretches of coast, a baroclinic coastal jet parallels the coast in the direction of the wind. Upwelling of relatively cold and saline outer shelf water into coastal areas commonly occurs under strong northeasterly winds. Northeastward flow predominates in winter beneath the ice, but periodic southwestward currents are also common in winter.

Most storms come in summer and fall, from the southwest, augmenting the predominant northeastward water movement. Longshore flow rates as high as 200 cm/s and positive storm surges of more than 1.8 m (generating >3 m rise in sea level at the coast) have been recorded, but less severe storms are the norm. Tides are very small in comparison to wind-induced sea level changes.

Ice covers nearly all of the Barrow Arch for about 8 months each year. Shorefast ice extends out to approximately the 20-m depth contour by late winter. An open-water lead system commonly separates shorefast ice from moving ice in spring. About four times a year nearshore ice flows rapidly southward for several days when strong northeasterly winds cause ice plugging Bering Strait to break out and move southward into the Bering Sea.

An evaluation of hypothetical oil spills indicated that, in most cases, oil spilled in nearshore waters would move seaward rather than coastward. In open water, 30 days following a 1-day release of oil, only

20% would be evaporated; 40% would still be in the water column and 40% in the surface layer. Oil spilled under shorefast ice in early spring would subsequently be incorporated into the ice; it could possibly reach shore upon ice breakup, but more than likely would move seaward to the northwest. In a blowout situation where oil is released continuously from the sea floor, a relatively small amount of sea bottom (5–10 km²) would be measurably affected.

Oil spill containment and cleanup is most difficult in rough, ice-infested seas. Large percentages of oil spilled in calm, open water or on ice can be quickly recovered with existing technology. Containment and cleanup becomes increasingly difficult as oil disperses farther from its source.

Results of field research experiments show that rates of loss of oil from beaches are directly proportional to the intensity of wave action on the beaches. Laboratory experiments indicate that rates of oil weathering in Arctic waters decline rapidly from the time of the spill, such that almost steady-state conditions in such characteristics as dissolution and dilution, viscosity, and cohesion of slick components are reached within a few weeks or months. Most spilled petroleum components reach near equilibrium concentration values in the water column beneath slicks in a few days.

In the Barrow Arch, open coasts are more likely to be contaminated by oil spills than are semi-enclosed areas such as lagoons and inlets. However, should oil reach the relatively quiet waters behind islands or spits, its persistence there would be much greater than it would be in waters and beaches that are more exposed to wave action. Storm conditions favor more rapid removal of oil from coasts regardless of the site of deposition.

Discharges of drilling muds and cuttings are relatively predictable (in comparison to oil discharges) in quality, quantity, and location of release. The radius of measurable impact of muds and cuttings on benthic environments is typically 200–500 m from a drill site. In the water column a typical detectable plume would cover an area less than 1 km². The effects of drilling muds and cuttings are expected to occur over much smaller areas and cause fewer adverse consequences than would be the case should a major oil spill occur.

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3

Environmental Hazards to Petroleum Industry Development

by George S. Lewbel

With contributions from J. R. Harper, D. W. Hirschaut, H. Jahns, R. P. Johnson, D. E. Kenney, J. Kravitz, N. Masri, R. L. Phillips, R. W. Roberts, and D. K. Thurston. Meeting Chairman: W. M. Sackinger.

Environmental hazards that are potential concerns in the Barrow Arch include seafloor sediment instability, subsea permafrost, gas-charged sediment, sea ice, storms, and shoreline instability. Seismic and volcanic activity, important in some areas of the Alaskan continental shelf, are considered to be unlikely risks in the Barrow Arch.

As discussed in Chapter 1, the most likely initial means of drilling for oil would be by drillships operating for about 90 days during the open-water season. Floating or anchored platforms might be used in later years to extend the drilling season into the ice-covered period. Oil would most likely be carried to shore by subsea pipelines from ice-strengthened production platforms anchored on the sea floor. Drilling and production operations would be serviced by helicopters, icebreaking work-supply boats and barges, and perhaps air-cushioned vehicles. Icebreaking tankers are a possible alternative to pipelines for shipping produced oil to market.

Specific hazards to the types of operations envisaged are potentially several. Sediment movement associated with unstable areas on the sea floor might cause stress on pipelines on or buried in the sea floor, or erode sediments from above buried lines in shallow water such that ice gouge could become a problem. Gas-charged sediments could promote blowouts if penetrated during drilling operations. Moving sea ice poses a risk to shipping and drilling activities that occur near each end of the open-water season or in winter. Storms, particularly those in ice-infested waters, generate waves and currents potentially hazardous to drilling and production platforms. Unstable shorelines could pose risks for shore-based facilities such as docks and pumping stations.

3.1 POTENTIAL SEAFLOOR HAZARDS

3.1.1 Surficial Geology and Sediment Stability

Much of the Barrow Arch lies on the broad, flat continental shelf. The average depth is about 50 m, though northern parts of the area extend over the shelf break to depths of approximately 80 m. Even on the relatively flat shelf, however, there is some vertical relief (Fig. 3.1). Herald and Hanna shoals reach to within 14 to 20 m, respectively, of the surface. The head of the Barrow Sea Valley, with depths exceeding 60 m, lies just north of Peard Bay. There are also many nearshore shoals, generally in water less that 25 m deep, especially off the capes.

Bedrock in the area consists mainly of hard Cretaceous sandstone. Out to a distance of at least 30 km from shore, the bedrock has only a thin unconsolidated overburden, and outcrops of bedrock are common (Moore 1964; Creager and McManus 1967; Grantz *et al.* 1982). Much of the sediment layer is less than 5 m thick. Between Point Barrow and Icy Cape, sediments are thickest near the shoreline (Fig. 3.2), reaching a maximum depth of about 15 m. The thickest sediment lies in the shoals off the capes (Creager and McManus 1967), and landward of the barrier islands.

In some areas, relict channels and valleys exist. Within these features, deeper sediment may be found (Grantz *et al.* 1982). For example, the ancient channel of the Kuk River, west of Wainwright, is filled with 18–23 m of Holocene-Quaternary sediment. A complex of ancient valleys north of Herald Shoal contains up to 50 m of fill. Near the coast, such ancient features may be useful as routes for pipelines, since sediment layers elsewhere may be too thin to

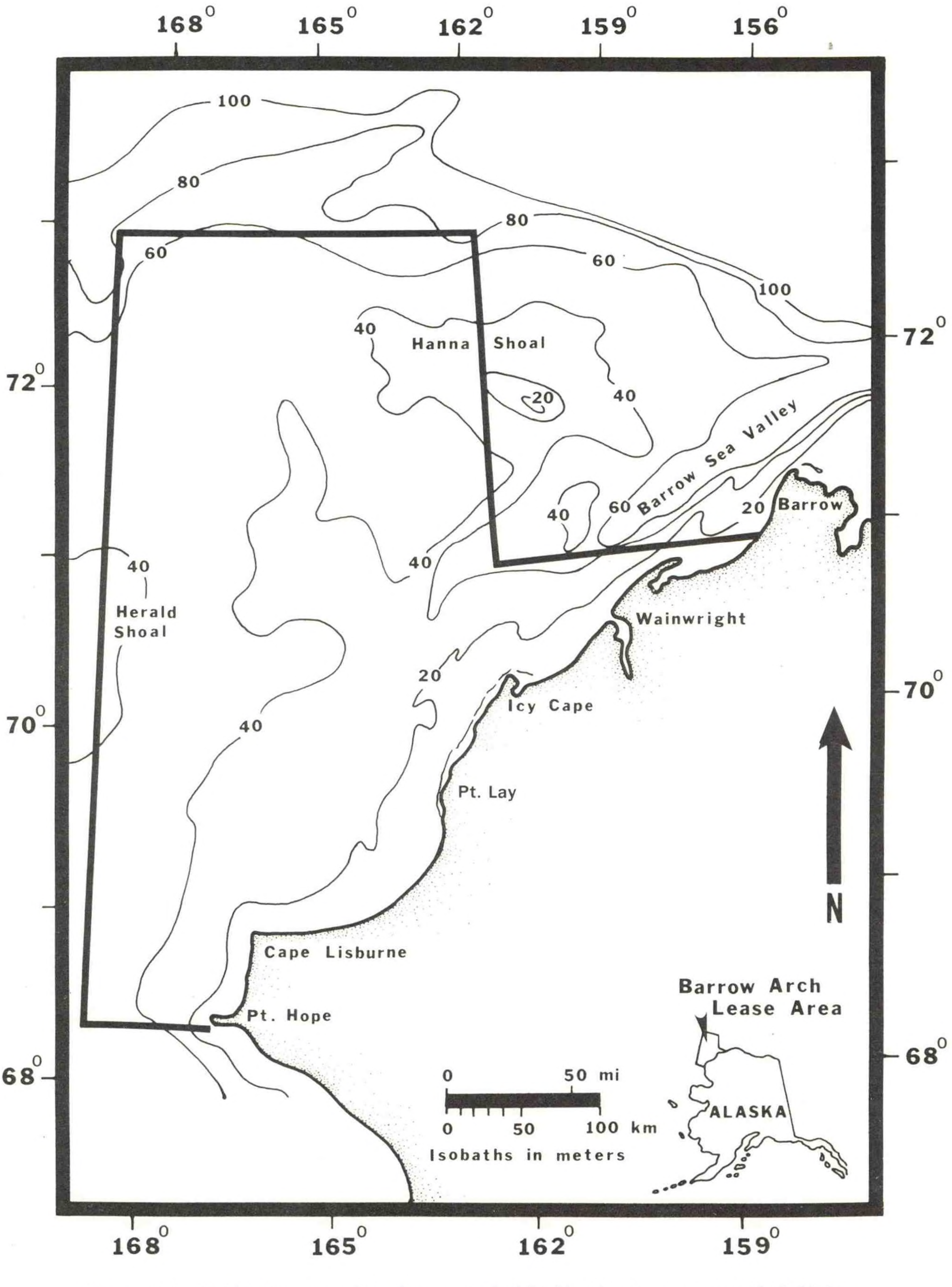

FIGURE 3.1—Shelf bathymetry of the Barrow Arch OCS Planning Area, eastern Chukchi Sea.

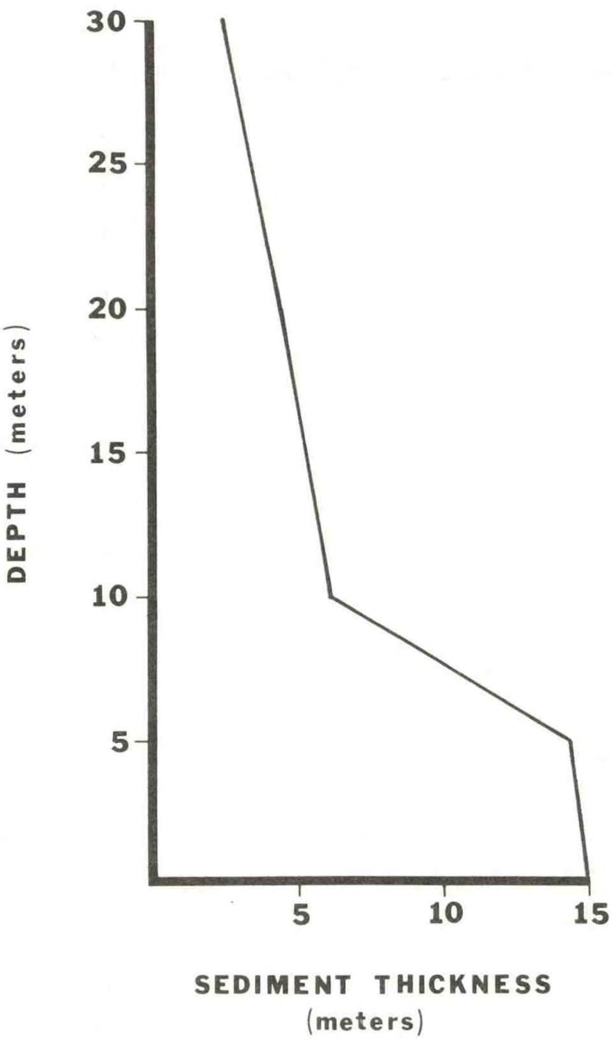

FIGURE 3.2—General sediment thickness as a function of water depth in the Chukchi Sea shelf between Point Barrow and Icy Cape.

provide protection from moving ice without trenching in bedrock.

Most of the unconsolidated sediments on the Chukchi shelf consist of mud, sand, and gravel (Fig. 3.3). Mud is usually restricted to the deeper parts of the shelf, and the lagoons and protected bays. Extensive gravel beds are found near shore, especially between Point Lay and Point Hope, between Icy Cape and Wainwright, and between Point Franklin and Skull Cliff. The gravels are probably derived from coastal bedrock cliffs. Gravel patches, which may also include boulders, support kelp beds between Point Franklin and Skull Cliff, and south of Wainwright (Hanna 1954; Phillips *et al.* 1982; Phillips and Reiss 1983).

There are many sandy areas in the Barrow Arch which change shape, size, and position. Nearshore, in water depths less than 10 m, there are small patches of sand ridges up to 30 cm in height, usually separated by gravel. These ridges are oriented 90° to shore. The ridges are believed to be formed by shoaling waves, probably under storm conditions.

Farther offshore, within the influence of the Alaskan Coastal Current (*see* Chapter 2 for descriptions of currents), there are extensive, low profile, migrating sandwave fields. They have been found west of Point Lay, west and north of Icy Cape, north of Wainwright, and north of Point Franklin. The migrating sandwave fields consist of long ridges up to 0.5 m high and occur in waters as shallow as 16 m. Ridges in most areas tend to be oriented roughly normal to shore, implying net transport is to the northeast. The sandwave fields are often patchy, and interspersed with regions of gravel and bedrock.

In some areas, such as Icy Cape, there are large submarine sandbanks. Some of these large features are probably formed by coalescence of migrating sand waves that "stall" in particular locations due to current patterns. East of Icy Cape, sandwave migration is toward the west (probably caused by a current eddy; *see* Chapter 2), while sandwave migration is to the northeast on the southern side of the cape. The confluence has produced a 16-m-high sandbank rising from a depth of 22 m to 5 m. Sandwaves or ripple marks on the top of the bank are up to 1 m high. Large sandbanks have been detected in other areas in water as deep as 56 m. Between Icy Cape and Cape Lisburne, there are other sandbanks up to 12 m high, extending upward from depths of 23–30 m. These may have been formed from a combination of ice groundings and sandwave migration.

The distribution, and rate and direction of movement, of the large sandbanks is not known. The large banks may even give rise to other sandwave fields, serving as temporary reservoirs for sand passing through. For example, the sandbanks near Icy Cape apparently furnish sand to sandwave fields to the north. Not all of the large banks are sand. A gravel ridge at a depth of 10 m has been found, and there are other ridges of muddy sand.

The source of the sediment responsible for the sandwave fields, banks, and ridges is not known. It is doubtful that the sandwave fields are drowned barrier islands. Erosion of coastal tundra with high sediment content has been described as the main source of sediment supplied to the coastal zone (Owens *et al.* 1981), and is the most likely source for the sandwave fields and sandbars. Local rivers probably carry relatively small amounts of sediment to the coast; furthermore, much of their sediment is dumped in nearshore lagoons (Harper 1978). It is possible that an appreciable amount of sand from inland is carried to the coast by aeolian transport,

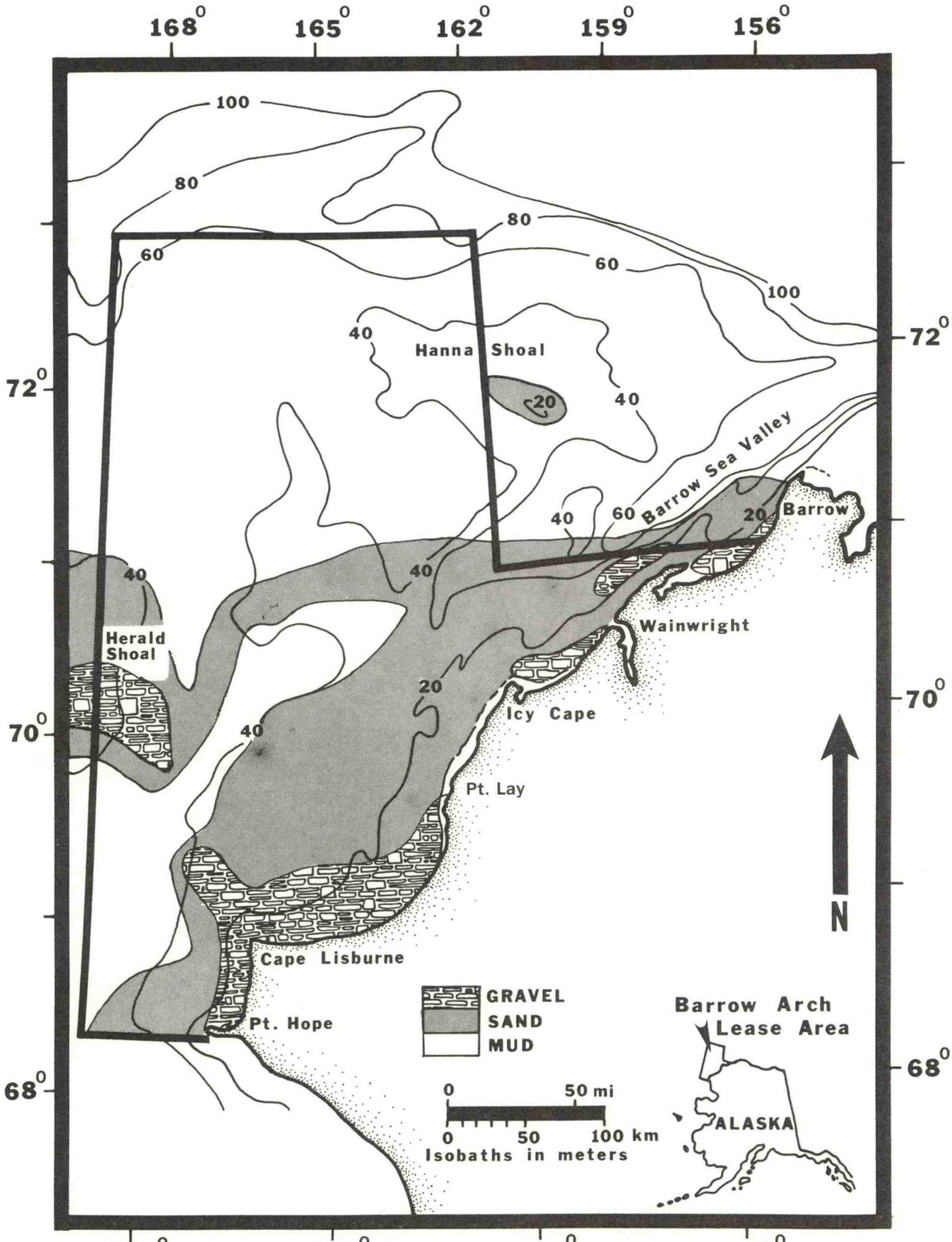

FIGURE 3.3—Distribution of surficial sediments within the Barrow Arch. (Provided by W. Sackinger.)

perhaps from great distances.

As a result of the impermanent nature of many of these seafloor features, they may be potential obstacles to navigation and construction. Frequent surveying is likely to be necessary, and seasonal dredging in areas of vessel traffic may be required. Pipeline routes will also have to take periodic burial and exposure into account unless they are trenched into bedrock, or placed within ancient river channels or valleys.

In addition to these types of seafloor instability, there may be a potential risk of seafloor slumping along the northern border of the planning area, on the shelf–slope break (Fig. 3.3). This hazard cannot be evaluated due to lack of high-resolution regional seismic data.

3.1.2 Subsea Permafrost

In lieu of any specific data, but in the presence of a good deal of circumstantial evidence and speculation, the prevailing opinion at the synthesis meeting was that subsea permafrost will be minimal or nonexistent throughout the planning area, except possibly very near the coast, and perhaps contained in layers within bedrock. The surficial sediments overlying bedrock are thought to be too thin to have retained subsea permafrost. Coastal submerged areas are thought to have been under water for a long time. Evaluation of data in Coachman *et al.* (1975) indicates that average annual benthic water temperatures of at least the environments nearer shore may be above the freezing point.

3.1.3 Hydrates or Other Gas-charged Sediments

Gas hydrates in other areas have typically been found at drilling depths of 200–300 m. Profiles to date in the Chukchi Sea have not shown any likely major areas of gas hydrates. There may be some gas-charged sediment in the fill of the ancient river channels and valleys (e.g., the Kuk River paleochannel), and hydrates may possibly be found in other areas. There are no seismic data to confirm or reject the premise. In Norton Sound in the northern Bering Sea, gas-charged sediments have been found to be a common phenomenon (Kvenvolden *et al.* 1981).

3.2 CHUKCHI POLYNYA AND SEA ICE

3.2.1 Chukchi Polynya

First-year ice can build up very rapidly in late winter and spring in the eastern Chukchi Sea due to the existence of a persistent polynya along the coast (Stringer 1982). Within the polynya, open water and very low air temperatures result in continuous ice formation. The polynya is formed when prevailing winter and spring winds toward the west blow, moving ice away from shorefast ice. This tends to keep the polynya open from January onward. Its average width between February and April is 1 km or less (Fig. 3.4). Between May and June, it is wider near Cape Lisburne than near Barrow (Fig. 3.5). The polynya is usually open wider at its southern end than at its northern end at any given time. Off Point Lay, its average width is about 75 km in June. It continues to expand, until by August it is virtually always open at the southern end, and its average width at Point Lay is over 300 km. In September, the polynya as such has been replaced by open water unbounded by ice. In October, the freezing process begins again.

The polynya contributes a great deal of highly saline, cold water (''brine rejection;'' Schumacher *et al.* 1983) to the bottom water in the winter. During the freezing process, salt is extruded and sinks rapidly. The hydrographic signature of this water is distinct and detectable far to the north of the point of origin, confirming transport of water into the Arctic Ocean.

The Chukchi Polynya is an important migration pathway for bowhead and beluga whales and eider ducks in spring before the ice opens elsewhere (*see* Chapters 4 and 5). At the same time, it is an area where oil could potentially be released (*see* Scenario 2 in Chapter 2). Consequently, the potential conflicts between development and environment could be particularly great here.

3.2.2 Ice Islands

Ice islands are large, thick pieces of sea ice that usually come from near the northern edge of Ellesmere Island in the high Arctic and are carried westward in the Beaufort Gyre with the pack ice, passing north of Point Barrow. The most severe conceivable ice hazard would be the passage of an ice island or island fragment through an area containing offshore structures. This ''worst case'' situation is considered unlikely, and radar and satellite data should make it possible to predict the trajectory well in advance. At any rate, few ice island fragments have been observed moving onto the shelf of the Chukchi Sea (W. Sackinger, pers. comm.). They are mostly confined to the deeper water of the Arctic Ocean.

3.2.3 Fast Ice and Beached Ice

On the eastern side of the Chukchi Polynya, the fast ice typically extends from shore outward as far as the 20-m contour (Fig. 3.6) (Stringer 1982). Floes may periodically jam into the fast ice along the coast. When this occurs, if the slope of the beach is less than 10°, ice can easily push on up the beach, and may create large gravel or sand ridges in its path. For example, between Point Belcher and Point Franklin there is an area where ice pushing common-

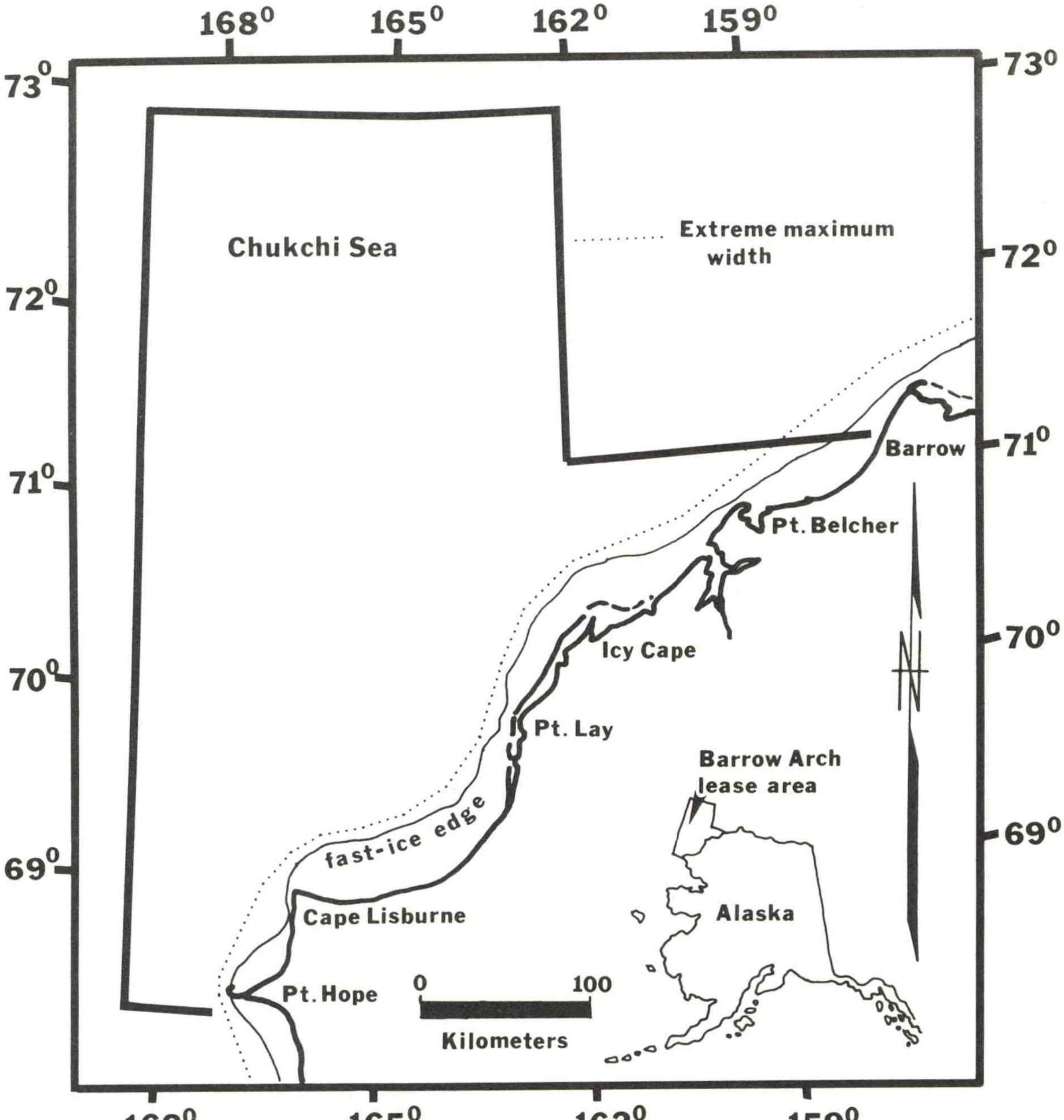

FIGURE 3.4—Extreme maximum width in March of the Chukchi Polynya in the Barrow Arch, 1974–81. (From Stringer 1982.)

ly recurs; in this area there is overriding of ice. Occasionally—perhaps every 10-15 years on the average, according to anecdotal reports—high offshore winds carry virtually all of the fast ice (and pack ice) out to sea during the winter.

3.2.4 Pack Ice

During average years the ice edge is directly off the northern area of the Barrow Arch in late October and early November (*see* Chapter 2 and Brower *et al.* 1977). During the following month or so, pack ice tends to move in from the Beaufort Sea, and the Chukchi Sea rapidly freezes throughout as first-year ice forms. The ice cover is augmented significantly by the formation of new ice throughout much of the winter at the edge of the Chukchi Polynya. Multiyear ice fields up to 6 m thick, interspersed with first-year ice, have been observed during the *Polar Star*

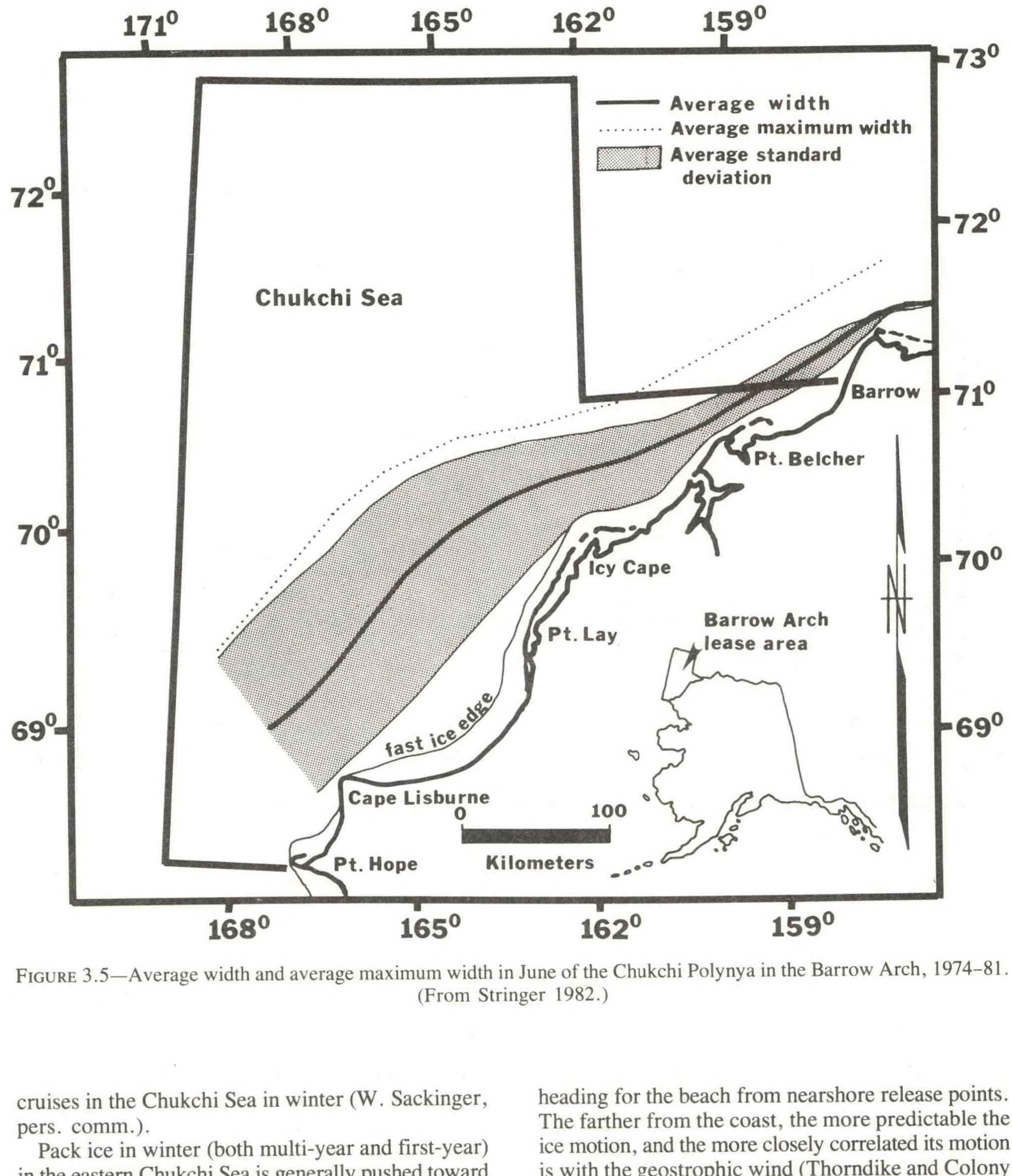

FIGURE 3.5—Average width and average maximum width in June of the Chukchi Polynya in the Barrow Arch, 1974–81. (From Stringer 1982.)

cruises in the Chukchi Sea in winter (W. Sackinger, pers. comm.).

Pack ice in winter (both multi-year and first-year) in the eastern Chukchi Sea is generally pushed toward the northwest, carried within the mean velocity field of ice in the entire Arctic Ocean basin (Fig. 3.7). It also moves northwestward in response to strong winds from the northeast, and in response to northerly currents. Close to the coast, ice movement is least predictable. Several surface drift trajectories near Peard Bay in August 1983 (with buoys and vessels frozen into the ice) mainly followed wind direction, heading for the beach from nearshore release points. The farther from the coast, the more predictable the ice motion, and the more closely correlated its motion is with the geostrophic wind (Thorndike and Colony 1982). A simple isotropic model can therefore account for much of the ice motion in the Chukchi Sea.

Changes in wind direction, or reverse in transport direction of ice, can cause repeated episodes of compression and expansion. Large pressure ridges and rubble fields have been mapped along the Barrow Arch, especially offshore from the headlands (Fig. 3.8). Longshore movements of ice also contribute

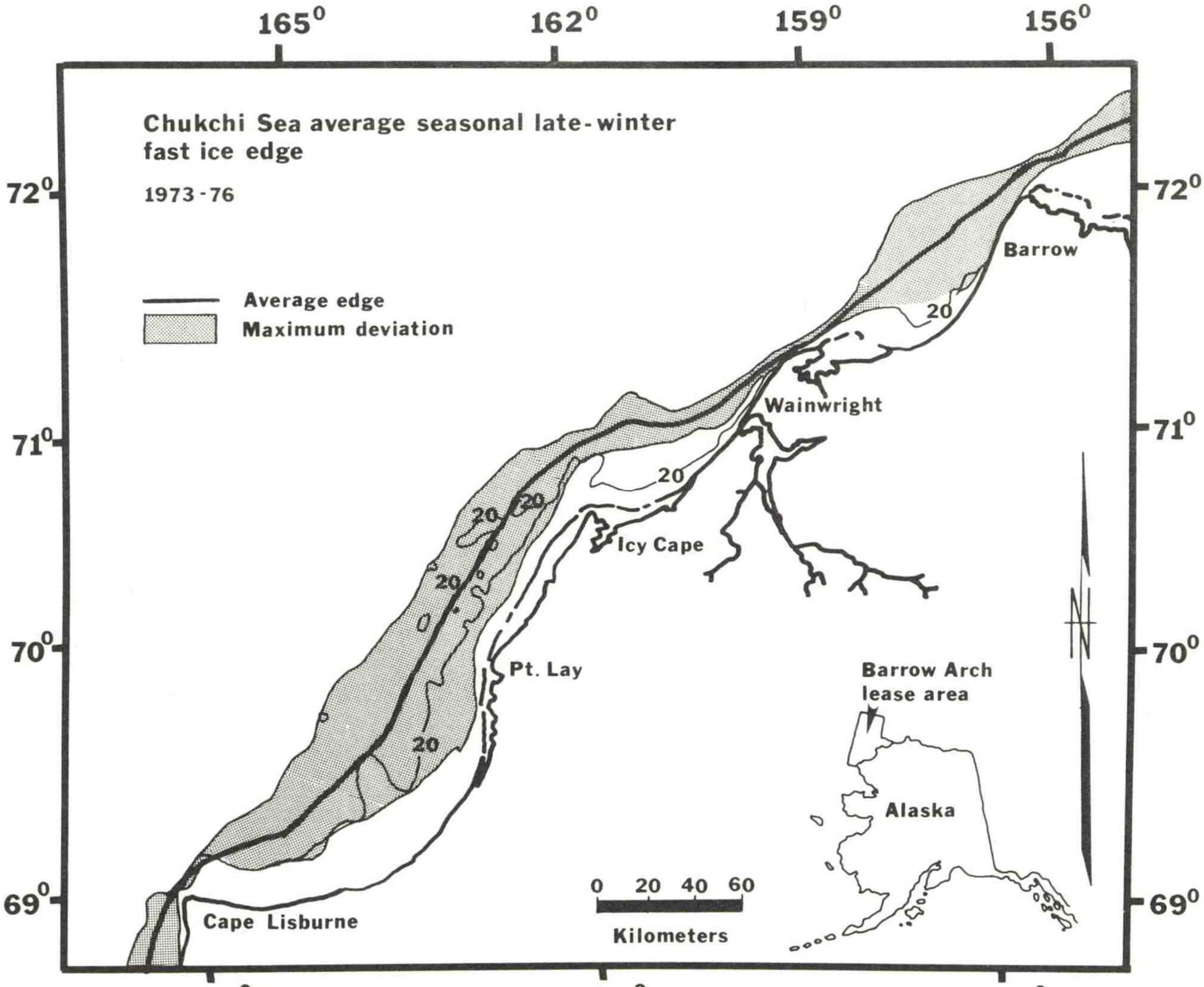

FIGURE 3.6—Average extent and maximum observed deviation of the shorefast ice edge in the Barrow Arch, 1973–76.

to compression zones. Ice-pushed ridges of sediment are sometimes formed offshore by grounded ice; for example, off Skull Cliff (Stringer 1982).

Ice gouging is a potentially serious hazard to petroleum development on the Chukchi Sea shelf (Fig. 3.9). Gouging occurs to relatively great depths within the Barrow Arch, partly because of the conduit for deep-draft ice provided by the Barrow Sea Valley. Ice gouges on the bottom have been seen in water exceeding 60 m in depth, but gouges are relatively rare in water deeper than 54 m (Grantz *et al.* 1982). Ice gouges offshore decrease to the south, with high-relief areas such as Hanna and Herald shoals and the sandbanks mentioned above showing the most pronounced gouging. Ice gouges 3–4 m deep have been detected on top of Hanna Shoal, and 4.5 m deep in water 36–40 m deep (Grantz *et al.* 1982; Toimil 1978). Ice gouges where the water is 30 m deep or less seldom exceed 3 m in depth (Stringer 1982).

Many of the subsea sandbanks lie in the region where the pack ice impinges against the shorefast ice (averaging about 20 m in water depth). Grounding of high-pressure ridges is common in this zone. The farther the banks lie from shore, the more "organized" or parallel the gouges appear to be. The gouges roughly parallel the bathymetric contours in deeper water, and on shores adjacent to steep slopes or capes. In water less than 15 m deep, gouges are often randomly oriented. The age of the gouges is unknown; presumably they fill with sediment in time.

Protection will clearly be necessary for pipelines extending between offshore fields and onshore processing and storage facilities. Sediment depth may not be adequate in most regions to provide sufficient

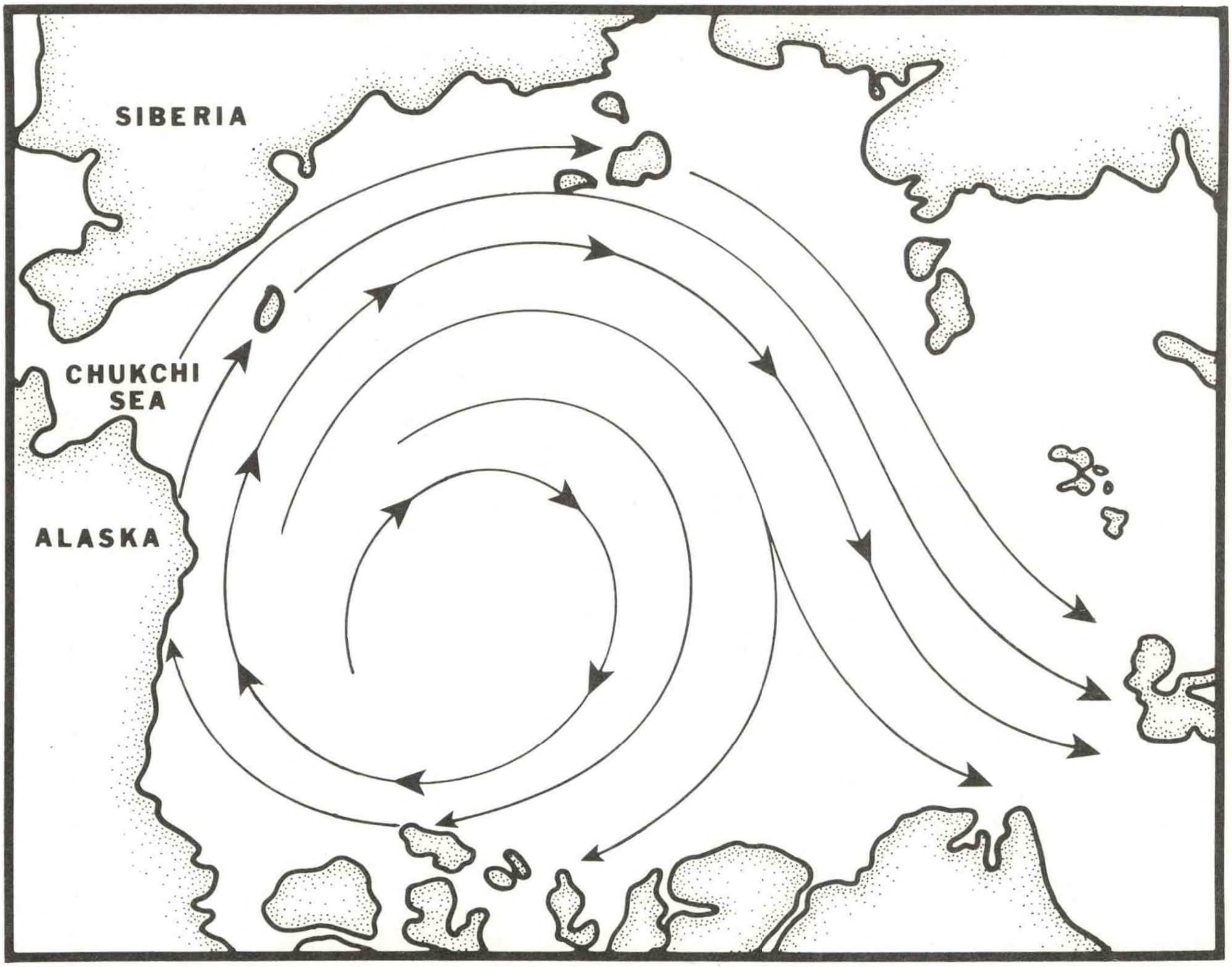

FIGURE 3.7—Field of mean ice motion in the Arctic Ocean Basin. (From Colony and Thorndike 1983.)

protection for pipelines. Trenching in bedrock or in ancient river channels or valleys may be the best alternative.

3.2.5 Ice Breakout and the Coastal Jet

Perhaps the most striking ice transport event affecting the Barrow Arch is the formation of a "coastal jet" of ice following a breakout at the Bering Strait. In winter, ice moves both southward and northward through the Bering Strait but under most conditions the rate of movement is slow. Change in the direction of ice movement sometimes causes divergence zones or leads to form in the vicinity of the strait, since flow either to the north or the south may cause some ice to be blown away from the "bottleneck" while other ice is trapped there. An arch of pack ice often forms, blocking much of the ice movement for long periods of time, though some ice continues to break away and move through despite the blockage (W. Sackinger, pers. comm.).

When strong southward transport occurs, it can break up the jam at the strait and move large masses of ice into the Bering Sea. This breakout has been associated with the existence of high pressure over Cape Schmidt in Siberia and low pressure over Kodiak. There is also some evidence that under-ice currents are involved. K. Aagaard (pers. comm.) analyzed current data from September–March, 1976–77, and concluded that southerly flow events in the Bering Strait in this period occurred 28% of the time and had a mean duration of 3.2 days and a maximum daily mean value of 1.3×10^6 m^3 s^{-1}, corresponding to a mean velocity of 34 cm/s across the strait (see Table 3.1).

Whatever the cause, when the ice arch "fails" at the strait, fragmentation propagates through the ice to the north, and ice rushes southward. Along the eastern Chukchi coast, a jet of ice extending sometimes the entire length of the eastern Chukchi Sea moves as a single mass, causing tremendous rubble

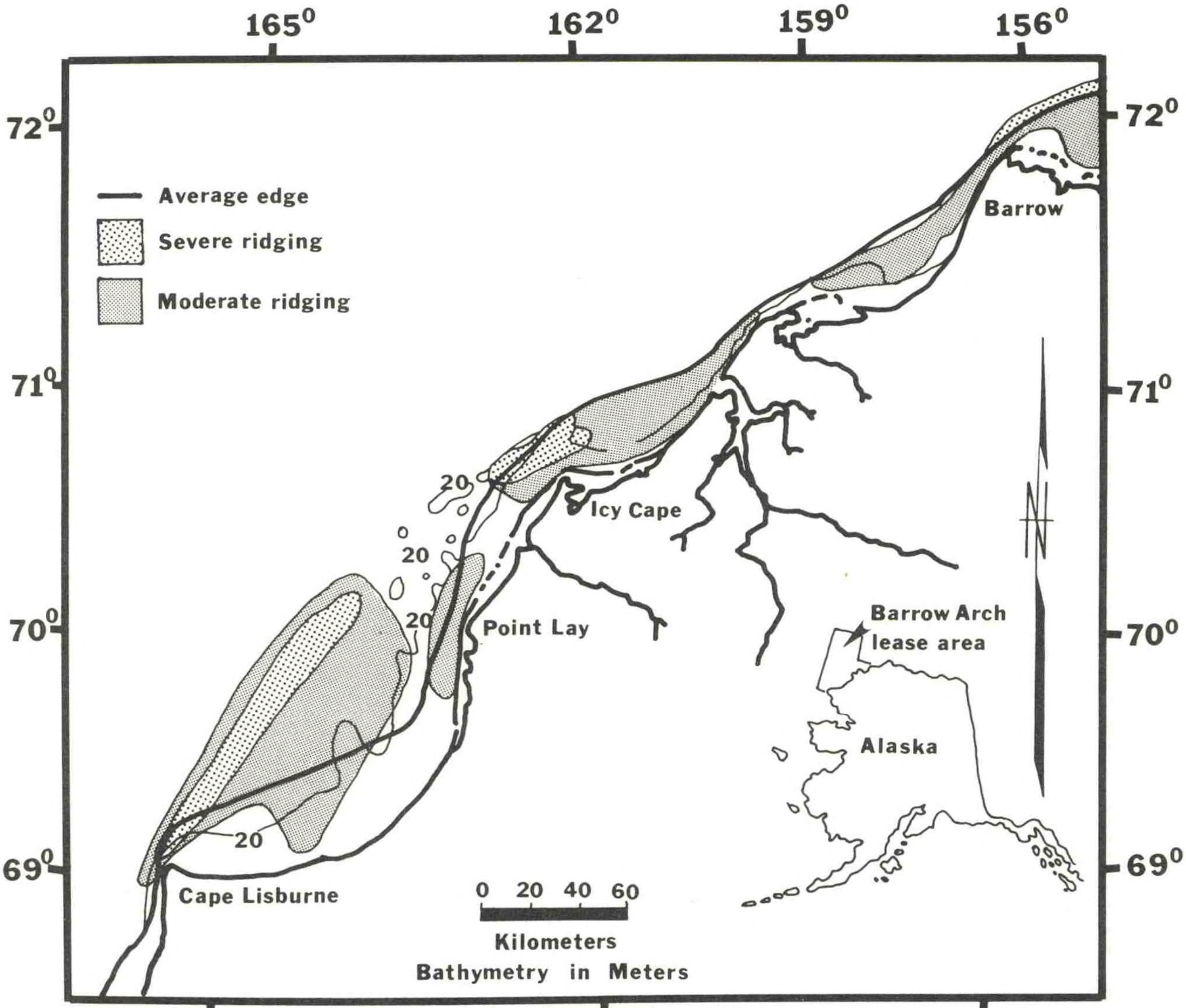

FIGURE 3.8—Morphology of sea ice in the Barrow Arch in early spring. Shorefast ice edge and recurring zones of ice ridging are shown. (From Stringer 1982.)

flow along the coast. Southward rates of movement up to 130 km/day have been observed (Fig. 3.10) (Pritchard 1978). Breakout occurs about 4($\pm$2) times a year, usually in early to midwinter, and each breakout usually lasts about 4 days (W. Stringer, pers. comm.).

3.3 COASTAL GEOLOGIC PROCESSES

The Barrow Arch coastline is relatively stable compared to that of the Beaufort Sea. Barrow Arch coastal erosion (retreat) averages about 0.3 m/yr, compared to Beaufort retreat rates of 1–2 m/yr (Harper 1978). Erosion of the high tundra cliffs ranges from 0.1 to 0.3 m/yr (Fig. 3.11). Low tundra cliff erosion averages about 0.5 m/yr. The barrier islands of the Barrow Arch are also less frequently breached by waves and ice than are barrier islands of the Beaufort Sea. Nonetheless, the Chukchi barrier islands are sometimes washed over by storms.

This relative stability is somewhat enigmatic. The Beaufort coast may be described as "storm dominated," with low erosion rates during calm periods alternating with very high rates during storms. Storm effects on the Chukchi, while important, are not as striking in comparison to average erosion conditions (Owens *et al.* 1981; Owens and Harper 1983). The coastline of the Barrow Arch borders on waters where the wind has a greater fetch in open-water season, and thus is exposed to higher average wave energy and erosion potential than is the case on the Beaufort coast (Table 3.2, Fig. 3.12).

Rates of coastal ice movement along the shoreline are much higher in the Barrow Arch than in the Beaufort Sea. The Beaufort Sea coast is exposed to essentially a solid sheet of fast and grounded ice for much of the year. This sheet of ice shows relatively little movement compared to the ice along the Barrow Arch coast, which forms and "works" vigorously throughout the winter. Coastal ice movement along the Barrow Arch is relatively great due to the presence of the Chukchi Polynya and to the periodic breakouts of ice through the Bering Strait that cause massive nearshore ice flow. The barrier islands and the gravel beaches are often subject to overriding and pushing by ice (Owens and Harper 1983). This process may displace sediment on beaches, as mentioned above, or deposit sorted material from the littoral zones to the beach.

The main reason for the comparatively low retreat rates of the tundra cliffs is that their composition resists erosion. Many of the coastal cliffs contain high percentages of well-sorted sand and gravel sediments, which are not as easily eroded as the organic-rich cliffs of the Beaufort. The high tundra cliffs also have relatively low proportions of ice compared to Beaufort Sea coastal bluffs, and therefore are resistant to erosion by thawing (Owens *et al.* 1981). However, a relatively low retreat rate does not necessarily mean a low amount of supplied sediment. The Chukchi cliffs contribute greater volumes of sediment to the sea than do the Beaufort cliffs, since the Chukchi cliffs have high sediment percentages and are taller on the average.

3.4 STORMS

General characteristics of storms in the Barrow Arch are discussed in Chapter 2. As noted, few field data are available on the frequency or magnitudes of storm surges in the Chukchi Sea. The best estimates of tides, sea level, and currents during storm surges are probably those from Kowalik and Matthews' (1982) surge model, which has been tested with good agreement against measured data from the Canadian Beaufort Sea.

The hazards to petroleum development operations that are of greatest concern are the very infrequent major storms from the southwest. Onshore facilities stand to be damaged by these events. As described

TABLE 3.1—Approximate statistics on southward flow in the Bering Strait, September–March, 1976–77.

Month	No. of Events	Duration (days)	Mean Duration (days)	Daily Mean Max. 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 = 7	2.3	0.9	24
				1.3	34
				0.5	13
October	2	3+8 = 11	5.5	1.4	37
				4.5	118
November	4	3+2+2+2 = 10	3.3	0.8	21
				1.9	50
				0.7	18
				1.0	26
December	3	4+3+2 = 9	3.0	1.9	50
				1.2	31
				1.1	29
January	3	1+3+5 = 9	3.0	0.3	8
				1.1	29
				1.0	26
February	2	4+4 = 8	4.0	1.8	47
				1.4	37
March	2	4+2 = 6	3.0	1.5	39
				0.4	10
Sept.–Mar.	19	60	3.2	1.35	34

SOURCE: Provided by K. Aagaard.

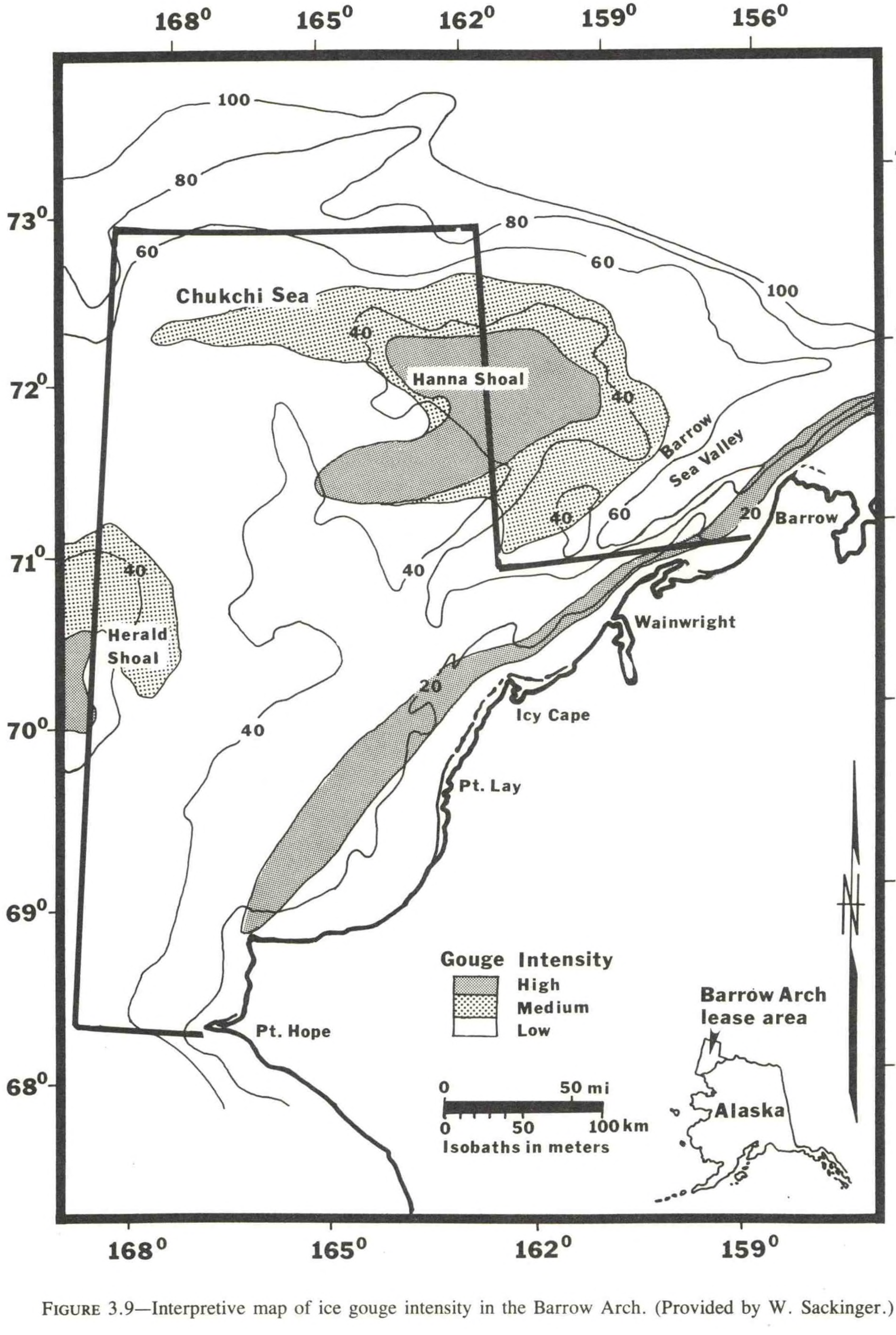

FIGURE 3.9—Interpretive map of ice gouge intensity in the Barrow Arch. (Provided by W. Sackinger.)

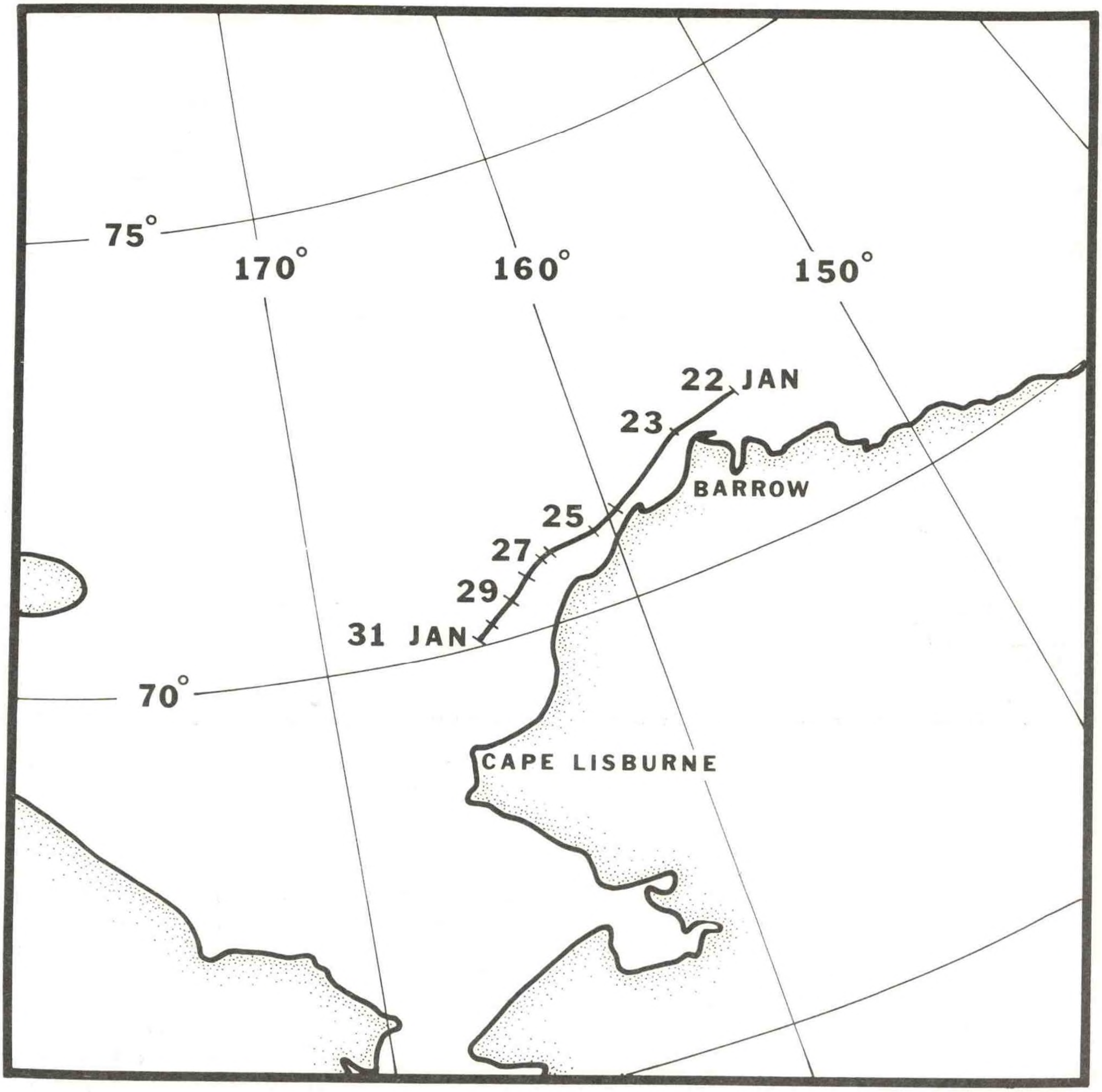

FIGURE 3.10—Buoy trajectory during ice breakout in the eastern Chukchi Sea in late January 1976. (Provided by R. Pritchard.)

in Chapter 2, expected maximum increases in sea level ($\sim$ 1.9–2.0 m) due to storms in late summer and early fall might generate surges onshore to the 3–4-m elevation contour. These surges probably recur about once every 125 years. Surges of 2–3 m at the shore might recur once every 10 years.

3.5 SUMMARY

Environmental hazards that oil and gas developers could encounter in the Barrow Arch include (1) those on and beneath the sea floor, (2) those associated with sea ice, and (3) those related to shoreline stability and storm surge effects. Sea ice appears to offer by far the greatest threat.

Potential seafloor hazards include those arising as a consequence of sediment thinness and instability, subsea permafrost, and gas-charged sediment. Sediments are so thin in places that channeling in bedrock beneath the sediments might be required to keep subsurface pipes safe from ice scour. The deepest sediments are in relict channels and valleys. Migra-

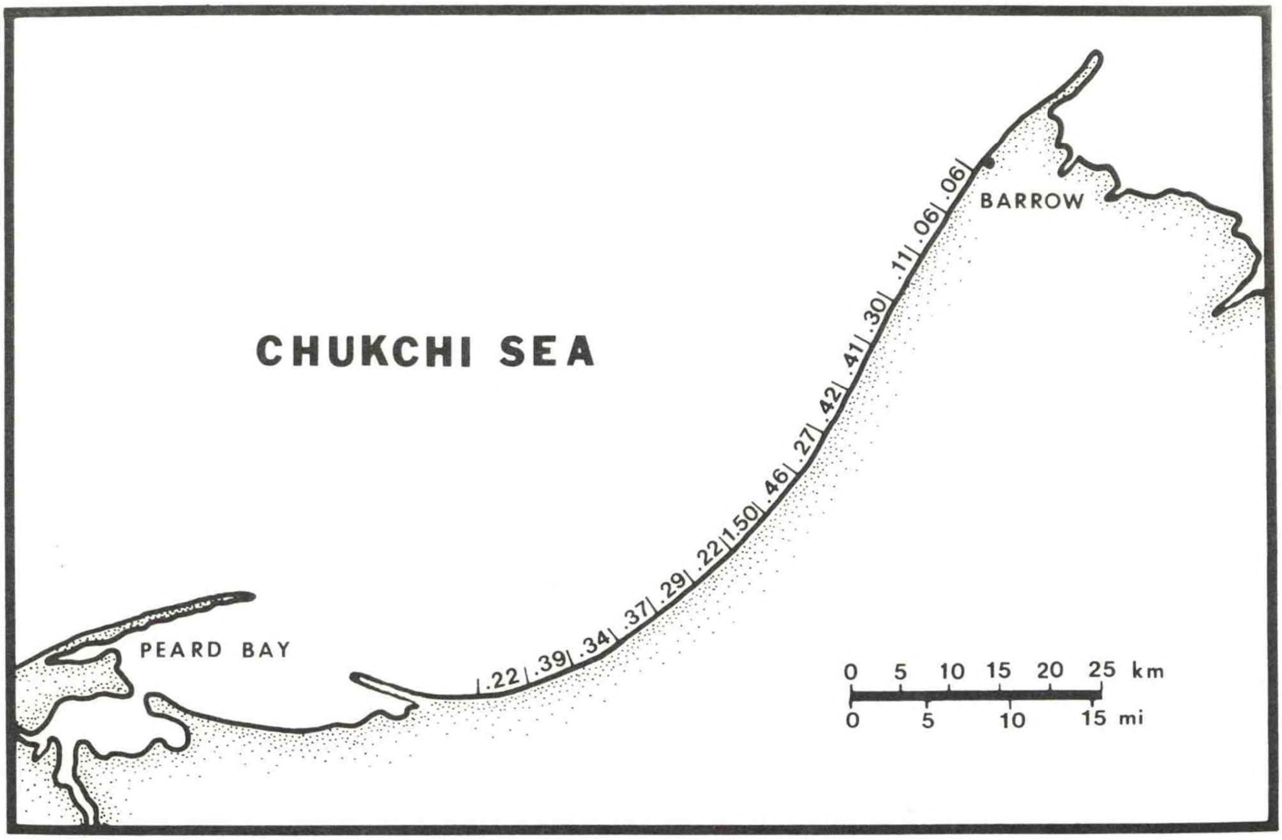

FIGURE 3.11—Average annual erosion (coastal retreat in meters/year) rates of the Alaska shoreline between Barrow and Peard Bay. (From Harper 1978.)

tion of seafloor sandwaves or ridges in some areas presents potential hazards to navigation and subsea pipes. The potential for seafloor slumping is localized at the shelf break in the extreme northern portion of the Barrow Arch. Subsea permafrost is thought to be minimal or nonexistent, though few data exist to demonstrate this. Likewise, there is little information on gas-charged sediments, but it is thought that if they occur at all, they would generally be localized in relict channels and valleys.

TABLE 3.2—Summary of process characteristics affecting coastal erosion in the Chukchi and Beaufort seas.

	Chukchi Coast	Beaufort Coast
Open-water season (months)	2–3	1.5–2
Mean open-water fetch (km)	50–200	10–100
Wave heights >1 m (%)	10	3
Total open-water wave energy* (ergs × 10^{14})	6.5	3.0

SOURCE: Owens *et al.* 1981.

* Wiseman *et al.* 1973.

One of the important features related to ice hazards is the Chukchi Polynya, an annually recurring ice lead system that stretches the length of the Barrow Arch at about the 20-m depth contour. The polynya forms under prevailing easterly winds in spring that blow the moving pack ice away from the shorefast ice, creating open-water areas. The polynya averages <10 km wide in March, and increases in width as spring progresses.

Other ice hazards include ice islands, normal movement of pack ice, and ice gouging. Ice islands, which are large, thick multi-year floes spawned in the high Arctic, could potentially cause great damage to offshore development or production operations, but they appear to be very infrequent on the shelf. Moving first-year and multi-year ice dominate shelf waters beyond about 20 m in depth for most of each year, severely restricting safe exploration and development operations in time and space. Ice breakout is an annually recurring phenomenon in winter in which southward-moving ice jams Bering Strait then "breaks out" to continue moving southward; this creates a rapidly moving "jet" of broken ice

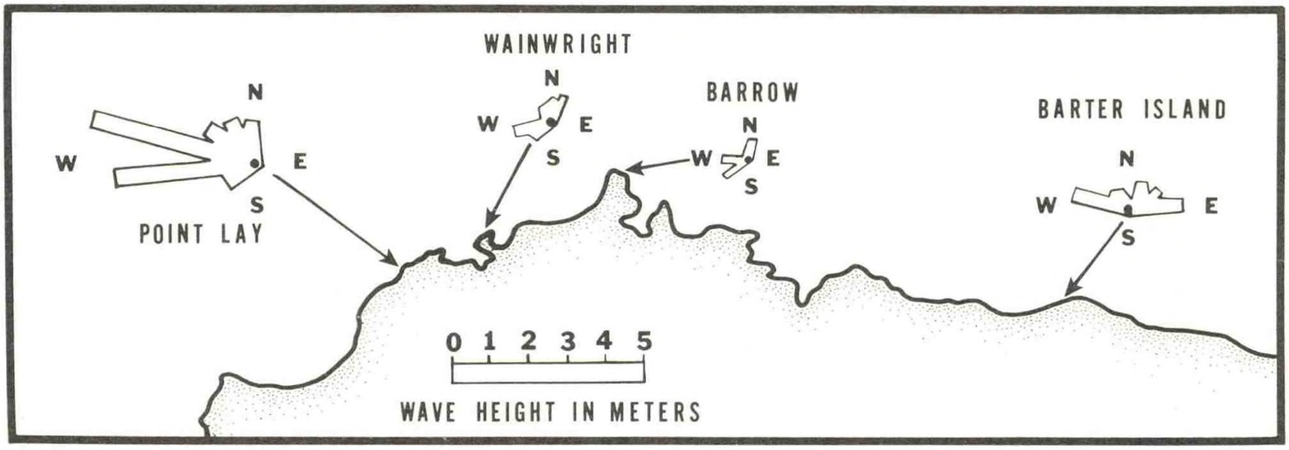

FIGURE 3.12—Hindcast maximum wave heights for September on the Chukchi and Beaufort sea coasts of Alaska. (From Owens *et al.* 1981.)

parallel to shore in the Barrow Arch that could be particularly hazardous to certain phases of operation. Ice gouging of bottom sediments, which occurs in all Arctic seas including the Barrow Arch, may occur at particularly great depths in the vicinity of the Barrow Sea Valley, where deep-draft ice can readily intrude into the planning area.

Coastal hazards are mainly a consequence of shoreline retreat and storm surge. The Barrow Arch coast is retreating (being eroded away) on an average of about 0.3 m/yr. Although this erosion rate is considerably lower than that of the Beaufort Sea coast (retreat rates of 1–2 m/yr), it still presents potential hazards to facilities built at the coast. The erosion is somewhat episodic, most occurring rapidly during infrequent, severe storms when coastal sea level and wave energy reach maxima.

Storms, in addition to their tendency to erode coastlines, may be hazardous to drillships or other facilities in shelf waters. Severe storms occur most frequently in late summer and fall, with southwesterly winds. The greatest storm-related hazards would probably occur late in this season, when chances of relatively large amounts of sea ice in the water are greatest.

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4

Marine Mammals

by Rolph A. Davis and Denis H. Thomson

With contributions from T. Albert, F. Awbrey, C. J. Cowles, M. Dahlheim, R. B. Dronenburg, M. A. Fraker, D. V. Holliday, B. Kelly, J. W. Lentfer, L. F. Lowry, C. I. Malme, S. E. Moore, B. F. Morris, G. W. Oliver, D. J. Rugh, and S. W. Stoker. Meeting Chairman: R. A. Davis.

Twenty-one species of marine mammals have been recorded from the Chukchi Sea (Morris 1981). Large numbers of walruses, spotted seals, bearded seals, belugas, gray whales, and bowhead whales use the Chukchi Sea as a migration corridor or summer feeding ground. The ringed seal, polar bear, and, to a lesser extent, bearded seal are year-round residents. Arctic foxes are year-round residents and, though not marine mammals, spend much of the winter feeding on the ice.

The Pacific right whale and narwhal are represented in the Chukchi Sea only by tenuous evidence. The fin whale is an occasional visitor. Blue, sei, humpback, minke, and killer whales and harbor porpoises, as well as northern fur seals, northern sea lions, harbor seals, and ribbon seals are rare or extremely uncommon in the Chukchi Sea, particularly the Barrow Arch area, and are not considered further here.

4.1 SETTING

The movement and distribution patterns of all marine mammals inhabiting the Chukchi Sea including year-round residents are affected by, and generally governed by, the seasonal cycle of sea ice. The patterns, therefore, are predictable to the extent that ice conditions are predictable. In winter, the nature and extent of fast-ice cover determines the distribution and abundance of polar bears, ringed seals, and arctic foxes in nearshore areas. The timing and nature of the opening of the flaw zone between the Chukchi pack ice and the coastal fast ice (Fig. 4.1) largely determine the timing of spring migration of bowheads, belugas, walruses, bearded seals, and migrant ringed seals. The timing of breakup of coastal fast ice determines the accessibility of nearshore littoral habitats to spotted seals and summering belugas. In summer, the polar pack ice front extends into the northern Chukchi Sea (Fig. 4.2). The location of this ice edge in relation to shallow benthic habitat is an important determinant of the distribution of the benthic-feeding walrus and bearded seal populations. In fall, the migrants retreat out of the Chukchi Sea in advance of newly forming ice.

4.2 SPECIES ACCOUNTS

4.2.1 Pacific Walrus

The Bering-Chukchi walrus (*Odobenus rosmarus divergens*) population is one of six populations presently occupying arctic regions; it includes 80% of the total world population of walruses (Fay 1982). The population in the Bering-Chukchi area contained approximately 250,000 animals in 1980 (S. Stoker, pers. comm.). Numbers have been increasing since censusing began in the 1950's and the population may now be at or near pre-exploitation levels (Fay 1982) and near the carrying capacity of its environment (Fay *et al.* 1977; S. Stoker, pers. comm.).

Fay (1982) reviewed and summarized information on the distribution and movement of walruses. The Pacific walrus is closely associated with the moving pack ice throughout the year, and its distributions and the timing of its migrations are dependent on ice movements and ice conditions. Walruses overwinter in the Bering Sea near the edge of the pack ice. In May and June, they follow the retreating ice edge north and use the nearshore lead system to gain access to the eastern Chukchi Sea (Fig. 4.3). There are few

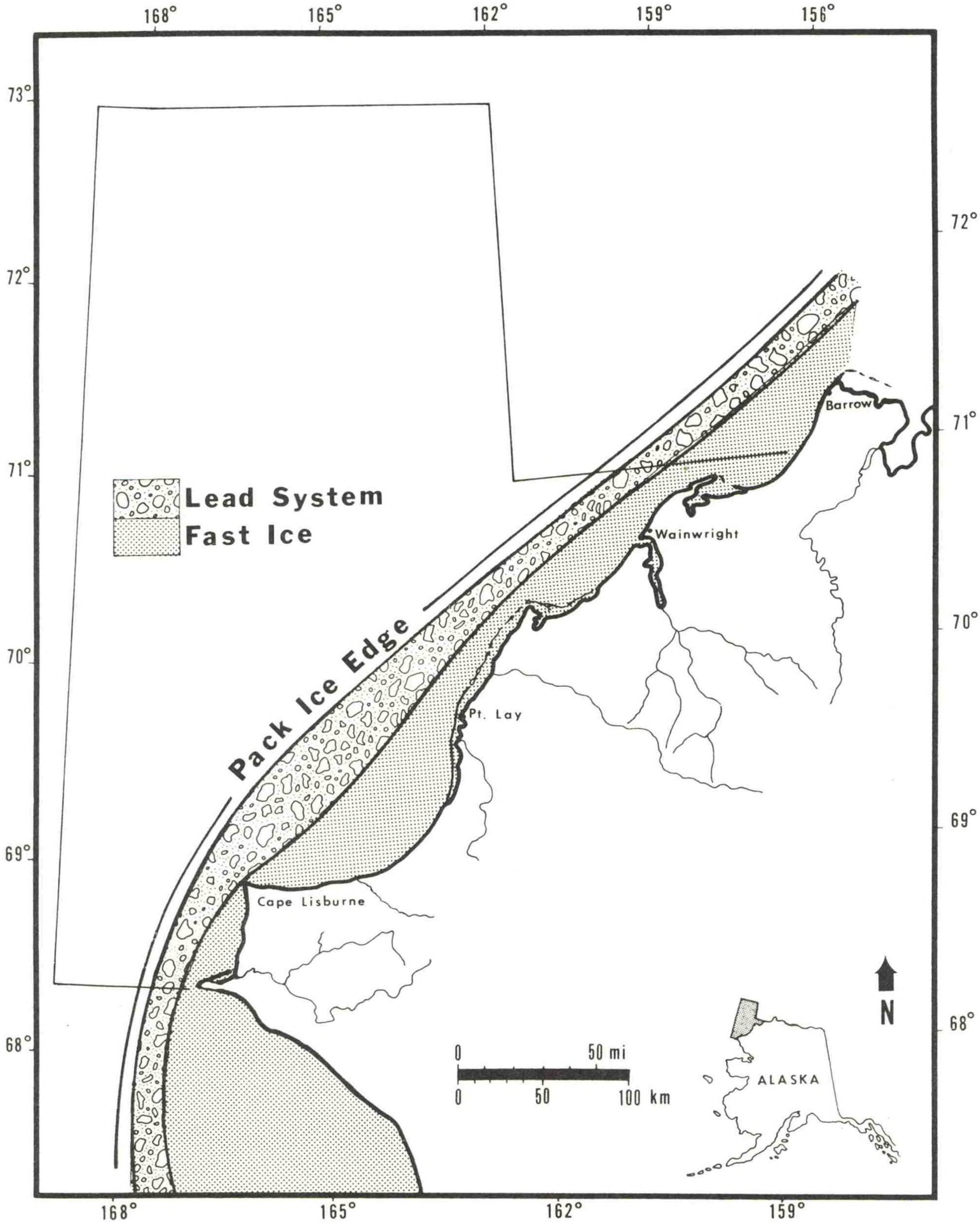

FIGURE 4.1—Schematic representation of springtime ice conditions in the eastern Chukchi Sea. The open-water lead system is an important migration corridor used by bowhead and beluga whales, walruses, and spotted and bearded seals.

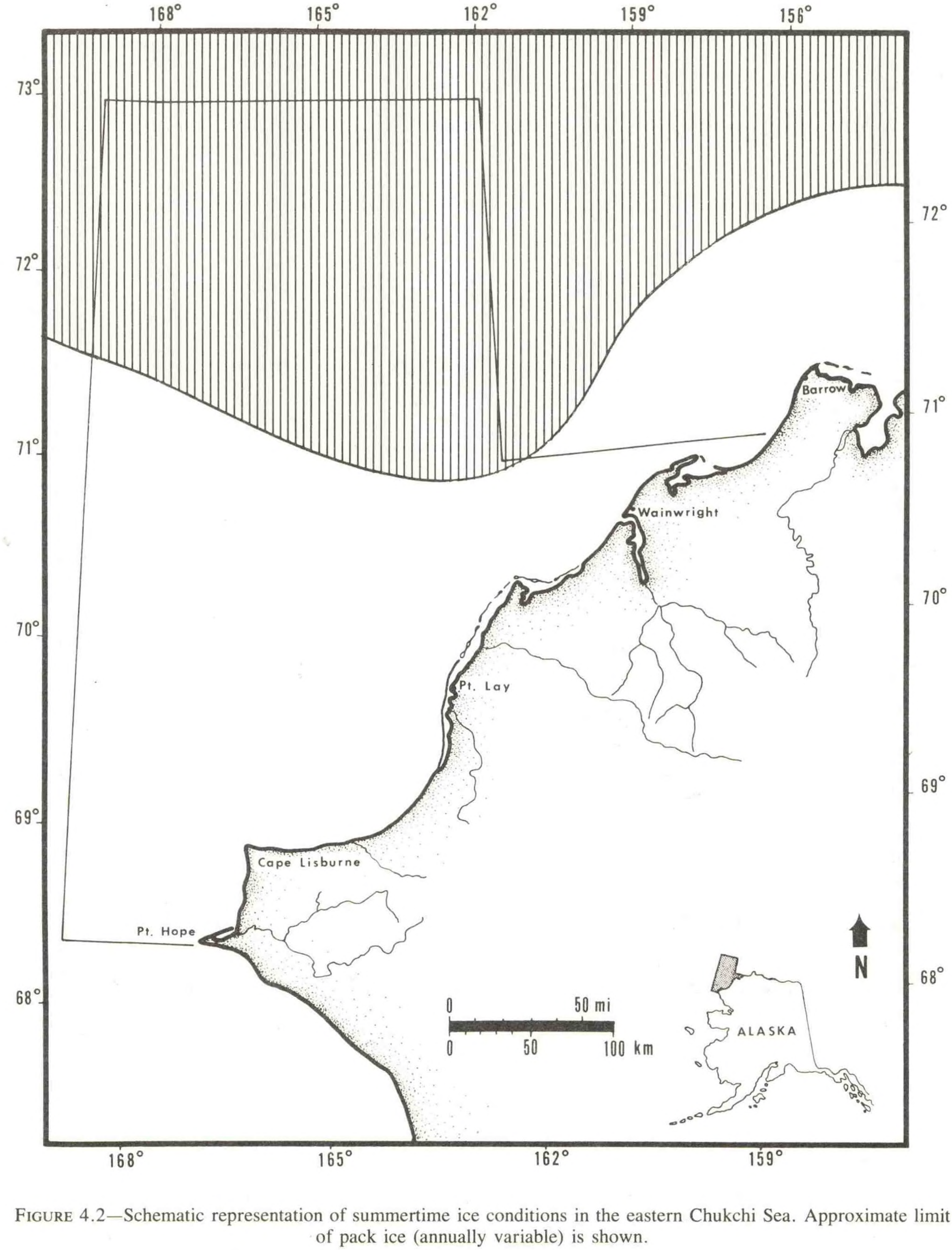

FIGURE 4.2—Schematic representation of summertime ice conditions in the eastern Chukchi Sea. Approximate limit of pack ice (annually variable) is shown.

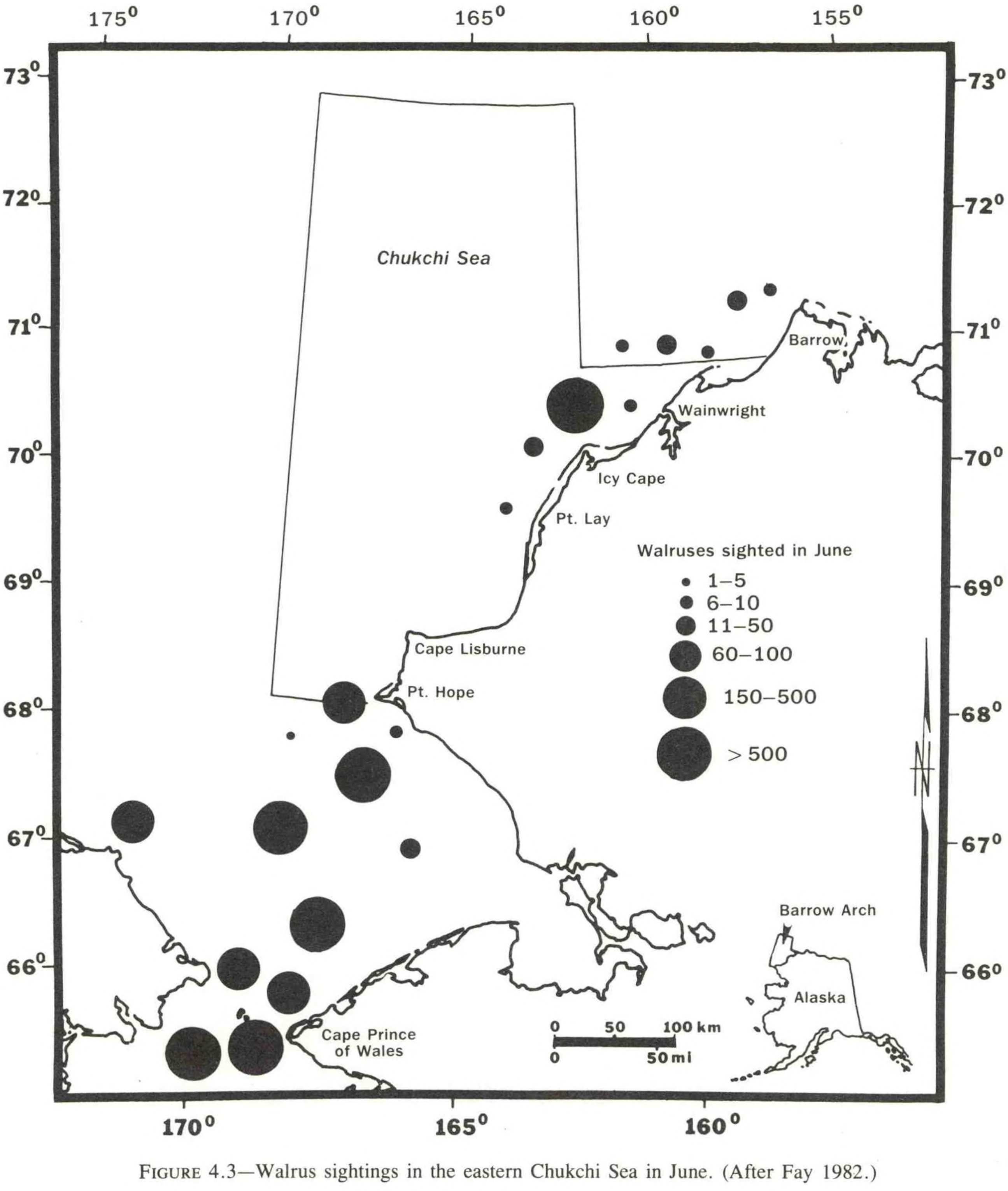

FIGURE 4.3—Walrus sightings in the eastern Chukchi Sea in June. (After Fay 1982.)

data on the timing and numbers of animals that follow the nearshore lead system into the Barrow Arch area. Apparently, however, animals move north through the Bering Strait in three pulses. Males move through the area first, followed by females with young and then by the remainder of the population. About 60% of the population summers in Soviet waters of the western Chukchi Sea but it is not known what proportion, if any, of these animals pass through the Barrow Arch en route to the summering grounds (Fay

1982; S. Stoker, pers. comm.).

In summer, when the ice edge is over the continental shelf, most of the walruses are in open pack ice (0-50% cover) along the ice edge in the northern Chukchi Sea. There is a nursery herd composed of females with young and some males, representing about 40% of the population, in the American Chukchi and a herd dominated by males in Soviet waters (S. Stoker, pers. comm.). At this time, about 90% of the animals are thought to be associated with ice and the remainder are distributed through ice-free waters south of the ice. In years when the pack ice drifts close to shore, large numbers of walruses can be found in nearshore waters; for example, off Peard Bay and Wainwright. Fay (1982) summarized walrus sightings in summer; Figure 4.4 illustrates the September period. It should be noted that this figure undoubtedly overemphasizes sightings in nearshore waters.

In the typical summer situation, walruses may be distributed through about 150,000 km² in the eastern Chukchi Sea (Fay 1982). Recurring concentrations of walruses in specific geographic parts of this area are unknown; rather, the animals may occur throughout the region, their distribution being a function of ice conditions. When the pack ice edge is over the deep water of the continental slope and the seabed is thus not accessible to the benthic-feeding walrus, many animals may use a haulout site northeast of Cape Lisburne. Walruses leave the Chukchi Sea in advance of newly forming ice in October. By November most of them are in or south of the Bering Strait.

Males reach full sexual maturity at 8 to 10 years of age, and females at 9 to 10 years. Breeding occurs every 2 years or at longer intervals. Mating takes place in midwinter, implantation 5 months later, and birth of a single calf the following spring. Young are nursed for at least 1 year and are weaned during the second year. The mean birth rate for the population of fertile females is about 37% per year; for the population as a whole it is about 14–17% (Fay 1982).

Walruses are primarily benthic feeders requiring waters less than 80 m in depth. More than 60 genera of marine organisms are preyed upon by walruses (Fay 1982); however, in the northern Bering Sea and Bristol Bay, 80% of their prey consists of clams (S. Stoker, pers. comm.). The most commonly eaten bivalves are *Hiatella, Mya, Spisula,* and *Serripes.* Generally only the soft parts (siphons, feet) are consumed when prey is abundant. The walrus is a selective predator. It seeks out large, nutritious prey including large bivalves, gastropods, and crabs, and ignores abundant dominant forms such as ophiuroids, amphipods, and polychaetes (Fay *et al.* 1977). There are few data on walrus diet specifically from the Barrow Arch. However, the large data base from the Bering Sea is probably applicable to the Chukchi Sea since walruses have similar diets in all areas that have been studied (Greenland—Vibe 1950; Hudson Bay and Foxe Basin—Mansfield 1958).

Fay (1982) reviewed the feeding energetics of walruses. He estimated that the average walrus weighs 720 kg and consumes 6.2% of its total body weight per day, and he assumed that 96% of the intake is molluscan soft parts. Because the walrus eats only about 25% of the bivalve, its impact on the benthos is about four times its daily intake (Fay *et al.* 1977). For example, an average walrus takes about 171 kg of bivalves per day. Fay *et al.* (1977) estimated that the walrus population (then estimated at 200,000 animals) was consuming virtually the entire annual productivity of its principal prey. The walrus population was thus near the carrying capacity of the environment. This conclusion is supported by recent evidence (S. Stoker and L. Lowry, pers. comm.): (1) the average size of prey items taken has declined since 1975, (2) between the 1950's and 1977, the mean annual birth rate for adult females declined from 38 to 30%, (3) there have been increased incidences of abortion and calf mortality, (4) the physiological condition of the animals has deteriorated over the last 10 years, (5) recent studies of herd composition indicate that few walruses less than 5 years of age presently occur in the Chukchi Sea, and (6) walruses are occupying new areas. The last point is illustrated by the increasing numbers (10,000-20,000 males) of walruses that now remain in Bristol Bay in summer. It is conceivable now that the walrus population has depleted the stock of bivalves that increased during the most recent period of low walrus population levels. The walrus population may now face a decline because of stress on food resources (S. Stoker, pers. comm.).

The combined Soviet and American annual harvest was about 7,500 animals in 1980 and 1981. Between 1,000 and 2,000 animals are taken in Alaska, with 100–500 of these taken in the Barrow Arch (Fay 1982; S. Stoker, pers. comm.). Most are taken in Barrow and Wainwright. Some walrus hunting also occurs at Point Hope and Point Lay. Ice conditions determine accessibility of the animals to hunters and the harvest. Males are, and have been, hunted preferentially, resulting in a 3:1 ratio of females to males in the population. This has helped the population of this polygamous animal to recover to pre-exploitation levels.

4.2.2 Spotted Seal

The Bering–Chukchi population of spotted seals (*Phoca largha*) is estimated to number 200,000 to 250,000 animals. The spotted seal differs from the closely related harbor seal (*Phoca vitulina*) in that

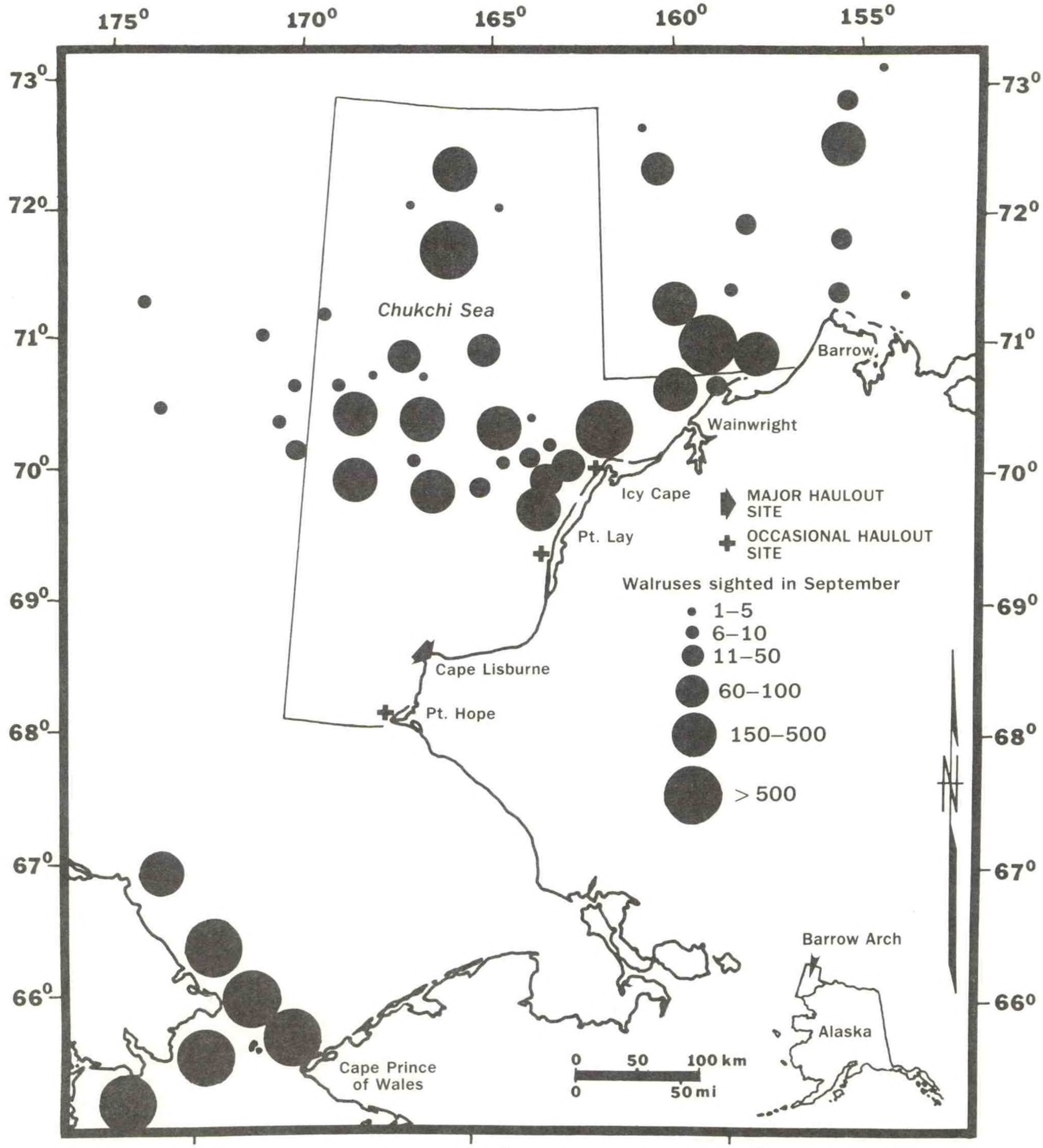

FIGURE 4.4—Walrus sightings in the eastern Chukchi Sea in September and summer haulout sites in the Barrow Arch. (After Fay 1982; Frost *et al.* 1983.)

it is adapted to breed on the ice (Bigg 1981). In winter and spring it is found along the Bering Sea ice front from Bristol Bay to Kamchatka (Fay 1974). At break-up, spotted seals migrate to nearshore areas of the Bering and Chukchi seas and make use of littoral habitats during summer (Fay 1974; Bigg 1981). In the Barrow Arch, they are found primarily in and around the coastal lagoons, especially Kasegaluk

Lagoon, from May to October (Frost *et al.* 1983).

Two major haulouts in the region are at Akoliakatat Pass and Utukok Pass (Fig. 4.5). More than 1,000 spotted seals frequent each of these two locations. Smaller haulouts are found at the mouth of the Kugrua River in southern Peard Bay, the mouth of the Kuk River near Wainwright, and other locations on barrier islands and in estuaries (Frost *et al.* 1983). The numbers of spotted seals using the Barrow Arch are unknown, but are as large as those found in any other Alaskan area. Spotted seals haul out at protected locations, especially on sand and gravel spits, and move out of the lagoons to feed.

Pups are born on the ice in late March and April and are suckled for about a month (Burns *et al.* 1972). Males mature at 3 to 6 years, females at 2 to 5 years; 85 to 92% of mature females produce a pup in any 1 year. Mortality during the first year is about 43% (Bigg 1981).

The diet of spotted seals in the Barrow Arch area is not well documented (Lowry *et al.* 1980a). Based on results from other areas, it would appear that the spotted seal eats primarily fish (Bigg 1981) and that its principal prey in the Barrow Arch may be capelin, smelt, Arctic and saffron cods, and sculpins (Lowry *et al.* 1980a). Ashwell-Erickson and Elsner (1981) studied the energetics of Bering Sea spotted seals. They estimated that a population of 1,000 spotted seals weighed 66.1 t and had a mean daily energetic requirement of about 35–38 $\times$ 10^5 kcal. Using their figure of 0.8 for net energy coefficient and assuming a diet of fish with energy content of 1,500 kcal/kg wet weight, a population of 1,000 seals would consume 3,042 kg of fish per day, or about 5% of the body weight of an average seal per day (averaged over the year).

Spotted seals are hunted in Alaska and Russia, but no reliable harvest statistics are available. The harvest in the Barrow Arch area may be several hundred animals per year (L. Lowry, pers. comm.).

4.2.3 Bearded Seal

The Bering–Chukchi population of the bearded seal (*Erignathus barbatus*) numbers approximately 300,000 animals. Its distribution is restricted to areas that provide access to the seabed and to suitable ice habitat. The bearded seal is an animal of the pack ice. In winter, most of the population is found over the shallow waters of the Bering Sea where the ice is in constant motion. Some animals may winter in the pack ice and shear zone of the Chukchi Sea but most are excluded because of the very heavy ice cover (Burns 1981). Very little specific distributional information is available for the winter period.

Bearded seals maintain their association with ice throughout the year, and their movements and distribution are governed by the ice conditions. In spring, northward movement through the Bering Strait occurs between mid-April and the end of June, but primarily from late May to late June. Movement into and through the Chukchi Sea is thought to be primarily along the flaw zone along the northwest coast of Alaska. However, there are few quantitative data on the timing of this movement or on the proportion of the population that uses this lead system.

In summer, most bearded seals are associated with the edge of the polar pack ice in the northern Chukchi Sea (Burns 1981). They do not haul out on land and only low densities are found in open water south of the pack ice. Bearded seals tolerate a wide variety of ice conditions, but may be more abundant at or near the fringe of the pack ice (L. Lowry, pers. comm.). Since they feed on bottom-dwelling and bottom-associated prey, bearded seals are restricted to relatively shallow waters. Bearded seals feed in waters of up to 75–100 m in depth (K. Frost, pers. comm.), although they can feed in deeper waters if necessary (Vibe 1950). Most of the Barrow Arch is less than 100 m deep and thus provides "ideal" habitat for bearded seals. There are no known specific offshore geographic areas that are used by concentrations of these seals.

In years when the pack ice is close to the Alaskan coast in summer, bearded seals can be quite common in nearshore waters, particularly between Wainwright and Barrow (K. Frost, pers. comm.). In years when the polar pack ice moves off the continental shelf into deep water, there may be major changes in the distribution of the seals; however, information on this situation is unavailable.

Most female bearded seals attain sexual maturity at 6 years of age and all are sexually mature by age 8 (Burns and Frost 1979). Ovulation occurs every year and the pregnancy rate appears to be approximately 82 to 85%. Ovulation and breeding occur in May, implantation is in July, and the fetus requires 9 months for growth to full term. The mean birth date for the Bering–Chukchi population is 20 April (Burns and Frost 1979). Lactation lasts fewer than 3 weeks (Burns 1967).

The bearded seal is primarily a benthic feeder. Fish are generally unimportant and compose less than 10% (by volume) of their diet (Johnson *et al.* 1966; Lowry *et al.* 1980a, 1980b). There is some seasonal variability in the diet of the bearded seal. Off Point Hope and in the Bering Sea, clams are the major food item in summer (Johnson *et al.* 1966; Lowry *et al.* 1980b). During the remainder of the year, shrimps and brachyuran crabs are the major prey species. Fifty-two bearded seals collected off Wainwright between the beginning of June and the end of July had been feeding primarily on clams (46% of content by

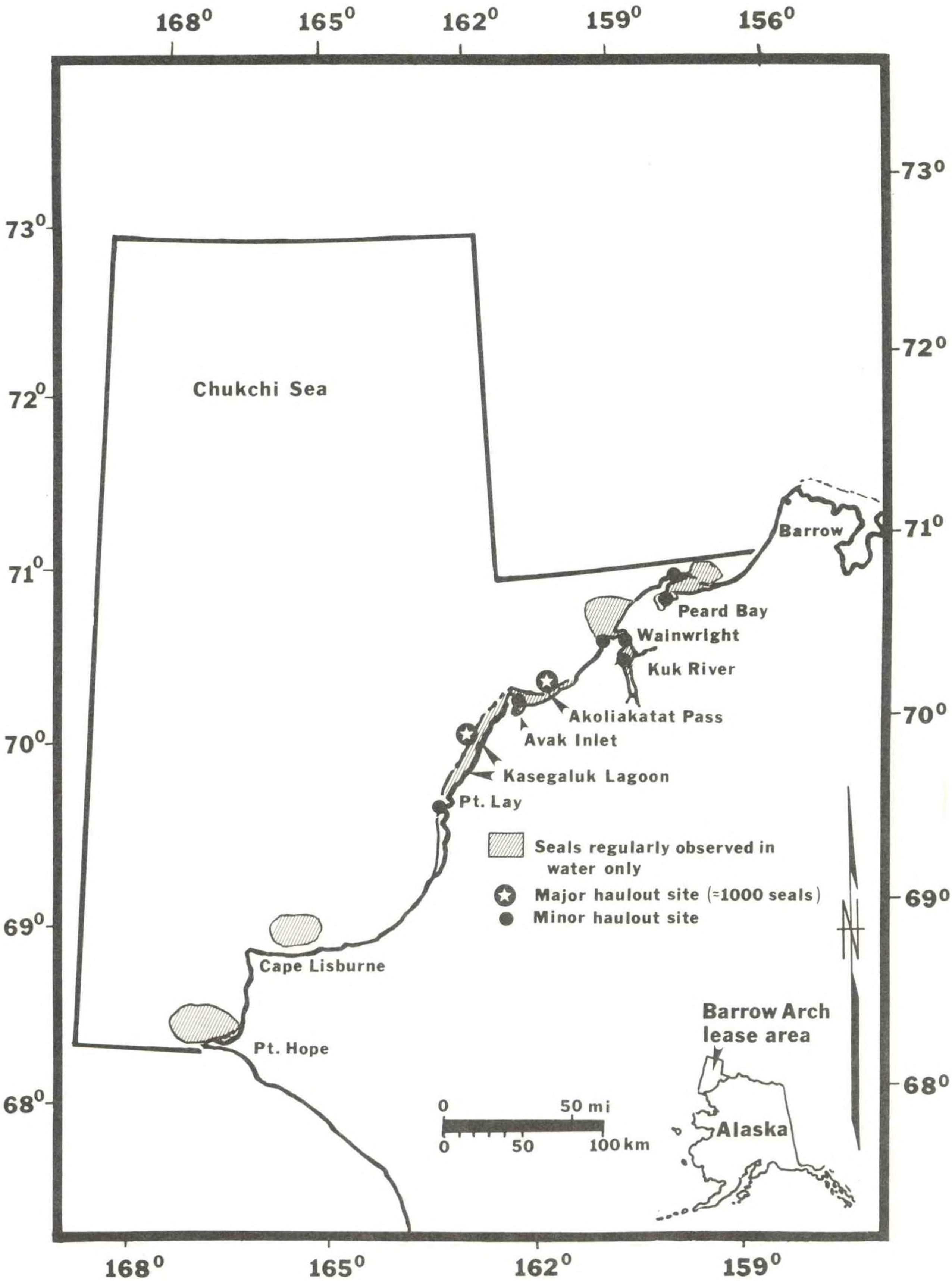

FIGURE 4.5—Distribution of spotted seals in the Barrow Arch in summer. (After Frost *et al.* 1983.)

volume) and shrimps (29%) (Lowry *et al.* 1980a).

Off Shishmaref (Kotzebue Sound) and in the Bering Strait there appear to be some age class differences in the diet of bearded seals (Lowry *et al.* 1980b). As the seals become older, clams, brachyuran crabs, sculpins, and flatfishes become more important in the diet, while shrimps, isopods, and saffron cod decrease in importance.

There appears to be little competition between bearded seals and walruses for benthic resources. Bearded seals are not dependent on clams and can switch to other species when clams are not available. Therefore, the over-cropping of clam populations by walruses would lead to only a change in diet for the euryphagous bearded seal rather than to a reduced seal population (Lowry *et al.* 1980b).

Between 1966 and 1977, the total American harvest of the Bering–Chukchi bearded seal population averaged 1,784 animals/year, with 4,760 animals being taken in 1977 (Burns and Frost 1979). The combined American–Soviet harvest for this period averaged 4,439 animals/year.

The bearded seal is very important to the economy and lifestyle of the people inhabiting the Barrow Arch area. Its meat is a preferred food and its tough skin is used for skin boats, footwear, and lines. There are no reliable recent data on harvest levels of this species by the communities in the Barrow Arch area. However, between January 1977 and June 1978, 675 bearded seals were harvested at Point Lay, Wainwright, Barrow, Nuiqsut, and Kaktovik. The total value of this harvest was estimated at $192,603 (Burns and Frost 1979). During this period, 954 animals (representing $275,068 in value) were also taken in Kotzebue Sound and Point Hope. At Point Hope, 203 animals were harvested between November and June 1960 (Johnson *et al.* 1966).

4.2.4 Ringed Seal

The ringed seal (*Phoca hispida*) is widely distributed in ice-covered Alaskan waters. The total Alaskan population is unknown but may number 1 to 1.5 million seals. The proportion using the Barrow Arch is unknown, but the Chukchi Sea is regarded as better ringed seal habitat than either the Beaufort or Bering seas.

The ringed seal is very strongly associated with ice. It is widely distributed through the Bering and Chukchi seas in winter. Stable shorefast ice is the preferred habitat of breeding ringed seals (McLaren 1958; Burns *et al.* 1981). The fast ice in the Barrow Arch supports higher densities of ringed seals than the fast ice in areas to the east and south. Over 4 years, uncorrected densities on fast ice in the Beaufort Sea ranged from 0.2 to 1.1 seals/km^2, whereas densities in the Barrow Arch ranged between 0.7 and 2.4 seals/km^2; densities in Kotzebue Sound were similar to those in the Beaufort (Burns and Eley 1978).

In 1976, uncorrected densities in the Chukchi and Beaufort pack ice were only 0.08 and 0.04 seals/km^2, respectively (Burns and Eley 1978). However, the areal extent of the pack ice is much greater than the fast ice and three-quarters of the population may inhabit the pack ice in winter (L. Lowry, pers. comm.). In Baffin Bay, seals of the pack ice population are smaller and have different diets and gut parasite loads during the summer (Finley *et al.* 1983a). Comparisons of fast ice and pack ice populations have not been made in Alaskan waters.

Although substantial numbers of ringed seals winter in the Chukchi Sea, there is also an influx of seals through the Bering Strait into the Chukchi Sea in May and June (L. Lowry, pers. comm.). The proportion of the summer population that winters in the Chukchi Sea is unknown. In spring, large numbers of ringed seals haul out on ice in the lead systems of the shear zones, although, again, it is not possible to state what proportion of the population occupies this zone. In the Canadian Beaufort Sea, most of the ringed seals that occupy the shear zone are nonbreeding subadults (Stirling *et al.* 1977). These subadults are the prime prey of polar bears.

In summer, as the coastal fast ice breaks up, ringed seals move offshore to the pack ice, where most of the population is thought to remain until freeze-up in the fall. Small numbers of primarily subadult seals remain in the open water south of the pack ice. In general, the data base on summer distribution of ringed seals is weak.

Young are born in late March and April and suckled for 4 to 6 weeks (Burns *et al.* 1981). In the fast-ice habitat, young are born in lairs in the snow over breathing holes (Smith and Stirling 1975). In the Bering Sea pack ice, some births occur on exposed ice flows rather than in lairs (Burns *et al.* 1981). There are no data on pupping habitat in the Chukchi pack ice. Females are impregnated soon after the birth of the pup but implantation is delayed 3½ months. Alaskan males mature at an age of 5 to 7 years and females are first able to bear young at an age between 6 and 10 years. The life span is greater than 20 years. The pregnancy rate for mature Alaskan females ranged from 91% in 1962–73 to 70% in 1975–76 (Burns and Eley 1978). In the Canadian Beaufort Sea, pregnancy rates of 0 and 11% were found in 1974 and 1975. The latter rates were associated with a major decline in population levels that was thought to be due to very heavy ice conditions. Part of this decline was due to emigration of ringed seals from the Beaufort Sea into the Chukchi Sea (Stirling *et al.* 1977).

The ringed seal in Alaska shows a marked seasonal variability in diet. Crustaceans are the principal prey in spring and summer, while Arctic cod form the bulk of the diet in winter (Lowry *et al.* 1980c). At Point Hope, Johnson *et al.* (1966) found that invertebrates, mainly shrimps, mysids, and amphipods, accounted for 57% of the ringed seal diet in March and April, and for 84% in May and 63% in June. In winter, the ringed seal feeds mainly on fish. Arctic cod represented 49% of the diet in November–December and 93% in January–February. Sculpins and saffron cod were also important in the diet in early winter.

The condition of Alaskan ringed seals also shows seasonal difference. In spring, the seals are leaner, feed less frequently, and catch less food. They lose about 30 g of body weight a day from March to September (Lowry *et al.* 1980c). In October and November, they gain about 93 g per day (Lowry *et al.* 1980b) when feeding on Arctic cod, which are a more concentrated source of energy (1,239 kcal/kg wet weight) than invertebrate prey (244–906 kcal/kg) (Lowry *et al.* 1980c). The October–November feeding period is probably critical to the annual energy cycle of the ringed seal.

Given an average weight of 13.9 kg for pups and 46.1 kg for seals greater than 5 years old (Lowry *et al.* 1980c), a net energy coefficient of 0.8 (Ashwell-Erickson and Elsner 1981), and a daily caloric requirement of 35 kcal/kg for adults and 110 kcal/kg for pups (Parsons 1977), adults and pups require a similar mean daily ration (averaged over the year) of about 1.4 kg when feeding on Arctic cod or about 3.2 kg when feeding on hyperiid amphipods.

Ringed seals are accessible to hunters for most of the year and may be the only marine mammals available for much of the winter. They are harvested more than any other species of seal. More than 1,000 animals are taken annually by the Barrow Arch communities; catch statistics are not available (L. Lowry, pers. comm.).

4.2.5 Polar Bear

Lentfer (pers. comm.) estimated that about 5,700 polar bears (*Ursus maritimus*) occur in Alaska. He identified two subpopulations with a limited amount of interchange (Lentfer 1974). The "west" subpopulation numbers about 3,800 animals and occupies the Chukchi Sea from the Wainwright–Point Lay area to the Bering Strait. The "north" subpopulation of about 1,900 animals occupies the northeastern Chukchi Sea east of the Point Lay area and the Beaufort Sea (J. Lentfer, pers. comm.). There is some mixing of the two subpopulations in the Point Lay–Wainwright area. Bears in the north subpopulation move between the American and Canadian sectors of the Beaufort Sea but no information exists at present on the extent of movements between the Alaskan and Soviet portions of the Chukchi Sea by bears of the west subpopulation (Lentfer 1983).

The distribution and movements of polar bears are tied directly to sea ice and the presence of seals, primarily ringed seals. In heavy ice years, some bears may move south of the Bering Strait in winter. In spring and summer, bears follow the retreating pack ice and remain on the ice through the summer. It is probable that bears are concentrated along the southern fringe of the pack ice at this time. In fall, bears move toward the coast as new ice begins to form. Pregnant females occupy dens on land near the coast in November and December and the rest of the population distributes itself over the winter sea ice. During the winter and spring, bears are mostly restricted to a zone within about 160 km of shore. In this zone, the density of bears averages about one per 70–130 km² (J. Lentfer, pers. comm.).

Polar bears wander widely through suitable ice habitat. The longest single movement recorded in Alaska is of a 4-year-old male that traveled 493 km in 2 months (Lentfer 1983). A radio-tagged female with two cubs traveled 58 km in 1 day, entered 10 ringed seal dens, and ate four seal pups (J. Lentfer, pers. comm.). Bears are opportunistic feeders, and transitory concentrations may occur at whale carcasses and at areas of thin ice where seals are most easily accessible. Minor concentrations of bears tend to recur at Icy Cape and Franklin Point in the fall and winter. In addition, an area of open water and thin ice is maintained by wind in the lee of grounded ice at an offshore shoal at 71°45' N., 161°15' W., about 120 km northwest of Wainwright. Bears occasionally concentrate in this area.

Major changes in the distribution of polar bears in response to major changes in seal populations have been documented. In 1974 and 1975, the population of ringed seals in the Beaufort Sea underwent a major decline (Stirling *et al.* 1977). Associated with the decline was the appearance of relatively large numbers of Canadian bears in the Barrow area and unusual movements of Barrow bears southwest to the Cape Lisburne and Point Hope areas.

Polar bears have low reproductive rates. The mean breeding interval for mature females is 3.6 years and mean litter size is 1.6 cubs (Stirling 1974a). On average, females first breed at 5 years of age and produce 0.45 cubs/year. Cubs are weaned at about 28 months of age (J. Lentfer, pers. comm.).

Polar bears give birth in snow dens on land; dens are occupied from November to March or April. Cubs are born in December and leave the dens with their mothers to travel on the sea ice in March or April (Harington 1968). The survival rate of cubs after weaning appears to be high (Stirling 1974a). In Alaskan waters, the bears may also use maternity dens located on drifting sea ice (Lentfer 1975). There is, however, no information on what proportion of the population dens on sea ice. Polar bear maternity dens have been found along the coasts of the Barrow Arch area, but no systematic searches have been made (J. Lentfer, pers. comm.).

Ringed seals are the principal prey of polar bears. The bears generally hunt young animals. They hunt preferentially in unstable pack ice and the shear zone rather than on the nearshore fast ice (Stirling *et al.* 1975). The unstable ice is the habitat of subadult and presumably inexperienced seals. Females with cubs tend to hunt on the fast ice in spring; they generally hunt along pressure ridges, and break into subnivean birth lairs and kill newborn pups (Stirling and Archibald 1977). In the Canadian Arctic, the majority of ringed seals killed by bears are between the ages of 6 months and 2 years (Stirling *et al.* 1975; Stirling and Archibald 1977). Smith (1980) has shown that ringed seals of this age class provide the greatest energy return to the bears and that mortality to this age class results in the least harmful effects on ringed seal populations. Polar bears often eat only the blubber and leave the rest of the carcass. However, the blubber contains most of the energetic content of ringed seals—67% for a yearling vs. 75% for an adult (Stirling and McEwan 1975). The remaining carrion may be important to the survival of subadult bears that are as yet unable to hunt successfully (Stirling 1974b), and to arctic foxes (discussed below).

Polar bears also eat bearded seals, carrion, and kills made by other polar bears. Subadult bears and females are often interrupted and displaced by males while on their kills (Stirling and McEwan 1975). Polar bears will also take belugas when the latter are trapped in newly formed ice (Freeman 1973). In the Barrow Arch, bears eat beached carrion, including the carcasses of seals, bowheads, belugas, and walruses (Lentfer 1972).

A 250-kg polar bear requires about 2×10^3 kcal/h when walking and about 180 kcal/h when at rest (Øritsland *et al.* 1981; Hurst *et al.* 1982). Application of these data to Stirling's (1974b) behavioral data yields a daily caloric requirement of 18×10^3 kcal for a 250-kg bear. An entire 1-year-old seal would provide energy for 3.7 days while the blubber alone would provide 2.7 days of energy, at 66.5×10^3 kcal and 49×10^3 kcal, respectively (Stirling and McEwan 1975). Stirling (1974b) observed a mean kill rate of one seal per 5 days per bear during poor hunting conditions off Devon Island.

Prior to 1972, the total Alaskan harvest of polar bears was about 250 animals per year, with males accounting for 80 to 85% of the catch. Since that time, however, trophy hunting has been banned and the total harvest in Alaska has been about 100 animals per year, with 24 bears per year harvested in the Barrow Arch, especially at Point Hope (Lentfer 1976, pers. comm.). These are minimum estimates; the actual number of bears harvested in the Barrow Arch is probably closer to 50 per year (L. Lowry, pers. comm.).

4.2.6 Arctic Fox

Many arctic foxes (*Alopex lagopus*) spend the winter on the sea ice of the Barrow Arch area, although there is no information on the proportion of the population that does so. As noted previously, polar bears often eat only the blubber from ringed seals they have killed; arctic foxes may scavenge the remaining high quality carrion (Stirling and Smith 1975). Arctic foxes are predators of ringed seal pups in some areas. In Amundsen Gulf, Smith (1976) found that foxes had located and marked 34% of 370 ringed seal lairs that he investigated and had entered over 90% of them. Fifty-three percent of those entered were birth lairs, but not all of these showed evidence of a kill. Smith estimated that from 1971 to 1974, the average predation rate by foxes on ringed seal pups was 26.1% per year, with an estimated range of 4.4 to 57.7%. He also found that the foxes appeared to utilize the entire carcass, remained with it for some time, and in some cases more than one fox had fed on the carcass. The level of predation by foxes on ringed seal pups in the Barrow Arch has not been quantified.

The mean daily energy requirement of an arctic fox in winter is between 349 and 522 kcal. A newborn ringed seal pup would provide 30–45 fox-days of energy and an almost weaned pup would provide 227–342 fox-days of energy (Smith 1976). Energy derived from a bear-killed seal is a function of the amount of the seal consumed by the bear.

Arctic foxes are important to local trappers but there are no statistics available on numbers harvested or on their abundance in the Barrow Arch. Based on personal observations and discussions with local hunters, J. Lentfer (pers. comm.) suggested that the coastal zone of the Barrow Arch supports a substantial population of arctic foxes.

4.2.7 Beluga (Belukha, White Whale)

The status of the beluga (*Delphinapterus leucas*) populations that winter in the Bering Sea is unclear. Burns (cited in Braham *et al.* 1984) estimated that all Alaskan populations totaled about 16,000 animals. Some of these animals summer in the Bering Sea—in the Bristol Bay–Kuskokwim area and in the Norton Sound–Yukon Delta area—but most migrate north through the Bering Strait in spring (Braham *et al.* 1984). The spring migration follows the shear zone lead system and the adjacent loose pack ice along

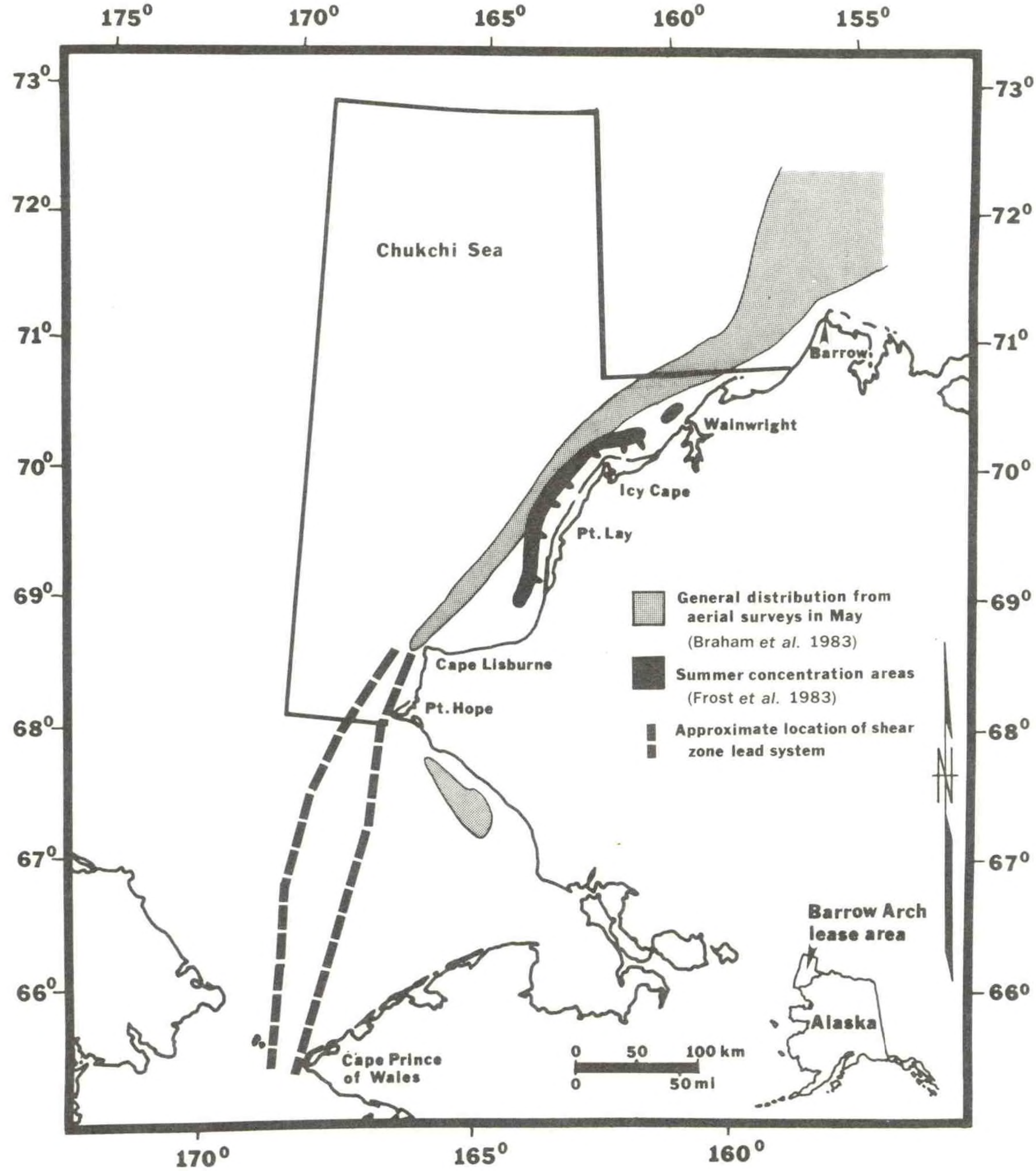

FIGURE 4.6—Distribution of beluga whales in the Barrow Arch in spring and summer. (After Frost *et al.* 1983.)

the northwest coast of Alaska (Fig. 4.6) (S. Moore, pers. comm.). Peak passage through the Barrow Arch occurs in April and May, with the last animals passing Point Barrow in early June (Johnson *et al.* 1966; Braham *et al.* 1984; L. Lowry, pers. comm.). These belugas, an estimated 11,500 in all, constitute the eastern Beaufort Sea, or Mackenzie estuary, stock (Davis and Evans 1982).

A second group of belugas moves into the Barrow Arch after the eastern Beaufort Sea stock has left. This second group summers in the Kasegaluk Lagoon area (Fig. 4.6); it numbers 1,500–2,500 animals, although there is substantial annual variability (K. Frost and L. Lowry, pers. comm.). The whales arrive in the Kasegaluk Lagoon area in mid- to late June after the fast ice has broken away from the coast. There is no information on whether these animals are the same as those that occur in Kotzebue Sound in June or if two stocks are involved. The stock identity of the Kotzebue and Kasegaluk animals is an important management problem that could be addressed using the tagging methods developed by L. Lowry of the Alaska Department of Fish and Game.

Belugas occupy the Kasegaluk Lagoon area from late June to early August. They congregate in the passes leading into the lagoon but spend most of their time in the nearshore waters outside the lagoon (L. Lowry, pers. comm.). Most calving occurs at this time and the whales also feed in the area.

There have been no studies of the diet of the whales in the Kasegaluk area; it is probable, however, that their diet is similar to that of belugas in the Kotzebue Sound area (Seaman *et al.* 1982). They probably feed on saffron cod, smelt, capelin, salmonids, and sculpins (L. Lowry, pers. comm.). According to hunters, early arriving belugas have usually eaten shrimp, squid, and small fish, whereas later in the summer they have usually eaten fish (Seaman *et al.* 1982).

Although belugas are found primarily in the Kasegaluk Lagoon area in July and early August, small numbers may occasionally occur in other nearshore waters from Cape Lisburne to Barrow (L. Lowry, pers. comm.). The whales leave the coastal waters around mid-August but their movements at this time are poorly understood. It is possible that the whales move offshore where they associate with loose ice in the southern fringe of the pack ice.

The large population that summers in the eastern Beaufort Sea and Amundsen Gulf begins its migration to wintering areas in late August and September (Fraker 1980). The first movements appear to be northward away from coastal waters and toward the pack ice. The main emigration from the Canadian Beaufort Sea is primarily through offshore waters in September (Davis and Evans 1982). The fall migration routes and timing through the Chukchi Sea are not well documented. In late September and October, belugas have been observed in open pack ice 100–160 km offshore northeast and northwest of Barrow (S. Moore, pers. comm.). Little else can be said of the fall migration through the Barrow Arch except that there is no evidence to suggest that a coastal migration occurs. Belugas regularly reach the St. Lawrence Island area, south of the Bering Strait, in November (Braham *et al.* 1984).

There is, as yet, no agreed upon method of aging belugas. Two dentinal layers may be deposited annually; however, the evidence is not conclusive and therefore hampers construction of population models and calculation of reproductive rates (Finley *et al.* 1983b). In eastern Canada, females mature when 9 or 10 tooth layers are present (5 years?) and males when 14–18 layers are present (7–9 years?). Conception occurs in May, gestation lasts 14.5 months, and lactation lasts 2 years; females produce a single calf about once every 3 years. Gross annual production of calves is estimated at 12% and instantaneous recruitment is about 9% of the total population (Brodie 1971; Sergeant 1973). No comparable data exist for Alaskan waters.

An average of 50–60 belugas are harvested annually in the Barrow Arch area (Table 4.1). At Point Lay, the whales are taken in drive hunts in the shallow lagoons and the loss rate is near zero. Off Barrow and Point Hope, where hunting occurs in the leads in the ice, the loss rate is 30–80% (L. Lowry, pers. comm.). Hunters from Wainwright take a few whales in the spring leads but most whales are shot from boats in summer (Nelson 1981).

4.2.8 Gray Whale

The gray whale (*Eschrichtius robustus*) is classified as an endangered species by the Endangered Species Act. However, the species has recovered from commercial whaling and apparently is not biologically endangered. The gray whales that inhabit the Chukchi Sea in summer belong to the "California stock" that winters in the coastal waters of Mexico. This population migrates along the west coast of North America and reaches the Bering Sea in June (Rice and Wolman 1971; Braham *In press*). Occasionally, gray whales have been recorded in the nearshore lead systems at Point Hope and Barrow in early June (F. Durham and A. Brower, cited in Braham *In press*). However, the gray whale is not typically closely associated with ice and the main movements into the Chukchi Sea occur after the pack ice has retreated northward.

Reilly *et al.* (1983) used three estimation procedures to determine that the California stock of gray whales numbers between 15,647 and 17,577 animals. The distribution of these animals in summer is only partly known. Thomson and Martin (1983) estimated that about 2,850 gray whales summered in the Chirikov Basin (between St. Lawrence Island and the Bering Strait) and the waters around St. Lawrence Island. Their estimate was derived by applying a correction factor for subsurface animals (Miller 1983; Würsig *et al.* 1983) to aerial surveys conducted in

TABLE 4.1—Annual harvest of belugas in the Barrow Arch.

Location	Time	No. of Belugas Harvested	
		Range	Mean
Point Hope	Spring	10–53	28
Point Lay (lagoons)	Summer	3–30	13
Wainwright	Spring–Summer	0–37	10
Barrow	Spring	4–5	4–5

SOURCE: L. F. Lowry, pers. comm.

1981 by Ljungblad *et al.* (1982) and in 1982 by Miller (1983). Russian workers estimate that 7,700 to 7,800 gray whales summer in the Soviet portions of the northern Bering Sea and the western Chukchi Sea north to Wrangel Island. Application of the methods of Thomson and Martin (1983) to the data of Ljungblad *et al.* (1982) yields an estimate of about 1,650 gray whales in the nearshore waters of the U.S. portion of the Chukchi Sea in 1981. About half of these animals were in the Barrow Arch. Very small numbers of gray whales penetrate eastward into the Beaufort Sea (Rugh and Fraker 1981; Moore and Ljungblad *In press*).

The foregoing estimates account for about 12,300 gray whales. The remaining 3,300–5,300 animals are most likely present in the offshore waters of the Chukchi Sea. An unknown, but probably substantial, proportion of these animals likely summers in the offshore waters of the Barrow Arch. However, the numbers involved are unknown because very few surveys of the offshore areas have been conducted. It should also be noted that there is apparently some annual variation in the distribution of summering gray whales. The numbers of animals observed during aerial surveys of the nearshore waters of the Barrow Arch were greater in 1982 and 1983 than in 1980 and 1981 (S. Moore, pers. comm.).

In autumn, gray whales are dispersed throughout much of their northern range, including the Chukchi Sea (Braham *In press*). Movements out of the Chukchi Sea have not been documented. The population leaves the Bering Sea in late November and early December (Rugh and Braham 1979).

In the Chirikov Basin in 1982, Würsig *et al.* (1983) found that gray whales fed during 79% of the time in July and 69% in September. During concurrent aerial surveys in the Chirikov Basin, 46% of the gray whales seen were associated with a mud plume, indicating recent feeding on the sea bottom (Miller 1983). About 40% of the gray whales seen during aerial surveys in the nearshore waters of the Barrow Arch in 1982 and 1983 were associated with mud plumes (S. Moore, pers. comm.). This figure is similar to that found in the Chirikov Basin, and suggests that the Barrow Arch may also be an important feeding ground for gray whales.

Gray whales are benthic feeders. Their main food items consist of infaunal and epibenthic amphipods (Bogoslovskaya *et al.* 1981; Thomson and Martin 1983; Nerini *In press*). Other prey are also taken but do not constitute a significant portion of their diet. When feeding, gray whales appear to suck up the top few centimeters of substrate, retaining the amphipods and expelling the sediment (Thomson and Martin 1983). In many areas, including the Barrow Arch, gray whales are often observed feeding in or near the surf zone (S. Moore, pers. comm.); in these instances, littoral amphipods and mysids may be the principal prey.

Würsig *et al.* (1983) found that gray whales in the Chirikov Basin made about 198 feeding dives per day in July and 164 per day in September. The daily ration for an average-sized adult gray whale weighing 23 t, while on its summer feeding grounds, appears to be about 700 kg/day wet weight (Thomson and Martin 1983).

Thomson and Martin (1983) found that gray whales consume approximately 5% of the overall annual productivity of their principal prey in the Chirikov Basin; this level is sustainable by the prey populations. However, to meet their energy requirements, gray whales must feed on dense concentrations of prey and it is the numbers and locations of these concentrations that determine the carrying capacity of the range. The extent and distribution of patches of prime feeding habitat have not been investigated in the Barrow Arch. Benthic studies conducted by Stoker (1978) indicate that areas of prime gray whale feeding habitat may be scarce in offshore waters of the Barrow Arch. Gray whales have been observed feeding very close to shore in and near Peard Bay and other areas in the Barrow Arch (Kinnetic Laboratories 1983; S. Moore, pers. comm.). If so, those areas that do exist could be of critical importance to the gray whale.

Gray whales reach sexual maturity at a mean age of about 8 years. The mean date of conception is 5 December; gestation lasts about 418 days, and the mean date of birth is 27 January (Rice and Wolman 1971; Rice 1983). Weaning of young may occur gradually after about 7 months (Rice and Wolman 1971). The pregnancy rate is about 56%. The maximum theoretical calf production is 12.8% of the population; however, mortality is high in the calving lagoons and during the first part of the northward migration. Off California, the proportion of calves in the northward migration is between 4 and 5% (Swartz and Jones 1983). The population appears to be increasing at a rate of 2.5% per year (Reilly *et al.* 1983).

Gray whales are harvested by the Soviets, who take about 170 animals per year under an International Whaling Commission quota. In U.S. waters, they are hunted off St. Lawrence Island (one or two animals per year) and were hunted in the Barrow Arch area (one or two animals per year) in the 1950's and early 1960's (Marquette and Braham 1982).

4.2.9 Bowhead Whale

The "Bering Sea" or "western Arctic" stock of the bowhead whale (*Balaena mysticetus*) is considered to be an endangered species. It winters in the

Bering Sea and migrates through the Chukchi Sea to summering grounds that are primarily in the Canadian Beaufort Sea. Bowheads winter in the pack ice in the western and central portions of the Bering Sea (Brueggeman 1982; Braham *et al.* 1984). The animals follow the shear zone lead system across the mouth of Kotzebue Sound and past Point Hope and Cape Lisburne. They then follow the lead system northeast through nearshore waters to Point Barrow (Fig. 4.7). East of Point Barrow, bowheads move east and east-northeast through the offshore pack ice into the Canadian Beaufort Sea and Amundsen Gulf (Fraker 1979; Braham *et al.* 1980a; Ljungblad *et al.* 1980, 1982, 1983; Ljungblad 1981).

The timing of the spring migration is dictated by ice conditions. The main movement through Barrow Arch waters usually occurs from mid-April to mid-May, although major movements can occur in late May in response to heavy ice conditions. Some of the recent data from the ice-camp observations at Barrow are summarized in Table 4.2. In at least one instance (1978), bowheads moved from Cape Lisburne to Barrow in 4 days (D. Rugh, pers. comm.).

It is generally believed that virtually all of the western Arctic bowhead population passes Point Barrow in the spring and that most of the animals summer in Canadian waters. The weighted average estimate of the population size based on 4 years of observations at Barrow is 3,871 ± 254 bowheads (Scientific Committee, I.W.C., July 1983). Thus, it would seem that most of the animals that pass Barrow in spring reach the Canadian Beaufort Sea.

There is, however, some indication that our understanding of bowhead movements may be incomplete. As Fraker (1983) points out, major historical catches of bowheads by the commercial whalers occurred during July, August, and September in the Bering and Chukchi seas (*see also* Braham *et al.* 1984). These records thus indicate that, at least historically, the Chukchi Sea and the Barrow Arch were important summering grounds for the bowhead. However, there are very few summer records for any area west of the Canadian Beaufort Sea in recent years. This is probably partly a function of lack of research in areas west of Point Barrow but may also accurately reflect the present distribution of the population. Ljungblad *et al.* (1983) observed substantial numbers of bowheads offshore in the eastern American Beaufort Sea in August 1982. L. Lowry (pers. comm.) has observed bowheads off Point Barrow in mid-August and local whalers have two records of single bowheads off Wainwright in recent years. However, a series of joint U.S.-U.S.S.R. research cruises in the Chukchi Sea failed to find any evidence that bowheads presently summer in the Chukchi Sea (Miller *et al.* 1983).

The principal migration of bowheads out of the Canadian Beaufort Sea begins in the first half of September (Davis *et al.* 1982). Migration through the American Beaufort is relatively leisurely, with feeding occurring in some areas. Substantial numbers of bowheads do not reach the longitude of Barrow until late September (Ljungblad *et al.* 1983).

There is little information on routes that bowhead whales take through the Chukchi Sea. Between Barrow and Wainwright, small numbers of bowheads were observed moving southwest in late September to mid-October in 1982 and 1983; these animals were from 1 to 45 km offshore (S. Moore, pers. comm.). There is no evidence for a coastal migration through the Barrow Arch in fall (Braham *et al.* 1984). Based on the records of the commercial whalers, it appears that a substantial portion of the population migrates west across the northern area of the Barrow Arch to the Wrangel Island and Herald Island areas and the nearshore waters on the north side of the Chukotka Peninsula (reviewed by Miller *et al.* 1983; Braham *et al.* 1984).

There is no information on the proportion of the population that migrates southwest through the Barrow Arch as opposed to the proportion that migrates due west to Soviet waters. It is possible that the bowheads that move west to Soviet waters follow the edge of the loose pack ice or the edge of the continental shelf where upwelling may concentrate food organisms. However, it is not known whether bowheads feed during their fall migration through the Chukchi Sea. Feeding apparently does occur in the waters off the northern Chukotka Peninsula.

An important unresolved question is the relationship between the bowheads that summer in the Canadian Beaufort Sea and the early arrivals off the Chutotka Peninsula in Siberia. The intensive aerial surveys during fall migration (e.g., Ljungblad *et al.* 1983) indicate that bowheads do not begin to leave the Beaufort Sea until the last half of September. However, bowheads are present along the Chukotka Peninsula by early September (Doroshenko and Kolesnikov 1983). Braham *et al.* (1984) believed that these early arrivals off Chukotka represented early migrants from the Beaufort, whereas Bogoslovskaya *et al.* (1982) believed they were animals that did not migrate to the Beaufort Sea but instead remained in the Chukchi Sea.

The reproductive biology and population dynamics of the bowhead whale are poorly understood. The age of first breeding in males and females is unknown as is the average longevity of the whales. Mating has been observed from March through May (M. K. Nerini, pers. comm.), and thus some occurs when the whales are in the shear zone lead system in the Barrow Arch. The calving period extends from

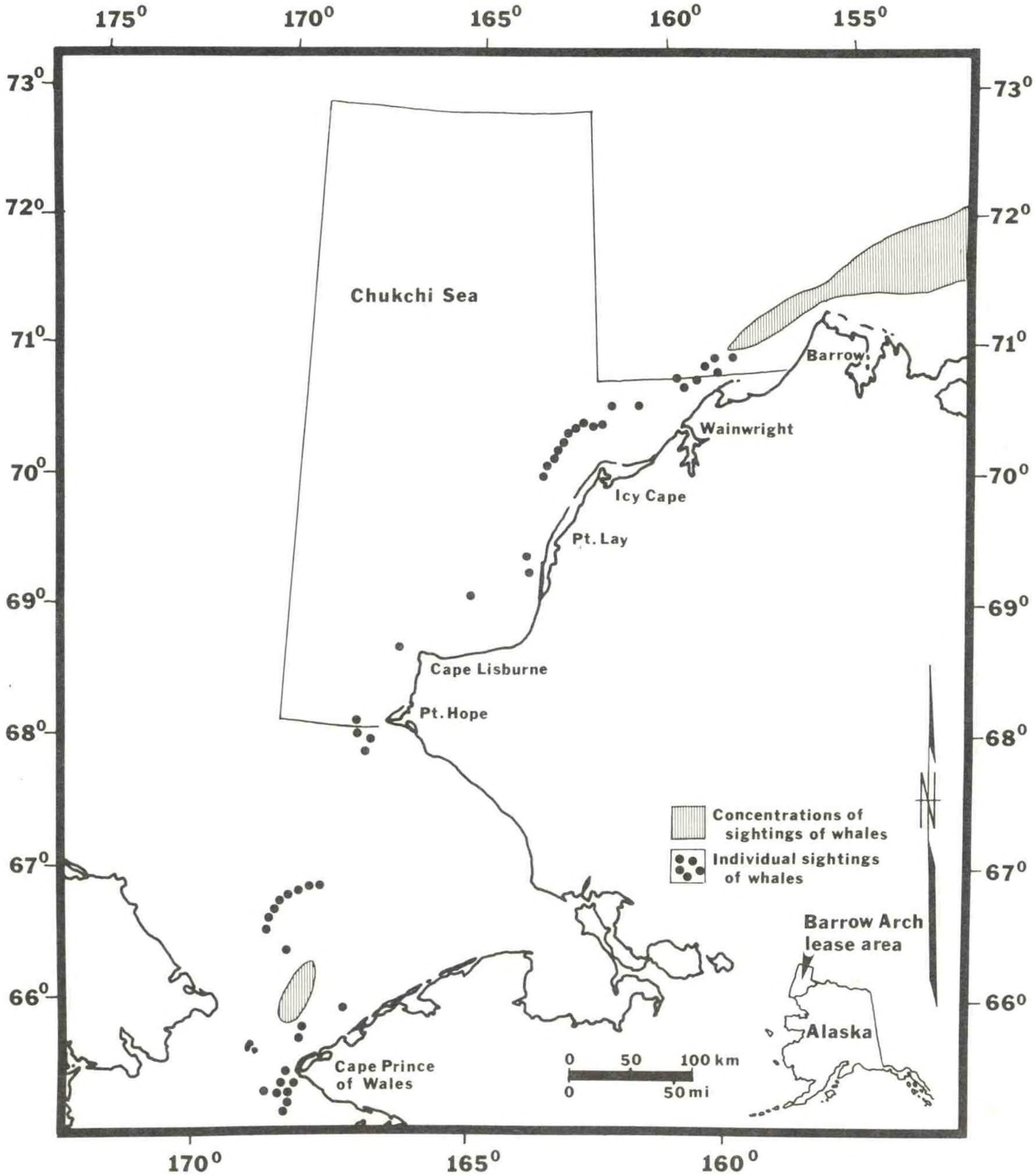

FIGURE 4.7—Bowhead whale sightings in the eastern Chukchi Sea in spring; 1976, 1980, 1981, and 1982 sightings combined. (From Ljungblad *et al.* 1980, 1982, 1983; Braham *et al.* 1984.)

March through early August with the peak probably occurring in May, and perhaps June (M. K. Nerini, pers. comm.; Davis *et al.* 1983). The gestation period is about 13 months and lactation extends for 7 to 9 months (Davis *et al.* 1983), or 12 months (M. K. Nerini, pers. comm.). Based on very small sample sizes, Nerini and coworkers at NMFS suggest that females calve every 3 to 6 years. However, much larger sample sizes are needed to refine this estimate.

Overall, bowheads are thought to have a very low reproductive rate and hence a correspondingly low rate of recovery from population losses. Several estimates of gross annual reproductive rate (percent of calves in the population) have been made, based on aerial, ship, and shore-based surveys. These surveys all indicate that calves constitute from 2 to 4% of the population (*cf.* Cubbage and Rugh 1982; Davis *et al.* 1982). However, recent studies suggest that these survey techniques underestimate the numbers of calves in the population and that the gross annual recruitment rate is higher than previously thought (Davis *et al.* 1983; Ljungblad *et al.* 1983). Unfortunately, because of differential distributions of the various age and sex classes, the actual gross annual reproductive rate for western Arctic bowheads is presently unknown.

Bowhead whales appear to feed in two ways: (1) by skimming the surface of the water and scooping up food with their mouths open, and (2) by filtering plankton from the water column (Griffiths and Buchanan 1982; Würsig *et al.* 1982). Analysis of stomach contents (Lowry and Burns 1980) and observations of behavior (Würsig *et al.* 1982) indicate that bowheads also feed on or near the bottom.

Lowry and Frost (1983) examined 20 bowhead stomachs from hunter-killed animals in Alaska (Table 4.3). Volumetric analysis of the samples showed that copepods and euphausiids were the dominant prey species of whales taken in these nearshore waters. Feeding appears to be more intensive during the fall migration than the spring migration (*see* Marquette *et al.* 1982; Lowry and Frost 1983).

Energetic requirements of bowhead whales were calculated as follows (LGL Ltd. *In prep.*). Mean sizes of mature and immature whales, pregnancy rates, and numbers of lactating females were calculated from data provided by Davis *et al.* (1983). Basic metabolism, energetic cost of warming air and food, and weight of the animal were calculated from data provided by Brodie (1981a). The energy costs of swimming were extrapolated to bowheads of various sizes from Sumich's (1983) single estimate for gray whales, using Tucker's (1975) general equation of body mass versus cost of transport for swimmers. Energetic costs of pregnancy and lactation were taken from Gaskin (1982). Caloric content of Arctic copepods and euphausiids is about 6.5 kcal/g dry weight (Percy and Fife 1981). The whales were assumed to spend 105 days feeding in Canadian waters and 60 days feeding in Alaskan and Soviet waters. Under these conditions daily energy rations were as shown in Table 4.4.

Griffiths and Buchanan (1982) calculated that a bowhead whale may have to feed on concentrations of zooplankton of about 6 g/m^3 continuously for 10 h to meet its energetic requirements. The animal also rests, washes baleen, and engages in social activity. Feeding in the dilute plankton of the Beaufort Sea must take place throughout most of the day. (There is no information on feeding rates in the Barrow Arch.) To meet the foregoing requirements, the whale must process food at the rate of about 40 kg/h. The stomach of a bowhead is relatively small (T. Albert, pers. comm.), and field sampling has shown that whales taken in autumn near Barter Island contained 19–45 liters of food (Lowry and Burns 1980). Bowhead whales appear to be adapted to feed on dilute concentrations of plankton. When feeding they may have to feed continuously, and may be unable to take advantage of an overabundance of food, should the situation occur.

The bowhead hunt is a critical element in the Inupiat culture and the muktuk of the bowhead whale is an important dietary staple for communities in the Barrow Arch area. From 1970 to 1979, bowhead landings averaged 21 animals per year in the Barrow Arch area. From 1980 to 1982, an average of eight whales per year were landed (Table 4.5).

4.3 VULNERABILITY TO OCS DEVELOPMENT

Potential effects of offshore petroleum industry activities on marine mammals may occur at the level of either the individual or a population. To evaluate the importance of various concerns one should examine the sensitivity of the individual to the activity. For example, how do individuals react to seismic exploration activity, or how is an animal affected by contact with a surface oil slick? The sensitivities of individuals of various species to offshore oil and gas lease activities are addressed in later sections of this report. Of equal concern is the question "What is the vulnerability of the whale population to offshore activities?" Vulnerability is a function of the proportion of any population that could be affected by an industry activity or group of activities. A population that is concentrated in a restricted area or habitat

TABLE 4.2—Timing of movement of bowhead whales past Barrow during spring migration.

Date	Peak Passage	Range	Reference
1976	1st half of May	20 April–early June	Braham *et al.* (1977)
1978	late April, 1st half of May	21 April–30 May?	Braham *et al.* (1979)
1979	mid-May	8–23 May	Braham *et al.* (1980a)
1980	end of May	21 May–2 June	Johnson *et al.* (1981)
1982	end of April, 1st half of May	26 April–end of May	Dronenburg *et al.* 1983)

(e.g., bowheads in the shear zone lead in spring) is more vulnerable to industry activity (e.g., oil spills) in that area than is a widespread species with only a few individuals in any particular area. In the following paragraphs we examine the potential vulnerability of the various species by season.

4.3.1 Winter

Relatively few species of marine mammals are present in the Barrow Arch area in winter. The coastal fast ice supports breeding ringed seals and polar bears. Fast ice in the Barrow Arch supports higher densities of seals than does fast ice in the Beaufort Sea. The seals are typically fairly evenly distributed throughout the fast ice, as are the bears that feed on them. Densities of ringed seals are higher in the active shear zone than in either the adjacent fast ice or polar pack ice; again, they are likely to be fairly evenly distributed throughout this habitat. The shear zone is also likely to be an important habitat for bears, and a few bearded seals also overwinter in this habitat. Farther offshore on the polar pack ice, densities of ringed seals and bears are presumably lower than on the fast ice but because of the large areas involved large numbers of seals may be present. Overall, neither the ringed seal nor the polar bear population is particularly vulnerable in winter because of their widespread distributions.

There are two site-specific potential concerns. Pregnant female polar bears den and give birth in snow lairs along the northwest coast of Alaska. There are no known denning concentrations in this region but there have been no systematic denning surveys conducted along this coast. Such surveys should be conducted before the locations of new shore-based facilities are determined.

On-ice seismic activity could affect ringed seals breeding on the fast ice. Although there may be no effects at the population level, local effects could nevertheless occur that would impair hunting opportunities near communities. This question is presently being studied by B. Kelly and J. Burns of the Alaska Department of Fish and Game for the Minerals Management Service. Results to date suggest that major effects from on-ice seismic activity probably do not occur, although there may be some very localized effects near the actual seismic lines (B. Kelly, pers. comm.). This study is ongoing.

4.3.2 Spring

The principal habitat change in spring is the opening of the shear zone lead system between the landfast ice and the pack ice (Fig. 4.1). Mammals, primarily ringed seals and polar bears, that occupy the landfast ice and pack ice remain widespread in relatively low numbers and, thus, they are not particularly vulnerable to offshore activities. However, the nearshore lead system is a major migration route for several species of importance.

Virtually the entire population of nearly 4,000 bowheads that summers in the Canadian Beaufort Sea passes through the nearshore lead system from mid-April to early June. In some years the migration can be quite compressed, with most of the animals passing Barrow in a 2-week period. Regardless of the specific timing in any particular year, all of the animals must pass the same point along the lead, often within a few kilometers of the fast-ice edge. Clearly, the bowhead population should be classified as vulnerable during its spring migration through the Barrow Arch. It is concentrated both spatially and temporally.

Belugas also follow the nearshore lead system during their spring migration to the Canadian Beaufort Sea. Less detailed information about the specific timing of this migration is available for belugas than for bowheads but most animals move through the lead system in April and May. Some of the animals move through the open ice along the offshore edge of the lead rather than the lead itself. It is believed that the entire "eastern Beaufort Sea stock" of 11,500 animals moves through the nearshore lead and adjacent pack ice. Hence, the beluga population is vulnerable to potential effects in this area.

Walruses, bearded seals, and spotted seals also use the nearshore lead system in May and June to gain access to the Barrow Arch. Although a substantial number of animals may be involved there are no

TABLE 4.3—Contents of stomachs of bowhead whales harvested in Alaska.

Location	Season	Sample Size	Euphausiids (%)	Copepods (%)
Barrow	Autumn	2	90.3	Not reported
	Spring	4	59.1	30.7
Kaktovik	Autumn	8	31.2	66.1

SOURCE: Lowry and Frost 1983.

quantitative data available, so it is not possible to determine what proportion of the populations of these species use the nearshore lead system. However, the animals that use the system are geographically concentrated and the three species are at least potentially vulnerable.

4.3.3 Summer

In the ice-free summer period, the coastal lagoon systems are used by belugas and spotted seals. The belugas occupy the nearshore waters outside the lagoons and often concentrate at the passes into the lagoons, at which time they are taken by hunters from Point Lay and Wainwright. The status of the belugas using Kasegaluk Lagoon is unknown. The 1,500 to 2,500 animals involved may represent an entire stock or population, or they may be part of the stock that also uses Kotzebue Sound in summer. Even in the latter case, the animals in the Barrow Arch area would represent a substantial proportion of the population in a restricted area and hence the population would be vulnerable. Less is known about the spotted seals in the coastal lagoon systems. They clearly represent a smaller fraction of their total population than do belugas in the lagoon systems, but the spotted seal haulout sites in the lagoons are among the largest known in Alaska.

Gray whales occupy the nearshore and offshore waters of the Barrow Arch (including Peard Bay) in summer. It is not known how many animals are involved, and their distribution patterns, particularly offshore, are poorly known. There is some evidence that good feeding habitat for gray whales may be patchily distributed in the Barrow Arch but there are no data on the number and locations of these patches, if indeed they exist. Major recurring concentrations of gray whales are unknown in the Barrow Arch. Thus, their vulnerability is probably not great.

Several species of marine mammals are associated with the offshore pack ice in the Chukchi Sea in summer (Fig. 4.2). Bearded seals, ringed seals, and polar bears are closely associated with the large expanses of mobile pack ice. Substantial proportions of the populations of each of these species may occur in and adjacent to the pack ice. Bearded seals are thought to frequent primarily the looser ice near the edge. There are no systematic data on the ice habitat preferences of the three species in summer.

Walruses are also associated with the pack ice edge in the Barrow Arch. About 40% of the Pacific walrus population is found in the American Chukchi Sea in summer. About 10% of these animals are distributed in open-water areas, with the remainder found in the open pack ice. Large herds can be found in relatively small areas of ice but these concentrations apparently do not recur in the same geographic area from year to year. Rather, their distribution at any particular time is determined by the location of the drifting pack ice. In general, this distribution makes the walrus population relatively invulnerable to direct effects from oil and gas activities. However, quite substantial numbers of individuals in large herds might occasionally be susceptible to at least short-term effects. A small terrestrial walrus haulout is present in the Cape Lisburne area. Although this is the only terrestrial haulout in the Barrow Arch, the number of walruses that use it is small (a few hundred animals) and represents much less than 1% of the summer population in the American Chukchi Sea.

4.3.4 Fall

The fall migrations of marine mammals through the Barrow Arch are not particularly well understood. Most of the seal species (and the walrus) apparently move out of the area in response to the advancing ice cover. It is not likely that major concentrations recur in specific areas of the Barrow Arch, and the species are probably relatively invulnerable.

Substantial proportions of the bowhead and beluga populations probably migrate west through the northern portions of the Barrow Arch to Soviet waters. The routes of these animals are not known but may be determined by the southern limit of heavy pack ice. Some bowheads and gray whales move southwest through the nearshore waters of the Barrow Arch but large concentrations have not been found, and the

TABLE 4.4—Daily energy rations* of bowhead whales feeding in the Beaufort and Chukchi seas.

	Adult Male	Pregnant Female	Lactating Female	Immature
Length (m)	14.5	14.5	14.5	11
Weight (kg)	51,800	51,800	51,800	22,620
Daily ration (kg, wet weight)	872	916	1,338	443

* For method of calculation, see text.

animals are not constrained in their choice of routes by ice at this time. It is possible that bowheads, gray whales, and belugas are relatively invulnerable to population effects during fall migration, but information on specific routes, times, and feeding behavior is lacking for this period.

4.4 SENSITIVITY TO NOISE AND DISTURBANCE

The question of the potential effects of noise and disturbance on marine mammals is very complex and not well understood. It is not the purpose of this report to provide a complete review of this question, nor is the intention to provide an impact assessment of offshore exploration in the Barrow Arch. Such an assessment requires detailed information about the proposed exploration and development plans and is premature at this time. Several recent reviews of the known and potential effects of offshore petroleum lease development activities are available (Geraci and St. Aubin 1980; Gales 1982; Richardson *et al.* 1983a). In the following sections we review some of the more recent research studies that are particularly relevant to the species of concern in the Barrow Arch. Brief presentations on these studies were made at the synthesis meeting.

4.4.1 Whales vs. Seismic Noise

There has been much recent concern about the potential effects of seismic exploration on marine mammals. Geophysical exploration by impulses of sound produces underwater noise with source levels far above those of other routine activities associated with offshore oil exploration and production. In the open-water season, impulsive noise is usually created by arrays of airguns with source levels of 245–250 dB/1 μPa-m (Richardson *et al.* 1983a). Received levels exceed 150 dB to a radius of at least several kilometers, and the noise is often detectable 25-100 km away (Ljungblad *et al.* 1980, 1982; Greene 1982, 1983, pers. comm.; Malme *et al.* 1983; Reeves *et al.* 1983).

Bowhead whales have been observed in the presence of seismic noise at distances of 3–99 km from seismic vessels (Reeves *et al.* 1983; Richardson *et al.* 1983b, pers. comm.). General activities of these whales have usually seemed normal, including surfacing, diving, traveling, feeding, socializing, and calling. No clear evidence of avoidance of active seismic vessels has been found in these studies. Subtle differences in surfacing, respiration, and diving behavior have sometimes been found between bowheads in the presence and absence of seismic noise. However, the differences have been small and inconsistent. These subtle and inconsistent differences in behavior may represent natural variability in bowhead behavior rather than any real reaction to seismic noise. Reeves *et al.* (1983) reported an observation of unusual "huddling" behavior in the presence of seismic noise, but similar observations were obtained in the absence of noise.

No controlled experiments to test reactions of bowheads to full-scale seismic noise have been done. However, three sub-scale tests of reactions to a single 40-cu-in. airgun have been done on the summering grounds (Fraker *et al.* 1982; Richardson *et al.* 1983b, pers. comm.). Noise from this airgun deployed 3–5 km from bowheads was similar to that from a full-scale seismic ship about 20 km away. During each experiment, bowheads were observed before, during, and after the airgun was fired. No clear reactions were detected.

Gray whales have been observed in the presence of seismic noise in Alaskan waters (Ljungblad *et al.* 1982), and reactions of migrating gray whales to seismic noise have recently been tested experimentally off California (Malme *et al.* 1983). The latter work provides the strongest evidence that gray whales are sensitive to seismic noise. Average pulse pressure levels of ≥ 160 dB/1 μPa produced clear behavioral reactions: the whales generally slowed, turned away from the noise source, and increased their respiration rates. They sometimes moved closer to shore, or into a "sound shadow" created by topography. The ≥ 160-dB average pulse pressure level corresponded to peak levels ≥ 170 dB, and occurred at ranges <5 km from a full-scale seismic vessel. Available data were inadequate to determine whether gray whales reacted to seismic noise with average pulse pressure levels of 140–160 dB (Malme *et al.* 1983).

TABLE 4.5—Average number of bowhead whales landed and struck and lost per year in the Barrow Arch area, 1970–79 and 1980–82.

Location	Year	Landed	Struck and Lost
Point Hope	1970–79	6.2	5.3
	1980–82	1.7	1.7
Wainwright	1970–79	1.6	4.5
	1980–82	2.0	0
Barrow	1970–79	13.5	12.2
	1980–82	4.3	7.0
Barrow Arch total	1970–79	21.3	22.0
	1980–82	8.0	8.7

SOURCES: Braham *et al.* 1979, 1980b; Marquette and Bockstoce 1980; Johnson *et al.* 1981; Marquette *et al.* 1982; Dronenburg *et al.* 1983.

The evidence from observations of bowhead and gray whales indicates that these species show little if any overt response to seismic boats more than a few kilometers away, despite the fact that intense noise pulses ensonify the water to considerably greater ranges from seismic boats. In the case of gray whales, avoidance responses and other behavioral changes do occur when a seismic vessel approaches within 5 km. No experimental data are available on effects of seismic activity on belugas.

4.4.2 Belugas and Disturbance

Several recent studies of the reactions of belugas to industrial activities have been conducted. They illustrate the complexity of interpreting the results of single studies. A great many factors appear to influence the reactions of belugas to various types of noise and disturbance.

F. Awbrey, Hubbs Sea-World Research Institute (HSWRI), reported on two seasons of fieldwork in the Snake River, Bristol Bay, on the reactions of belugas to playbacks of industrial noise, particularly the semisubmersible drilling rig Sedco 708 (source level 163 dB/1 μPa). Whales within 1.5 km responded to the starting and stopping of the noise by swimming away. However, the animals apparently were unaffected by continuous noise, approaching to within 300 m before turning back on one occasion and passing by at 15 m on another occasion. Similar results were found in captive animals: reactions to percussive and transient sounds but acclimation to continuous loud sounds. The strongest reactions by belugas in the Snake River were to outboard motor boats. Whale hunting in the area is done from these types of boats.

Awbrey also reported on two other studies using captive belugas at HSWRI. Tests of the low frequency hearing thresholds indicated that beluga detection thresholds were about 125 dB/1 $\mu Pa^2/Hz$ for frequencies from 125 to 500 Hz. This finding had been previously suspected but had not been demonstrated. It is important because many of the most intense underwater sounds from industry and shipping occur at these low frequencies and belugas are very hard of hearing at these frequencies. Awbrey suggested that the test animals may have been reacting to vibration rather than sound in the test tanks. He also noted that these may be masked hearing thresholds rather than absolute thresholds because the background noise in the test tanks was high—about 85 dB/1 μPa at low frequencies.

Captive belugas were exposed to intense noise levels (150 dB/1 μPa) and monitored to determine whether physiological stress occurred. Catecholamine levels in the blood were used as an indicator of stress. The results seem to indicate that stress levels did not increase as a result of the exposure to noise.

M. A. Fraker summarized his studies of belugas in the Mackenzie estuary and southeastern Beaufort Sea in the late 1970's and early 1980's. Belugas in this area were relatively tolerant of stationary sources of underwater noise such as artificial drilling islands, but did take evasive action at distances up to 2.4 km away to avoid moving vessels. The whales seemed to be more sensitive to noise and disturbance in shallow water than in deep water. In addition, belugas appeared to be more sensitive to vessels when the whales were in confined areas, such as leads in the ice, than in open, ice-free waters. The long-term monitoring studies of the whales in the Mackenzie estuary indicate that the numbers of animals and habitat use in the estuary have not been affected by the substantial oil industry activities that have occurred in the southeastern Beaufort Sea adjacent to, but not in, the shallow estuaries used by the whales.

Belugas have apparently adapted to regular ship traffic in Cook Inlet (M. Dahlheim, pers. comm.), Churchill, Manitoba, and the Gulf of St. Lawrence (D. Sergeant, Canada Department of Fisheries and Oceans, pers. comm.). In the Gulf of St. Lawrence, the whales are disturbed by boats that move into shallow bays used by whales and by small boats that harass the animals; however, they show very little reaction to the high levels of ship traffic (18,000 passages a year by oceangoing vessels) in nearby shipping lanes.

In some situations, belugas may not react to even very high levels of noise and disturbance. L. Lowry (pers. comm.) observed approximately 500 belugas in Kvichak Bay, inner Bristol Bay, during the king salmon run in late June to mid-July. The bay supports a very large salmon fishery, with about 500 fishing boats supported by high-powered tender boats and single-engine floatplanes. The whales consistently moved back and forth through the fishing fleet. Similar observations have been made of humpback whales feeding on capelin in close proximity to the large oceangoing Soviet trawler fleet on the Grand Banks off Newfoundland. Brodie (1981b) pointed out that the humpbacks may have few alternate sources of food and therefore they must feed in the area in spite of the presence of the trawlers. He suggested that there may be stress effects on these whales, but no data are available.

Finally, the complexity of interpreting whale responses to noise and disturbance is illustrated by studies conducted by LGL Ltd. of the responses of belugas to icebreaking ships in the Canadian eastern high Arctic. R. A. Davis reported that belugas along an ice edge across the mouth of a 35-km-wide fjord responded to a ship approaching from offshore when the ship was about 30 km away. The whales rapidly fled the ice edge and did not return for about 36 hours. Similar results were found during a second study in 1983. These responses are much stronger than observed in other areas. Two factors may, at least partly, explain these differences. First, belugas in the eastern high Arctic are naive with respect to ship traffic because very few ships have operated in this area in spring. Second, reactions may have been stronger because the ship approached the ice edge at right angles from offshore; the whales were effectively trapped between the approaching ship and the impenetrable fast-ice edge. This is analogous to the finding of Fraker that belugas are more sensitive in confined situations than in open water.

The implications of the recent work on belugas are that belugas in the Barrow Arch are likely to be sensitive to noise and disturbance when they are in the confined nearshore lead system during spring migration and when they occupy the nearshore waters of the Kasegaluk Lagoon area in summer. In these areas, mobile noise sources are likely to be more important. In other situations, belugas in the Barrow Arch are likely to be relatively insensitive to offshore lease exploration and development activities.

4.4.3 Bowhead Whales and Disturbance

Studies of the potential effects of noise and disturbance (apart from the seismic exploration discussed in the preceding section) on bowheads have been conducted in the Canadian Beaufort Sea by LGL for the Minerals Management Service. The studies began in 1980 and will conclude in 1984. (For results to date, see Fraker *et al.* 1982; Richardson 1982, 1983; Richardson *et al.* 1983b, *In prep.*) In general, bowheads show considerable tolerance to ongoing noise from offshore drilling and dredging but tend to react more strongly to rapidly changing situations such as an approaching boat or aircraft or a brief playback experiment. Bowheads swim rapidly away from boats that close to within 1 to 4 km; fleeing ceases when the vessel is a few kilometers beyond the whales but scattering of groups may persist for longer periods. Reactions to an approaching fixed-wing aircraft were frequent if it was below 1,000 ft (305 m) above sea level, infrequent at 1,500 ft (457 m), and undetectable at 2,000 ft (610 m). These conclusions are all based on studies of bowheads in essentially open-water conditions.

It is possible that stronger reactions would occur when the whales are in more restricted situations such as the nearshore lead system during spring migration through the Barrow Arch. Inupiat hunters state that bowheads are extremely sensitive to noises by the hunters in this situation. Gray whales may also be more sensitive in confined lagoons than in open water, although the fact that the lagoons are used by females with young calves may influence these differences (M. Dahlheim, pers. comm.).

The foregoing studies of bowhead reactions to noise, disturbance, and seismic activity have basically examined the short-term responses of the animals. This approach is valid because it is likely that the most severe short-term reactions will be the ones that are manifested in long-term changes. However, the short-term experimental approach will not actually yield predictions of longer-term effects. To examine the question of potential longer-term effects, Richardson *et al.* (1983c) and R. A. Davis (pers. comm.) examined the distribution of bowheads in relation to offshore hydrocarbon exploration activities on the summering grounds in the Canadian Beaufort Sea over the 4-year period 1980–83. This comparison may be relevant to the Barrow Arch situation because the levels of industry activity in the Canadian Beaufort Sea are already similar to those projected for the maximum levels likely to occur in the Barrow Arch area. During the 4-year study in the Beaufort Sea, the numbers of bowheads occurring in the zone of exploration activities steadily declined. Few bowheads have occurred in the industrial area in the past 2 years. It is very important to emphasize that bowhead distribution in summer seems to be naturally highly variable (Davis *et al.* 1983) and the changes from 1980 to 1983 may have little if anything to do with noise and disturbance from the industry. It is quite conceivable that the distributions of whales are determined by the variable distributions of the concentrations of zooplankton that the bowheads eat. With the available information, it is not possible to determine whether whale distribution is determined by food, industry activity, or some other factors or combination of factors. Clearly, this is a matter of some concern.

There is some concern among the hunters from Barrow that fall migrating bowheads now keep farther offshore in the area east of Barrow than they did in the mid-1970's. It is not at all clear what the causes of this change are except that there are several equally plausible explanations. The important point for this discussion is that, although the whales may be less accessible to coastal hunters, there is no evidence that the migration is being inhibited. Since there is no coastal bowhead hunting during the fall migration through the Barrow Arch, then slight changes in migration routes caused by industry would not be serious as long as the integrity of the migration is maintained.

4.4.4 Pinnipeds and Disturbance

No information on the potential effects of offshore exploration activities on bearded seals, spotted seals, and polar bears was presented at the workshop. Indeed, few relevant studies have been conducted. The potential effects of on-ice seismic activity on ringed seals have been discussed in preceding sections. The reactions of hauled out walruses to aircraft and ship disturbance were discussed. B. Kelly (pers. comm.) noted that herds of females with calves tended to stampede off the ice pans into the water when a ship approached, creating the potential for deaths of calves and separation of calves from their mothers. When the ship approached from upwind, herds stampeded an average distance of 71 m (range, 15–300 m; n, 39 observations); downwind, the average distance was greater (mean 207 m; range, 8–800 m; n, 21). Aircraft below 300 m altitude also caused stampedes. There was a subjective feeling that walruses were more sensitive to helicopters than to the fixed-wing aircraft (B. Kelly, pers. comm.; S. Stoker, pers. comm.). There is no information on how swimming walruses react to ship or aircraft traffic and it is not known whether walruses are more sensitive to disturbance when they are in areas confined by ice (e.g., the nearshore lead system in spring).

4.5 SENSITIVITY TO OIL

The workshop group did not have a detailed discussion of the potential effects of spilled oil on marine mammals, although the special case of the bowhead whale was discussed. In this section we provide a very brief summary of the available information on the topic so that readers can identify species, areas, and times of special concern in the Barrow Arch. Readers interested in more detailed and complete reviews of the potential effects of oil on marine mammals are referred to Geraci and St. Aubin (1980, 1982), Cowles *et al.* (1981), Smiley (1982), Engelhardt (1983), and Richardson *et al.* (1983a).

Several important questions need to be addressed in attempting to evaluate the sensitivity of marine mammals to oil spills. Can the mammals detect thin slicks of oil on the water surface? If so, do they avoid the oil? If oil is contacted, does it lead to changes in behavior or feeding? Does contact affect thermoregulation? Are there physical or physiological effects? Does death occur? Some of these questions are briefly reviewed below.

It is important to note a few of the characteristics of oil spills (e.g., blowouts) to put the potential problem in perspective. In the open-water situation, spilled oil evaporates and spreads very quickly. In addition, wind and waves cause the oil to disperse into the water column, at least temporarily. Thus, in most cases, we are interested in the effects of very thin slicks (a few microns) on the surface. An important exception might be a spill in a confined area such as a narrow lead system or a polynya. In this situation, spreading would be inhibited by ice, and wave-induced dispersion would be minimal. Consequently, thicker slicks might be expected.

4.5.1 Pinnipeds

The seal species that frequent the Barrow Arch are all hair seals (Phocidae), which rely on blubber rather than fur for insulation. Walruses are similar in this respect. It is not known whether these species can detect oil. However, numerous reports indicate that seals often do not avoid spilled oil.

Seals coated with "heavy" oil may have difficulty swimming or may suffocate when orifices become plugged (Davies 1949; Davis and Anderson 1976; Geraci and St. Aubin 1980; Smiley 1982). Fouling with light oil does not have these consequences (Geraci and Smith 1976). If they survive, seals gradually lose the oil when returned to clean water (Le Boeuf 1971; Davis and Anderson 1976; Geraci and Smith 1976).

Since adult seals and walruses are insulated with a thick layer of blubber, oiling of the skin does not appear to have any appreciable effect on thermoregulation (Øritsland 1975; Geraci and Smith 1976; Kooyman *et al.* 1976, 1977). However, newborn hair seal pups depend solely on their fur for insulation and would likely suffer thermal imbalance if oiled during the first 2 to 3 weeks of life (Irving 1972; Kooyman *et al.* 1976, 1977). The blubber layer of newborn walruses is not well developed, and they also appear to be susceptible to heat loss during the first few weeks of life (Fay 1982). The possible thermal consequences of oiling on walrus pups have not been studied.

Seals and walruses may ingest oil when feeding or when they open their mouths in oily water. When in newly spilled oil, the animals may also inhale its vapors. Oil droplets could be inhaled if the snout is covered with oil. Seals exposed to oil or fed oil-contaminated food showed the presence of hydrocarbons in the tissues and body fluids (Engelhardt *et al.* 1977). Hematology and blood chemistry appeared to be unaffected by oil, and tissue damage appeared to have been minimal (Smith and Geraci 1975; Geraci and Smith 1976; Engelhardt *et al.* 1977).

The most serious effects of oil appear to occur through external contact. The eyes are particularly susceptible to oil. Severe conjunctivitis, swollen nictitating membranes, and some evidence of corneal erosions and ulcers were noted in oiled ringed seals. However, these symptoms disappeared after 20 h in clean water (Geraci and Smith 1976).

An important consideration in assessing effects of oil is the physiological condition of the animal at the time of oiling. Smith and Geraci (1975) found that ringed seals stressed by captivity succumbed to oiling whereas free-ranging animals did not. Geraci and Smith (1976, 1977) pointed out that free-ranging animals under stress from severe ice conditions, malnourishment, molt, disease, parasites, or advanced age could be seriously affected or killed by oil. Animals arriving in the Barrow Arch after a long migration, walruses already stressed by limited food resources, and ringed seals during spring may all be more susceptible to the effects of oil than they would be in unstressed situations.

4.5.2 Polar Bears

There are two main differences between polar bears and seals with respect to the potential effects of oil. Polar bears rely on their fur as well as on a layer of blubber for thermal insulation (Irving 1972; Frisch *et al.* 1974) and oiled polar bears may ingest relatively large quantities of oil while grooming (Øritsland *et al.* 1981).

Experiments on live polar bears and on pelts have shown that oiled bears would suffer significant thermoregulatory problems (Øritsland *et al.* 1981; Hurst and Øritsland 1982; Hurst *et al.* 1982). Thermal conductance of the fur increased significantly after oiling and oiled bears showed increased metabolic rates and elevated skin temperatures.

Experimentally oiled bears ingested much oil through grooming. Much of it was voided in vomitus and feces, but some was absorbed and later found in body fluids and body tissues (Engelhardt 1981).

Other effects on the experimentally oiled bears included acute inflammation of the nasal passages, marked epidermal responses, anemia, anorexia, biochemical changes indicative of stress, renal impairment, and death (Engelhardt 1981; Øritsland *et al.* 1981). Many serious effects of oiling did not become apparent for several weeks after exposure to oil (Engelhardt 1981). It appears likely that heavily oiled bears would die. However, there is no information on the levels of ingested oil that would be lethal.

4.5.3 Whales

Due to their large size and the difficulty of studying them in the wild, there have been fewer studies of the effects of oil on live whales than on other live marine animals. However, because of the importance and perceived importance of whales in marine ecosystems, there has been a great deal of conjecture about these effects.

Four approaches have been used in studying the effects of oil on cetaceans: (1) direct experimentation on animals (Geraci *et al.* 1983); (2) direct experimentation on parts of animals that could be affected, such as baleen (Braithwaite *et al.* 1983); (3) extrapolations based on comprehensive anatomical studies (Albert 1981); and (4) observations of behavior in the wild (Evans 1982).

Beluga

No specific studies of the effects of oil on belugas have been reported. However, studies of other odontocetes are likely to be relevant. Dolphins are able to detect dark aggregated oil slicks and may actively avoid them after initial contact (Geraci *et al.* 1983; Smith *et al.* 1983). However, the study results suggest that thin slicks of light crude or refined oils would not be detected. Goodale *et al.* (1981) reported hundreds of white-sided dolphins in the oil slick from the *Regal Sword.*

There is little information on the potential effects of contact with oil by odontocetes. The scientific literature contains no reliable reports of whales being found coated with oil and there is no evidence of cetacean mortality due to oiling (Geraci and St. Aubin 1980). Geraci and St. Aubin (1982) showed that brief exposure to gasoline can have significant sublethal effects on dolphin skin, but these effects are not much more severe than those on skin of other mammals. Gasoline is not used in offshore exploration and crude oil was shown to have fewer effects than gasoline.

Caldwell and Caldwell (1982) could find no clinical effects attributable to hydraulic oil fed in low levels to a dolphin over a 3-month period. Based on a review of the literature concerning ingestion of oil by other mammals, Geraci and St. Aubin (1982) concluded that it is unlikely that any cetacean would ingest enough oil to cause death.

Baleen Whales

It is not known whether baleen whales such as bowheads and gray whales can detect oil slicks. There is some circumstantial evidence (reduced surface times and blow intervals) that gray whales may detect oil from natural seeps in the Santa Barbara Channel (Evans 1982). However, gray whales sometimes do swim through patches of thin oil (Watkins cited in Goodale *et al.* 1981; Evans 1982). Baleen whales were also observed feeding in the oil slick from the *Regal Sword* off Cape Cod. There have been no studies of the effects of ingestion of oil by baleen whales or of external contact with oil.

A major concern is the potential effect of oil on the baleen filtering system. Geraci and St. Aubin (1980) predicted that weathered oil and heavy refined products could foul the baleen and that lighter oils might physically damage baleen. Either of these situations would lead to reduced feeding efficiency. Studies of the effects of oil on the baleen of fin and gray whales (Geraci and St. Aubin 1982) and bowhead whales (Braithwaite *et al.* 1983) have been conducted recently. These studies showed that fouling with heavy, weathered oil will impair filtration efficiency, and probably feeding, at least temporarily. Effects on the baleen were largely reversible with prolonged exposure to clean water. In terms of actual sensitivity to oil slicks, it is likely that the bottom-feeding gray whale is less sensitive than the bowhead which feeds on the surface on some occasions. The situation with the bowhead is complicated by the fact that there is no information on the amount of feeding, if any, that it does in the Barrow Arch.

Based on intensive studies of bowhead anatomy and physiology, T. Albert (1981, pers. comm.) has raised several other potential concerns about the effects of oil on baleen whales, as follows.

Bowhead skin is characterized by dozens to hundreds of lesions (epidermatitis) characterized by a rough surface, erosion, and large numbers of bacteria and diatoms. In many cases, capillaries are close to the surface. Assuming a worst case, oil adhering to these lesions would allow pathogenic bacteria to multiply and enter the blood stream rather than being washed off. These bacteria and irritant action of the oil could cause further inflammation and erosion. A resultant severe inflammation of the skin could lead to thermoregulatory problems.

Tactile hairs are located around the blowhole and jaws. These tactile hairs may be important in prey detection and in informing the whale when its blowhole is above the surface. If oil remains adhered to these tactile areas, their sensory capability could be reduced or rendered inoperative. The functions of these tactile hairs are not presently known, however.

As a whale repeatedly surfaces in an oil slick, oil may adhere to the blowhole slits and be inhaled, leading to possible respiratory irritations. Geraci and St. Aubin (1982) do not believe this would occur.

Ingestion of oil by bowheads could have two effects. First, heavily weathered oil or tar balls could bind with strands of baleen hair that are normally found in the stomach. These oil-hair balls could block the very narrow tube that forms the third chamber of the stomach of the bowhead. Second, ingested oil could compromise the lymphoimmune system, resulting in decreased resistance to disease.

4.6 INFORMATION NEEDS

There are a great many gaps in the data base on marine mammals in the Barrow Arch, and gaps in information about the potential effects of OCS petroleum development activities on these mammals. These latter gaps are generic and apply to most Alaskan OCS areas; they have been adequately dealt with in other synthesis volumes and are not discussed further here. The following summarizes information needs directly relevant to marine mammals in the Barrow Arch. Needs are discussed on a species by species basis, not on the basis of relative importance.

Walruses are known to use the nearshore lead system in the spring but there is no information on the numbers of animals involved or the proportion of the population that is involved. Nearly all female and young walruses of the Bering–Chukchi population migrate to the American sector of the northern Chukchi Sea in summer. The importance of the Barrow Arch benthos to these animals is unknown.

Spotted seals use Kasegaluk Lagoon and Peard Bay in summer. These areas are important to the species but little is known about the actual numbers involved, their behavior, or feeding ecology. Ongoing studies in Peard Bay should fill some of these data gaps.

Ringed seals occupy the sea ice of the Barrow Arch throughout the winter and spring. They are found in high densities on the coastal fast ice and in lower but unquantified densities on the offshore pack ice. The breeding status of the pack ice animals has not been determined, thus it is not known whether all of the pups in the population are produced on the fast ice.

Site-specific information on denning by pregnant female polar bears is lacking. This information is required before the locations of coastal facilities can be determined.

The status of the belugas that occupy the Kasegaluk Lagoon area in summer is not known. It is important to know whether these whales represent an entire "stock" or part of another stock such as the Kotzebue Sound stock or, less likely, the eastern Beaufort Sea stock. The feeding ecology of the belugas in the Kasegaluk Lagoon area has not been studied.

Gray whales occur in the Barrow Arch during the summer open-water period. Large numbers of animals (up to several thousand) could be involved. However, there are no data on the number to be found in offshore waters and the distribution and behavior of these whales. It is probable that intensive feeding occurs but there are indications that available food may be patchily distributed. If this is the case, then specific parts of the Barrow Arch may be more important to gray whales than are other parts of the area.

The vast majority of the bowhead population moves through the Barrow Arch in spring and fall. In spring the animals use the nearshore lead system but the fall migration is not very well understood. Some animals move southwest through the area in late September and October but it is not known what proportion of the population does this. Large (but unquantified) numbers apparently migrate west through the northern Barrow Arch to Soviet waters. However, the timing and routes of this migration are unknown. The fact that bowheads appear along the

Chukotka Peninsula in early September, before the fall migration from Canadian summering areas reaches the American Beaufort Sea, is a significant inconsistency in our understanding of the western Arctic bowhead population. It is possible that some bowheads are present in the Barrow Arch in July and August, either as early returning migrants from the Beaufort Sea or as a remnant of the population that summered in these waters in the days of the commercial whalers.

4.7 SUMMARY

Of the 21 species of marine mammals that have been recorded from the Chukchi Sea, 9 are common either seasonally or year-round in the Barrow Arch. These are walrus; spotted, bearded, and ringed seals; polar bear and arctic fox; and beluga, gray, and bowhead whales. The distributions of these species in time and space are strongly affected by the seasonal cycle of sea ice, and are generally predictable to the extent that ice conditions are predictable.

The walrus population of the Bering and Chukchi seas, approximately 250,000 animals, is about 80% of the world's walruses. The bulk of the population is closely associated with the moving pack ice throughout the year, thus walruses are common in the Barrow Arch in late spring, summer, and fall, but uncommon in winter, when little moving ice is present. The relatively shallow shelf and high infaunal standing stocks of the Barrow Arch appear to provide excellent foraging for the benthic-feeding walruses; their food is primarily bivalve molluscs. The Barrow Arch walrus population has been increasing over the past few decades and may be facing a decline because of overuse of its food base.

All three species of seal—spotted, bearded, and ringed—respond to different ice conditions and thus the species are abundant at different seasons. Spotted seals are most abundant from May to October, when they feed and haul out in ice-free bays and lagoons. Bearded seals are generally most abundant in the Barrow Arch in spring and fall as they follow the broken-ice zone north and south, though many spend the summer at the edge of the polar pack ice in the northerly portions of the planning area. Ringed seals are most abundant in winter and early spring in the shorefast and pack ice areas. The diet of spotted seals is primarily fish, that of bearded seals is mainly benthic invertebrates, and that of ringed seals is fish (primarily cod) and crustaceans. All species of seal are taken by hunters; whether this or any other factors operative in the Barrow Arch regulate seal abundance is not known.

Polar bears and arctic foxes are the only two mammals in the Barrow Arch that are well adapted to moving about on a solid substrate (ice) in the marine environment. They are most abundant in fall, winter, and early spring, when ice covers much of the area. Polar bears are normally most common near land near Icy Cape and Point Franklin; in addition they frequently concentrate in winter at an offshore shoal area where open water and thin ice are maintained about 120 km northwest of Wainwright. Polar bears prey mainly on ringed seals; they also capture bearded seals and may at times feed on beached carrion (walruses, whales, seals). Arctic foxes forage out onto the sea ice, typically eating remains of polar bear kills and occasionally young ringed seals. Perhaps 50 polar bears and an unknown number of arctic foxes are harvested annually in the Barrow Arch area.

Beluga, gray, and bowhead whales are the only whales that annually occur in relative abundance in the Barrow Arch. About 11,500 belugas and about 3,850 bowheads (virtually all of the western Arctic stock) migrate through the area in spring and fall on their way to and from summering areas in the Canadian Beaufort Sea; about 1,500–2,500 belugas and a few thousand (good estimates not available) gray whales spend the summer in the Barrow Arch. The spring migrant belugas and bowheads follow the nearshore ice lead system; in fall they apparently move through the Barrow Arch farther offshore. Bowheads probably do not feed during their migration through the Barrow Arch. Belugas, at least those that summer in the Barrow Arch, probably eat forage fishes (cod, capelin, smelt), salmonids, and sculpins, and perhaps invertebrates such as shrimps and squid. Gray whales are benthic feeders, probably consuming mainly ampeliscid amphipods and mysids in the Barrow Arch.

Annual harvests of belugas in the Barrow Arch average 50–60 animals; bowheads harvested in and near the planning area (including all taken at Barrow) averaged about 21 per year from 1970 to 1979, and about 8 per year from 1980 to 1982. Whether these harvests are important in regulating population levels is not known. Very few gray whales are taken annually by hunters, and the gray whale population has been increasing in recent years.

The vulnerability of marine mammals to potential OCS development in the Barrow Arch varies seasonally, and is more or less proportional to how concentrated the animals are. In winter, few species are present in abundance or concentrated, and thus few are vulnerable—only ringed seals and polar bears are generally more common in winter than in other seasons. Bowhead and beluga whales are most vulnerable during their spring migration through the Barrow Arch, at which time they are concentrated in the narrow ice leads. Also somewhat vulnerable in spring (but less so than belugas and bowheads) are bearded and spotted seals and walruses, which are concentrated to some extent in late spring in the nearshore lead system. In summer, resident belugas and spotted seals become vulnerable where they concentrate in spatially restricted areas in and near lagoons and bays. At this time, gray whales, ringed and bearded seals, and polar bears are more widely distributed and thus less vulnerable. In fall, most species are relatively widely distributed and probably relatively invulnerable to effects of OCS activities.

Only pinnipeds (walruses and seals) and whales are expected to be sufficiently sensitive to noise or disturbance (activities of men and machines) to warrant special consideration in this regard. Much recent concern has arisen about the potential effects of seismic noise on marine mammals, especially whales. Existing data indicate that bowhead and gray whales show little if any response to seismic boats or to simulated seismic noise more than a few kilometers away. Belugas, especially those in semiconfined situations, have been observed to take evasive action or move away at varying distances (from a few to 35 km) when moving boats approached, but to be frequently tolerant of nearby noises and to acclimate readily to regular ship traffic.

With respect to other types of disturbance, bowheads show considerable tolerance to ongoing noise from offshore drilling and dredging operations, but tend to react more strongly to rapidly changing situations such as an approaching boat or aircraft. Long-term changes in bowhead distribution because of noise and disturbance are responses that have been postulated but not investigated. Belugas show great variations in responses to activities such as boat traffic or high levels of noise. They appear most sensitive when in confined areas; further, they show ready acclimation to disturbances not resembling the activities of hunters in pursuit. Hauled out walruses have been observed to stampede when aircraft or boats approached to within 15 to 800 m.

Discussions about the sensitivity of marine mammals of the Barrow Arch to being oiled include general known effects of oil on pinnipeds, polar bears, belugas, and baleen whales. Seals may not actively avoid oil in the environment, but those in the Barrow Arch are hair seals, and neither they (except perhaps young pups) nor walruses are likely to suffer severe thermoregulatory effects from being oiled. The most serious effects of oil on pinnipeds appear to occur through external contact, particularly to the eyes; the level of adverse response is more or less proportional to the initial stress level of the animals that are exposed.

Polar bears are sensitive to thermoregulatory effects of oiling of their fur and ingestion of oil from grooming of their fur.

No specific studies of beluga whale responses to oil have been reported, but data on other odontocetes suggest it is unlikely that belugas would be particularly sensitive to external contact with oil or that they would die from ingesting spilled oil. Likewise, there have been no studies of the effects of oil ingestion or external contact with oil on bowheads, gray whales, and other baleen whales. However, major concerns have been raised about the potential effect of oil on the baleen filtering system of these whales, and about the potential sensitivity of bowheads to bodily contact with or ingestion of spilled oil.

Information needs directly relevant to marine mammals in the Barrow Arch include (1) good estimates of distribution, abundance, and feeding dependencies of walruses and spotted seals; (2) abundance and distribution data on ringed seals in the pack ice zone; (3) documentation of denning locations of polar bears; (4) determination of the population affiliation and summer feeding ecology of belugas in the coastal zone; (5) estimates of numbers, distribution, and feeding behavior of gray whales in offshore waters; and (6) information on the timing and distribution of fall migration of bowheads in the Chukchi Sea.

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5

Marine and Coastal Birds

by David G. Roseneau and Dale R. Herter

With contributions from P. G. Connors, G. J. Divoky, R. E. Gill, Jr., W. A. Lehnhausen, and A. M. Springer. Meeting Chairman: D. G. Roseneau.

Bird use of the eastern Chukchi Sea, including the Barrow Arch OCS Planning Area, varies seasonally. Few birds are present during the winter months when ice cover is nearly complete, but several million individuals may use the region annually during spring, summer, and fall. The participants in the bird workshop summarized the available information on these birds, and attempted to identify and evaluate concerns regarding the birds' vulnerability to offshore oil development.

5.1 SETTING

The Barrow Arch provides habitat for both marine and coastal birds. Birds use terrestrial sites at the coast for nesting and feeding; and lagoons, wetlands, and marine areas for feeding and molting. Migration occurs over all habitats.

The nature of coastal landforms determines the suitability of sites for nesting. Most seabirds nest colonially on coastal cliffs, and are absent where cliffs are absent. Common eiders and arctic terns nest preferentially on barrier islands and spits. Many waterfowl and shorebirds nest in vegetated sites inland from the mainland coast.

Lagoons and semi-enclosed bays occur along much of the coast. These are important feeding and molting areas for many waterfowl and shorebirds from midsummer to fall. Wetlands and gravel beaches adjacent to these lagoons and bays, and to some extent along exposed coasts, are important feeding areas for shorebirds.

The marine environments beyond the barrier islands are used extensively for feeding by cliff-nesting seabirds, which forage for fish and invertebrates many kilometers from their colonies. Sea ducks, mainly eiders, feed on invertebrates and molt in the shallower marine waters. The open-water leads associated with the Chukchi Polynya are, in spring, an important migratory pathway for waterfowl and an important feeding area for seabirds.

5.2 SPECIES ACCOUNTS

The following accounts review available information on birds found within and adjacent to the Barrow Arch planning area.

5.2.1 Loons

The family Gaviidae (loons), which is confined to the Northern Hemisphere, contains four species of large diving birds. All four species are common to Alaska, but only three, the yellow-billed loon (*Gavia adamsii*), arctic loon (*G. arctica*), and red-throated loon (*G. stellata*) are common migrants in the eastern Chukchi Sea (Bailey 1948; Williamson *et al.* 1966), and only arctic and red-throated loons are common breeders in the Barrow Arch planning area (Lehnhausen and Quinlan 1981).

The spring migration of red-throated, arctic, and yellow-billed loons entering the eastern Chukchi Sea and Barrow Arch begins in late May or early June, peaks about late June, and continues into early July (Williamson *et al.* 1966; Lehnhausen and Quinlan 1981). The majority of these spring migrants may pass by offshore and some may become concentrated along the lead system (G. J. Divoky, pers. comm.). Fog can force migrants onshore (Williamson *et al.* 1966), and severe fog or exceptionally strong winds also may temporarily affect migrants, resulting in relatively large numbers of loons resting in these narrow leads. However, the rates at which loons migrate may be less affected by unfavorable winds than rates of migration of some northern waterfowl (Timson 1976). The total numbers of red-throated, arctic, and yellow-billed loons passing through the eastern Chukchi Sea and Barrow Arch in spring are unknown; the combined number is almost certainly in the tens of thousands. The majority of these migrants are transients en route to the Alaskan and Canadian Arctic Slopes (Johnson *et al.* 1975; Johnson and Richardson 1981) where breeding pairs disperse to nest at relatively low densities over the coastal plain (Martin and Moitoret 1981; Troy *et al.* 1983).

Typical densities of loons on the Alaskan Arctic Slope may range up to 5.0 birds/km² on the coastal plain (Derksen *et al.* 1981; Martin and Moitoret 1981; Troy *et al.* 1983).

All three species of loons nest along the coast of the Barrow Arch. Yellow-billed loons are the least abundant, and are irregular summer visitors to Kasegaluk Lagoon and Peard Bay (Lehnhausen and Quinlan 1981; D. R. Herter and R. E. Gill, unpubl. data). Combined densities of red-throated and arctic loons were only 0.2–0.4 birds/km² in coastal waters at Peard Bay in 1983 (Gill, unpubl. data), and 1.7 birds/km² in tundra habitats at Icy Cape in 1980 (Lehnhausen and Quinlan 1981). Arctic loons are the most abundant: the density at Icy Cape was 1.98 birds/km² in tundra habitats. Red-throated loons are moderately abundant: the density at Icy Cape was 1.41 birds/km² in tundra habitats.

The fall migration of yellow-billed, arctic, and red-throated loons tends to be concentrated along the coast of the Barrow Arch (Lehnhausen and Quinlan 1981; Divoky 1983). The loons migrate singly, in pairs, and as small flocks. Southward movement generally begins in late August, peaks in September (red-throated and arctic loons) or late September to early October (yellow-billed loons), and continues through October (Watson and Divoky 1972; Lehnhausen and Quinlan 1981). During unfavorable weather migrating loons rest on the water until conditions improve (Lehnhausen and Quinlan 1981).

All three species of loons are predominantly piscivorous, feeding on a variety of small fishes, and less commonly on marine and freshwater invertebrates (Palmer 1976). They can forage at great depths. Red-throated loons nesting near the coast tend to forage in both nearshore marine waters and large lakes, and arctic loons may also feed in nearshore marine waters, but may tend to obtain a greater proportion of their food from the nest-pond (Davis 1972; Bergman and Derksen 1977). Pairs of red-throated and arctic loons nesting along the coast of the Barrow Arch probably prey heavily on Arctic cod. Arctic cod were fed to young at nests along the Beaufort Sea (Divoky 1983). Foraging is probably restricted to within a few kilometers of the coast; relatively few individuals have been seen in the offshore zone during the breeding season (Divoky 1978).

5.2.2 Procellarids

Eight species of the family Procellariidae have been recorded in Alaska. Three of these species occur in substantial numbers, but only one species breeds in the state. Two of these three Alaskan species regularly visit the eastern Chukchi Sea and Barrow Arch in late summer.

Northern Fulmars

Northern fulmars (*Fulmarus glacialis*) breed in northern Europe, Greenland, Canada, and Alaska (Cramp 1977; A.O.U. 1983). World population size is unknown, but large—certainly in the order of several million individuals. As many as 2–3 million birds may inhabit Alaskan waters (Shuntov 1972; Sowls *et al.* 1978). The Alaskan population is centered in the western Gulf of Alaska and Aleutian Islands. A substantital number of fulmars also nest on St. Matthew and Hall islands in the east-central Bering Sea.

Northern fulmars do not breed north of St. Matthew and Hall islands in the Bering Sea (e.g., Sowls *et al.* 1978), and the majority of birds remain south of Bering Strait the year around (Hunt *et al.* 1981c). Nevertheless, some nonbreeders visit the eastern Chukchi Sea and Barrow Arch each summer (Jacques 1930; Bailey 1948; Watson and Divoky 1972; Harrison 1977; Lehnhausen and Quinlan 1981). Numbers of fulmars probably peak in the planning area during September, and most depart by late October. When present, the majority usually remain well offshore. Densities are typically low: Divoky and Good (1979) reported 0–10 birds/km² northwest of Cape Lisburne and south of Point Hope in August 1975, and Gould (1977) reported 0–9 birds/km² in the same general areas in September 1976.

Northern fulmars feed by seizing prey on the surface, and occasionally by plunging to depths of several meters. Their diet generally consists of fishes, cephalopods, crustaceans, and carrion. Principal prey of fulmars visiting the Barrow Arch are presumed to be small fishes and squid as in the southeastern Bering Sea (Hunt *et al.* 1981a), but they may also feed on dead or injured jellyfish, a variety of other carrion, amphipods (including *Parathemisto* sp.), euphausiids (*Thysanoessa* sp.), and polychaetes (especially *Nereis* sp.).

Short-tailed Shearwaters

Short-tailed shearwaters (*Puffinus tenuirostris*) breed in the Southern Hemisphere and migrate into Alaskan waters to feed on euphausiids, squid, and small fishes during the austral winter (Sanger and Baird 1977). Shearwaters are especially numerous in the Bering Sea: single flocks of several million individuals have been encountered there (Gould, pers. comm.; D. Roseneau, pers. obs.), and summer population estimates range between 9 and 45–65 million birds (Hunt *et al.* 1981c).

About 90% of the shearwaters found in the Bering Sea are short-tailed shearwaters, and although the majority of these summer south of Bering Strait (Hunt *et al.* 1981c), a relatively large number visit the eastern Chukchi Sea and Barrow Arch annually (Bailey 1948; Swartz 1967; Watson and Divoky 1972; Gould 1977; Harrison 1977; Lehnhausen and Quinlan 1981; Divoky, pers. comm.). Numbers of shearwaters probably peak in the Barrow Arch area during late August–September, and most depart by late October. Distribution is patchy, but total numbers and local densities may be relatively high: Bailey (1948) reported thousands of shearwaters at Barrow in October; Gould (1977) reported 100+ birds/km^2 northwest of Cape Lisburne in September 1976; Harrison (1977) reported 10–30 birds/km^2 near Barrow and Peard Bay in August 1976; and Lehnhausen and Quinlan (1981) estimated that more than 4,000 birds in 139 flocks of 1–150 individuals migrated south past Icy Cape in fall 1980.

Short-tailed shearwaters feed from the surface and by making shallow dives. Prey-patches can attract thousands of feeding birds. Principal prey of short-tailed shearwaters visiting the Barrow Arch in late summer and fall are presumed to be small fishes (including sand lance and capelin), squid, euphausiids (*Thysanoessa* sp.), and hyperiid amphipods (*Parathemisto* sp.).

5.2.3 Cormorants

Five species of cormorant are found over North American waters of the Pacific Ocean. Four of the five species breed in Alaska (Sowls *et al.* 1978; W. Lehnhausen, pers. comm.), but only one nests in the eastern Chukchi Sea and Barrow Arch.

Pelagic Cormorant

Pelagic cormorants (*Phalacrocorax pelagicus*), endemic to the North Pacific Ocean, breed from Baja, California to Cape Lisburne, Alaska in North America, and from northern Japan to the northeastern Chukchi Peninsula in Asia (Terres 1980; A.O.U. 1983). The total world population is unknown; however, it may not exceed a few hundred thousand individuals.

The Alaskan population of pelagic cormorants is estimated at about 90,000 birds (Sowls *et al.* 1978). The majority nest in the western Gulf of Alaska and southern Bering Sea. A smaller number also nest in the northern Bering Sea, but relatively few venture north of the Bering Strait.

Less than 500 pelagic cormorants are estimated to inhabit seabird colonies in the eastern Chukchi Sea (Sowls *et al.* 1978, unpubl. data; Springer *et al.* 1982, unpubl. data). They are irregular in pelagic and nearshore waters north of Cape Lisburne and fewer than 300 birds may frequent colonies adjacent to the Barrow Arch. About 40 pairs nest at Cape Lisburne, about 50 pairs nest at Cape Lewis, and several smaller concentrations of roosting or nesting birds are found at headlands between Kilikralik Point and Niak Creek, and at Corwin Creek Bluff (Springer and Roseneau 1978; Springer *et al.* 1982). Other small concentrations occur south of the planning area at Cape Thompson (about 10 pairs) (Sowls *et al.* 1978, unpubl. data; Springer *et al.* 1982).

Pelagic cormorants nesting adjacent to the Barrow Arch arrive in May and depart in October (Swartz 1966). When present, they forage widely in nearshore waters to the west, north, and east of the Lisburne Peninsula. Few birds are seen north of Ledyard Bay (Watson and Divoky 1972; Pitelka 1974; Lehnhausen and Quinlan 1981). Pelagic cormorants dive for food. Small fishes are the principal prey (Swartz 1966); the fishes most frequently eaten in the planning area probably include cods, prickle-backs, snailfish, and sand lance.

The annual productivity of pelagic cormorants nesting adjacent to the Barrow Arch has averaged about 2 young per pair (Springer *et al.* 1982).

5.2.4 Waterfowl

Thirty-six species of ducks, geese, and swans have beeen recorded on the Arctic Slope of Alaska. Information on the most numerous species found within or adjacent to the Barrow Arch is summarized below. Figures 5.1–5.3 show major migration routes and concentration areas of waterfowl and other water birds in and near the Barrow Arch.

Brant

Brant (*Branta bernicla*) are circumpolar in distribution and are divided into several races. The Pacific race (*B. b. nigricans*) breeds coastally from the Yukon-Kuskokwim Delta, Alaska to about the Perry River and Melville and Prince Patrick islands (and probably Victoria Island) in western North America, and eastward from the Taymyr Peninsula to Anadyr-land in eastern Asia (Cramp 1977; A.O.U. 1983).

Thousands of brant representing several populations migrate along the coast of the eastern Chukchi Sea. A large number of the migrants belong to the Alaskan Arctic Slope and western Canadian arctic population, which may total about 80,000 birds (mid-1950's estimate—King 1979). Many other migrants include subadults and failed breeders from southern populations that travel to the Arctic Slope to molt (King and Hodges 1979).

Spring migrants (breeders) arrive along the northeastern Chukchi Sea coast in late May and northward movements appear to peak in early June (Bailey 1948; Lehnhausen and Quinlan 1981). Few migrants appear to follow the spring lead system (Woodby and Divoky 1982) and the total number of spring migrants is relatively small, perhaps only a few thousand birds, suggesting the majority of the Alaskan Arctic Slope and western Canadian arctic breeders reach the Beaufort Sea coast by overland routes (Fig. 5.1).

Molt-migrant brant (subadults and failed breeders) begin to arrive along the northeastern Chukchi Sea coast by mid-June (Lehnhausen and Quinlan 1981). The majority are probably destined for communal molting sites near Teshekpuk Lake (Derksen *et al.* 1979). Their passage adjacent to the Barrow Arch is leisurely; northward movements continue through mid-July. Unlike the earlier migratory breeders, these molt migrants move adjacent to the coast and spend time feeding in coastal habitats. The total number of these migrants is large, around several tens of thousands of birds.

Brant breed along the northeastern Chukchi Sea coast (Bailey 1948; Lehnhausen and Quinlan 1981). However, pairs are likely to be scattered and densities relatively low. Brant also molt along the coast adjacent to the Barrow Arch. Several hundred molting birds were seen in the vicinity of Icy Cape in 1980, and reports were received that thousands of brant may molt along Kasegaluk Lagoon south of Utukok Pass (Lehnhausen and Quinlan 1981).

Thousands of brant migrate along the coast of the northeastern Chukchi Sea during fall (Bailey 1948; Timson 1976; Lehnhausen and Quinlan 1981). Southward movements begin by mid-August, peak during early September, and are probably complete by late September. Migrants tend to follow the coast adjacent to the Barrow Arch, but many flocks may take short-cuts overland behind prominent coastal features, including Point Barrow and Icy Cape. Passage of these migrants tends to be leisurely; thousands frequently pause to rest and feed in salt marsh and mud flat habitats. The largest concentrations of staging birds frequent the northern sector of Kasegaluk Lagoon, especially near Icy Cape (Bailey 1948; Nelson 1969; Lehnhausen and Quinlan 1981). Smaller concentrations may also occur at various points along southern Kasegaluk Lagoon. Several hundred birds have also frequented small lagoons east of Cape Lisburne in early September (Springer, pers. comm.).

Brant feed on a variety of emergent vegetation. Salt marsh habitats provide an important source of food for these birds while they are present in the arctic. At Icy Cape, brant fed heavily on salt grasses (*Puccinellia* sp.) and sedges (*Carex* sp.) in the marshes, and on marine algae (*Ulva* sp. and *Enteromorpha* sp.) in shallow lagoon waters and mud flats (Lehnhausen and Quinlan 1981).

Brant are an important subsistence resource in the northeastern Chukchi Sea. Hunters from Barrow, Wainwright, and Point Lay traditionally harvest large numbers of these birds every year (Bailey 1948; Nelson 1969). Icy Cape is an important fall hunting ground for people from Wainwright and Point Lay (Bailey 1948; Nelson 1969; D. R. Schmidt, pers. comm.).

Common and King Eiders

Common and king eiders (*Somateria mollissima* and *S. spectabilis*) have circumpolar distributions (Cramp 1977; A.O.U. 1983). Common eiders are divided into several races. The Pacific race (*S. m. nigra*) breeds coastally from the western Gulf of Alaska and Aleutian Islands northward and eastward to southern Banks and Victoria islands in western North America, and from the Kamchatka Peninsula to the New Siberian Islands in eastern Asia. King eiders breed from St. Lawrence Island and the eastern Chukchi Peninsula northward throughout the polar basin. World populations of both species are large, with at least a few million birds each (*see* Cramp 1977).

Large numbers of common and king eiders migrate annually through the eastern Chukchi Sea (Bailey 1948; Williamson *et al.* 1966; Flock 1972). King eiders, numbering about 1 million birds, are the most abundant (Thompson and Person 1963; Woodby and Divoky 1982). The majority of these migrants breed east of Point Barrow along the Alaskan Arctic Slope and in the western Canadian arctic. The total number of common eiders is considerably less, perhaps a few tens of thousands (Lehnhausen and Quinlan 1981; Woodby and Divoky 1982).

Spring migration of common and king eiders follows the lead system through the Barrow Arch (Fig. 5.1). King eiders begin to arrive about mid-May (as early as late April in some years), common eiders begin to appear during late May (possibly mid-May in some years), and northward movements of both species are complete by about mid-June (Lehnhausen and Quinlan 1981; Woodby and Divoky 1982). During the course of these northward movements, the eiders are strongly influenced by weather conditions. Headwinds or refreezing and closing of the leads can severely inhibit their progress, and concentrate them in areas where better conditions prevail

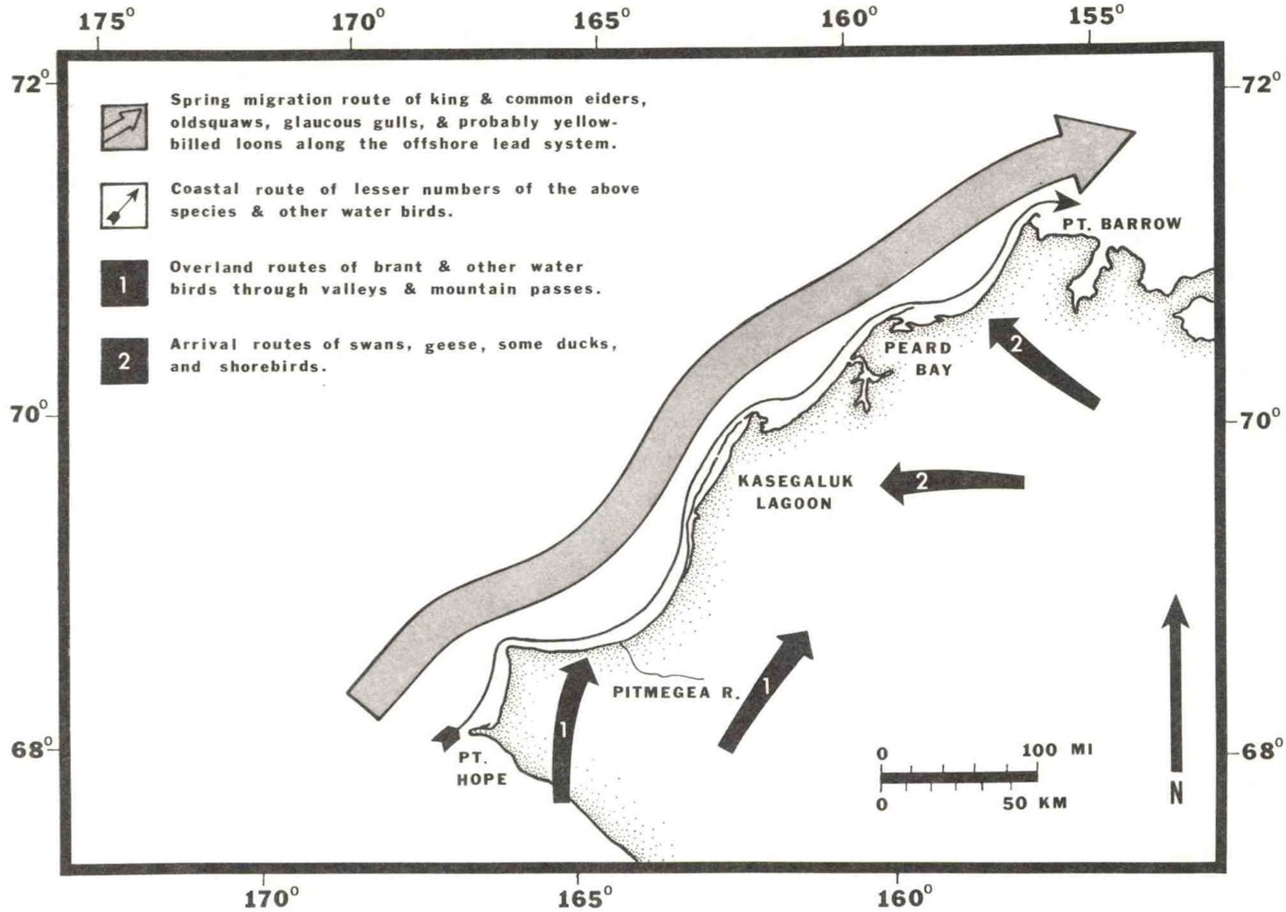

FIGURE 5.1—Spring migration routes of water birds in the eastern Chukchi Sea.

or in any remaining open water within areas experiencing less favorable conditions. However, once conditions improve, eiders proceed in a rush, and may fly long distances nonstop: in late May 1976, an estimated 500,000 king eiders may have flown more then 480 km from south of Cape Lisburne to Point Barrow in 1 day (Woodby and Divoky 1982).

In spite of the large migrations of common and king eiders passing through the Barrow Arch each spring, relatively few common eiders regularly breed adjacent to the planning area. Common eiders can be found along the entire coast between Point Hope and Point Barrow, but only scattered pairs nest in western Ledyard Bay and along the Lisburne Peninsula (Springer and Roseneau, pers. obs.). A few also nest on the spits and islands in Peard Bay in some years (Divoky 1973).

The majority, comprising at least a few thousand birds, are concentrated at colonies along the barrier islands and on the islets of Kasegaluk Lagoon (Sowls *et al.* 1978; Lehnhausen and Quinlan 1981; Herter, pers. obs.). These colonies range up to several hundred birds each, and most are located between the northern end of Kasegaluk Lagoon and Point Lay. Nesting phenology at these colonies may vary between locations and between years (Lehnhausen and Quinlan 1981). Eggs are usually laid between mid-June and mid-July, and hatching occurs from about mid-July through early August. Productivity undoubtedly varies, but may be relatively low: in 1980 one colony of 479 pairs failed entirely as a result of predation; and at another colony with 125 nests, clutch size was about 3.8 eggs but 66% of the nests failed and total production was 163 chicks (Lehnhausen and Quinlan 1981). Nesting success for eiders using barrier islands seems very dependent on inaccessibility of the island to mammalian predators (Schamel 1974; Lehnhausen and Quinlan 1981).

Beginning in early July, less than 1 month after the spring migration has ceased, hundreds of thousands of molt-migrant eiders (primarily king eiders) return along the coast of the Barrow Arch (Thompson and Person 1963) (Fig. 5.2). The initial migrants are mostly males. By mid-August the sex ratio shifts, and females and juveniles begin to predominate (Thompson and Person 1963; Timson 1976; Lehnhausen and Quinlan 1981).

Flocks of molt-migrant eiders are present in Kasegaluk Lagoon and Peard Bay after midsummer where they frequent the deeper ocean passes (King 1979; Lehnhausen and Quinlan 1981; Gill, pers. comm.). However, the majority may settle throughout the nearshore waters off Point Lay and in Ledyard Bay for much of July and August (Divoky and Good 1979; Springer *et al.* 1982).

Large movements of eiders (primarily king eiders) begin along the coast of western Ledyard Bay by late July or early August. For example, during 27–31 July 1980, about 50,000 birds were estimated to pass Cape Lisburne each day (Springer *et al.* 1982).

South of Cape Lisburne eiders proceed along pathways farther offshore. Few birds are seen passing Cape Lewis, 18 km south of Cape Lisburne (Springer *et al.* 1982).

Large-scale movements of eiders continue to occur along the coast of the Barrow Arch until early October. Some eiders remain as long as open water persists, occasionally as late as mid-November (Bailey 1948).

Common and king eiders dive for food, the latter sometimes reaching depths of 60 m (Palmer 1976). Most prey are obtained at or near the bottom, and consist almost exclusively of marine invertebrates. Bivalve molluscs, including blue mussels (*Mytilus edulis*) and small clams, are likely to compose large portions of their diets. In the northeastern Chukchi Sea, including Peard Bay, eiders may eat large numbers of gammarid amphipods (*Gammaracanthus loricatus*). In the nearshore zone of the Beaufort Sea, large isopods (*Saduria entomon*) were major prey of both species. Common eiders also frequently took mysids (*Mysis* sp.) (Divoky 1983).

Common and king eiders are important subsistence resources in the northeastern Chukchi Sea. Hunters from Barrow, Wainwright, Point Lay, and Point Hope traditionally harvest large numbers every year. The late summer and fall migration is especially important to the people of Barrow (Johnson 1971).

Oldsquaw

Oldsquaws (*Clangula hyemalis*), circumpolar in distribution, breed across Alaska in suitable tundra habitats, but are most common throughout western and northern Alaska (Gabrielson and Lincoln 1959). The total world population is large, probably in the tens of millions (S. R. Johnson, unpubl. ms.).

Oldsquaws breed along the entire coast of the northeastern Chukchi Sea adjacent to the Barrow Arch (Childs 1969; Pitelka 1974; Lehnhausen and Quinlan 1981; Gill, pers. comm.). Densities during the breeding season may reach 2–6 birds/km^2 (*see* Lehnhausen and Quinlan 1981), but relatively few are found on the barrier islands (Divoky 1978, D. R. Schmidt, pers. comm.).

At least several hundred thousand oldsquaws migrate through the Barrow Arch. The majority of these migrants breed eastward across the Alaskan Arctic Slope and in the western Canadian arctic.

The spring migration of oldsquaws through the Barrow Arch begins about mid-May and continues through early June (Lehnhausen and Quinlan 1981; Woodby and Divoky 1982). Some of these migrants appear to follow the spring lead system. About 32,000 birds were estimated to have passed along the lead system at Point Barrow during May and early June 1976 (Woodby and Divoky 1982). However, some migrants also follow the coast. About 2,000 birds were estimated to have passed Icy Cape in late May and early June 1980 (Lehnhausen and Quinlan 1981) (Fig. 5.1). Oldsquaws may also migrate over extensive areas of land and at high altitudes to northern tundra areas (Richardson and Johnson 1981).

Beginning in late June, shortly after the spring migration has ceased, a second, more substantial, northward movement of oldsquaws occurs along the northern Chukchi Sea coast (Lehnhausen and Quinlan 1981) (Fig 5.2). Molt-migrant birds probably consist of males, failed breeders, and nonbreeders from more southerly areas of northwestern Alaska. By mid-July relatively large numbers of these molting birds become established in the lagoons and along the barrier islands adjacent to the northern sector of the planning area where they remain throughout most of August. Known molting areas include Peard Bay with several hundred birds (Roseneau, pers. obs.); the northeastern sector of Kasegaluk Lagoon east of Icy Cape, with about 12,000 birds (W. Lehnhausen, pers. comm.); and the deeper portions of Kasegaluk Lagoon south of Icy Cape, hosting probably several thousand birds (Lehnhausen and Quinlan 1981; Herter, unpubl. data). Scattered flocks of molting oldsquaws may also be present in the southern sector of Kasegaluk Lagoon and at various points along Ledyard Bay.

Many oldsquaws leave the lagoons and begin frequenting the nearshore zone along the northern sector of the Barrow Arch by late August. The fall migration (Fig. 5.3) is underway by early September and tends to be more conspicuous than the spring migration. About 240,000 oldsquaws were estimated to have passed Point Barrow between 27 August and 16 September 1975 (Timson 1976), and about 186,000 birds were estimated to have passed Icy Cape between 22 August and 20 September 1980 (Lehnhausen and Quinlan 1981). During the fall migration, large flocks of hundreds or even thousands

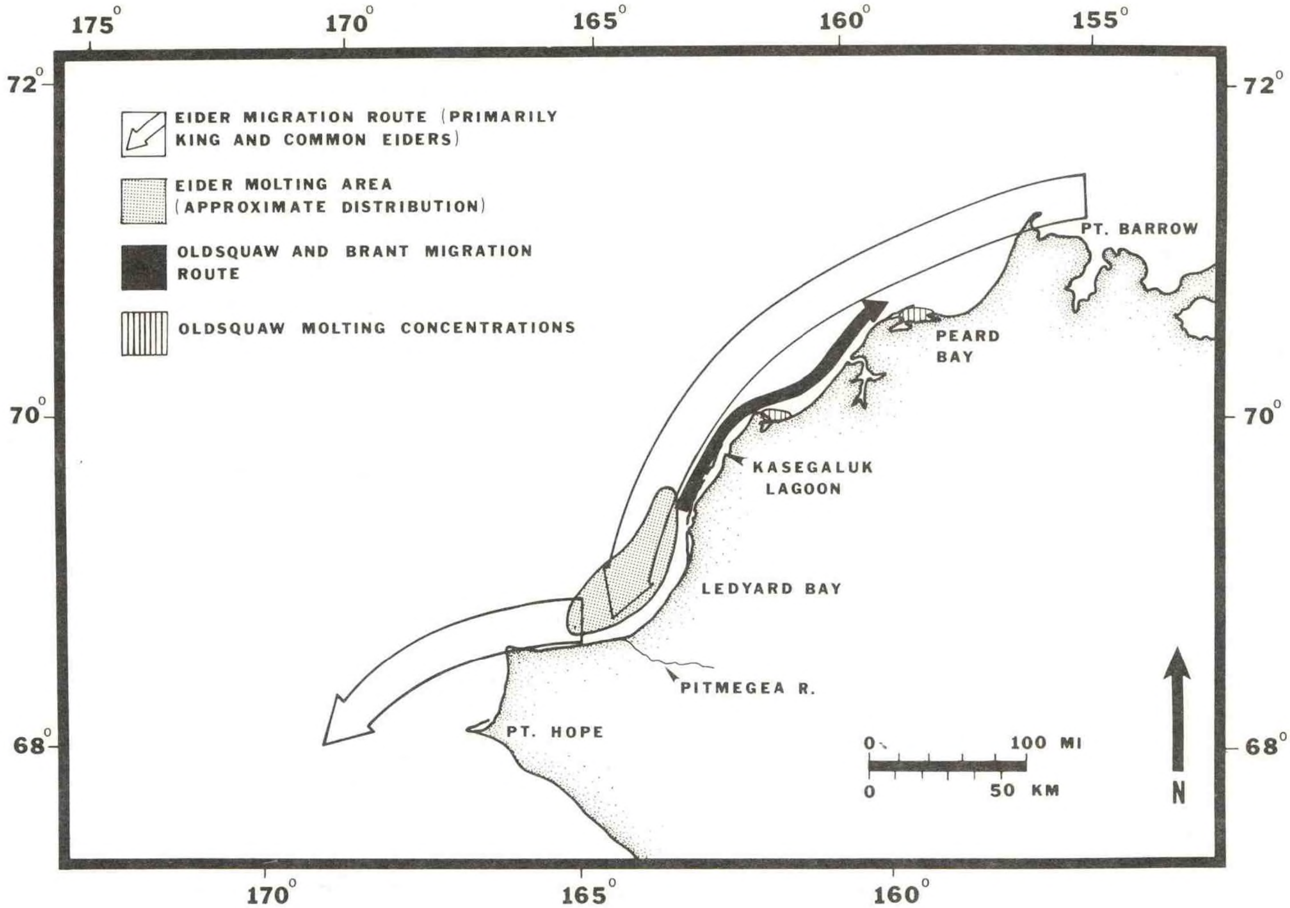

FIGURE 5.2—Molt migration routes and known molting concentration areas of waterfowl in the eastern Chukchi Sea.

of oldsquaws may stop, presumably to rest and feed, in the nearshore zone adjacent to the Barrow Arch (Bailey 1948; Timson 1976). Few birds remain in the planning area after mid-October (Bailey 1948). Unfavorable weather conditions may also force these migrating flocks to stop for brief periods (Lehnhausen and Quinlan 1981).

Oldsquaws feed on marine invertebrates and some fish in marine waters (Palmer 1976). Molting birds collected from Simpson Lagoon on the Beaufort Sea coast contained primarily mysids (*Mysis* sp.) and smaller numbers of amphipods, bivalve molluscs, isopods, and fish (Johnson and Richardson 1981). Stomachs of molting oldsquaws collected in Peard Bay contained fewer mysids; gammarid amphipods (*Gammaracanthus* sp.) were the predominant prey (Gill, pers. comm.).

Oldsquaws are an important subsistence resource for the villages along the northeastern Chukchi Sea. Although these ducks tend to be less preferred than geese or eiders (Nelson 1969), hunters from Barrow, Wainwright, Point Lay, and Point Hope may harvest large numbers of them every year.

Other Waterfowl

A variety of other waterfowl are found along the coast adjacent to the Barrow Arch (Bailey 1948; Gabrielson and Lincoln 1959; Pitelka 1974; Lehnhausen and Quinlan 1981). Several species deserve mention.

Northern pintails (*Anas acuta*) frequented the shorelines of Kasegaluk Lagoon and were the second most abundant species of waterfowl using salt marsh habitats at Icy Cape in 1980 (Lehnhausen and Quinlan 1981). They are likely to be common migrants and summer visitors in years of drought on North American prairies (Derksen and Eldridge 1980).

Small numbers of white-winged, surf, and black scoters (*Melanitta fusca, M. perspicillata,* and *M. nigra*) are also present along the coast and small flocks (usually less than 100 birds) frequent the nearshore and lagoonal waters (Bailey 1948; Lehnhausen and Quinlan 1981). Greater scaup (*Aythya marila*) and red-breasted mergansers (*Mergus serrator*) are

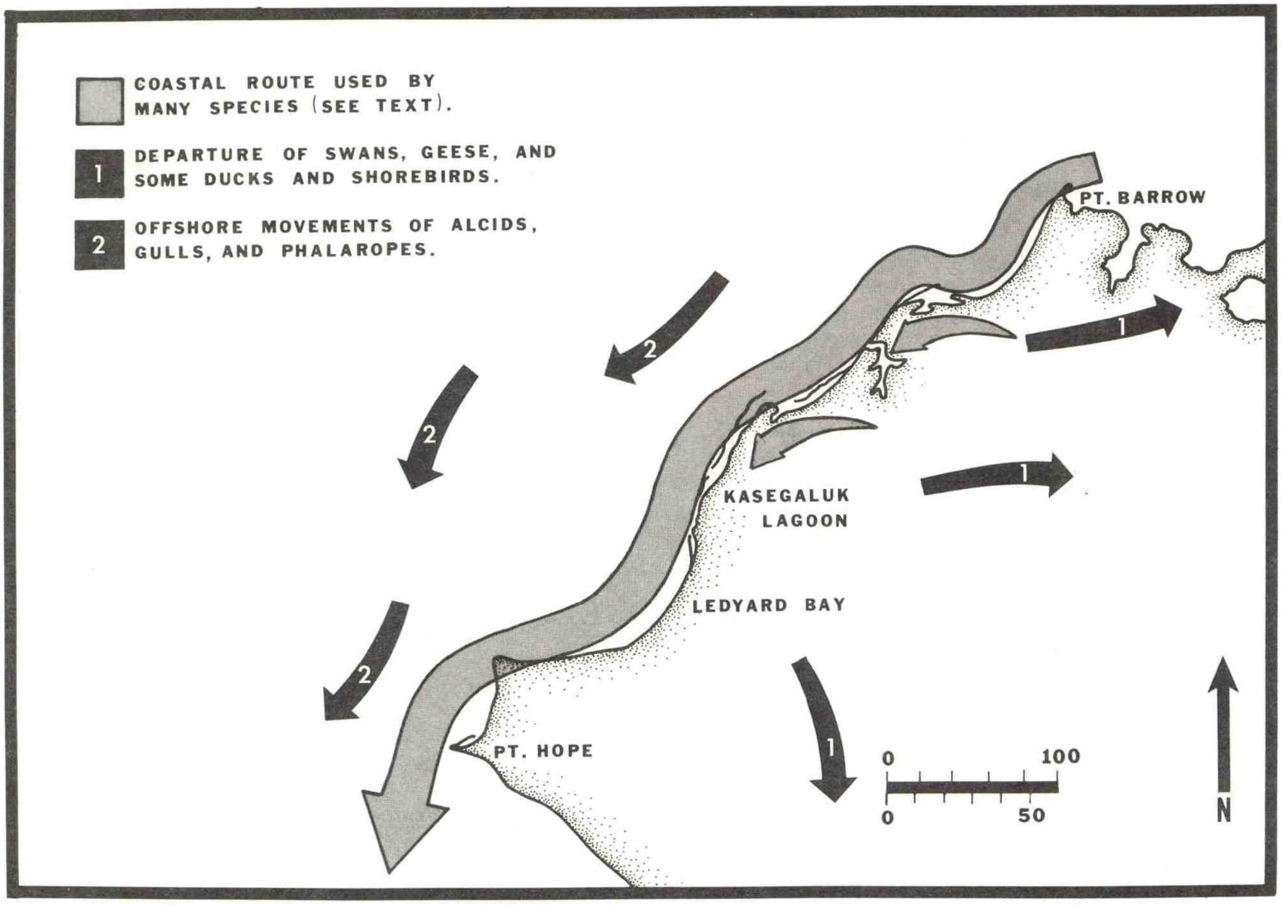

FIGURE 5.3—Fall migration routes of water birds in the eastern Chukchi Sea.

also found at low densities along the coast (Bailey 1948; Lehnhausen and Quinlan 1981; Gill, unpubl. data).

Spectacled and Steller's eiders (*Somateria fischeri* and *Polysticta stelleri*) are migrants along the spring lead system and along the coast. Steller's eiders historically nested on the Yukon-Kuskokwim Delta (Conover 1926), but few have been present in recent years (Gill, pers. comm.). Within Alaska, they may now breed in small numbers only in the vicinity of Barrow (Pitelka 1974).

Harlequin ducks are common along the shorelines of the Lisburne Peninsula (Williamson *et al.* 1966; Childs 1969; Springer and Roseneau, pers. obs.).

5.2.5 Shorebirds

Over 40 species of shorebirds (plovers, sandpipers, phalaropes, and their close relatives) have been recorded on the Arctic Slope of Alaska, and 12–15 species regularly breed within several kilometers of the northeastern Chukchi Sea coast adjacent to the Barrow Arch. All nest primarily on the tundra, but many species forage in shoreline habitat for part of the summer. The degree of attendance on these habitats varies among species, with the most widespread use occurring during late July, August, and early September.

Red and Red-necked Phalaropes

Red and red-necked phalaropes (*Phalaropus fulicaria* and *P. lobatus*) have circumpolar distribution (A.O.U. 1983; Cramp 1983). World population sizes are unknown. Red-necked phalaropes breed throughout Alaska wherever suitable habitat occurs, but red phalaropes are restricted to coastal habitats between the Yukon-Kuskokwim Delta and the U.S.-Canada border (Gabrielson and Lincoln 1959; A.O.U. 1983).

Red and red-necked phalaropes are the only shorebirds that use the nearshore and offshore waters of the eastern Chukchi Sea. Both species nest in wet coastal habitats adjacent to the Barrow Arch (Bailey 1948; Childs 1969; Pitelka 1974; Lehnhausen and Quinlan 1981). Red phalaropes are more abundant north of Point Lay, and red-necked phalaropes are more common along the Lisburne Peninsula.

The spring migration of phalaropes along the coast adjacent to the Barrow Arch is not conspicuous. The majority of these birds may fly at high altitudes. Migrants arrive in late May and early June (Lehnhausen and Quinlan 1981), but use of nearshore and littoral habitats is infrequent because of prevailing shore-ice conditions (Connors *et al.* 1979). Red phalaropes are the more abundant migrant: about 550 red phalaropes and 60 red-necked phalaropes were identified passing Icy Cape in the spring of 1980 (Lehnhausen and Quinlan 1981).

Red phalaropes were the most abundant shorebird found on the tundra at Icy Cape in July 1980 (Lehnhausen and Quinlan 1981). Their average density during that month was about 37 birds/km^2, and 17 nests were found. Red-necked phalaropes were less abundant, with an average density of 13 birds/km^2, and only 5 nests were found.

Large numbers (thousands) of migrating and staging post-breeding red phalaropes become especially common in the littoral zone north of Point Lay during July, August, and early September (Connors *et al.* 1979; Lehnhausen and Quinlan 1981; Herter, unpubl. data; P. Connors, pers. comm.; Gill, pers. comm.). August flocks are dominated by juveniles (Connors *et al.* 1979). During August and September, these birds gradually shift from the littoral zone to the nearshore and offshore zones adjacent to the Barrow Arch (Connors and Risebrough 1977; Connors, pers. comm.; Gill, pers. comm.; Divoky, pers. comm.). Some evidence suggests red phalaropes may also congregate along the ice edge after early July where they may feed on under-ice amphipods and other invertebrates (Nelson 1883; Bailey 1948; Watson and Divoky 1972).

As late summer movements of red phalaropes proceed, small flocks tend to disperse over much of the open ocean (Swartz 1967; Watson and Divoky 1972). Typical offshore densities may be 0–5 birds/km^2 (Divoky, unpubl. data). Offshore densities may be higher in the southern area of the Barrow Arch during late September when birds are rapidly departing the region. Large numbers of unidentified phalaropes (presumably mostly red phalaropes) were encountered well offshore of the Lisburne Peninsula on 28–29 September 1976; densities were about 100 birds/km^2 (Divoky and Good 1979). Few red phalaropes are likely to remain in the planning area beyond early October (Watson and Divoky 1972).

Large numbers (perhaps thousands) of migrating and staging red-necked phalaropes also appear along the coast adjacent to the Barrow Arch during late summer. These birds tend to frequent the nearshore zone south of Point Lay, where large flocks migrate and feed just outside of the surf zone during August and September (Springer and Roseneau, pers. obs.). Few red-necked phalaropes are likely to remain along the coast adjacent to the planning area beyond late September (Williamson *et al.* 1966; Lehnhausen and Quinlan 1981).

Prominent prey species of phalaropes in littoral, nearshore, and offshore zones near Barrow and in the Beaufort Sea have included calanoid copepods (*Calanus* sp.), amphipods (especially *Apherusa glacialis* and *Onisimus glacialis*), and mysids (*Mysis* sp.) (Connors and Risebrough 1977; Johnson and Richardson 1981; Divoky 1983).

Other Shorebirds

A variety of other shorebirds migrate into the coastal zone adjacent to the Barrow Arch during late May and early June (Bailey 1948; Childs 1969; Pitelka 1974; Lehnhausen and Quinlan 1981). The majority of use occurs in tundra areas. The most common species are pectoral sandpipers (*Calidris melanotos*), dunlins (*C. alpina*), semipalmated sandpipers (*C. pusilla*), and western sandpipers (*C. mauri*). Typical summer densities for each of these species in tundra at Icy Cape in 1980 ranged from 7 to 20 birds/km^2 (Lehnhausen and Quinlan 1981). Flocks of *Calidris* sandpipers, especially dunlins, semipalmated sandpipers, and western sandpipers, begin to frequent the littoral zone, including salt marshes and mud flats, during July. The numbers of these birds continue to increase through mid-August. Other species occurring commonly in littoral habitats include long-billed dowitcher (*Limnodrilus scolopaceus*), ruddy turnstone (*Arenaria interpres*), and, on ocean beaches, sanderling (*Calidris alba*).

The number of *Calidris* sandpipers using the littoral zone adjacent to the Barrow Arch during late summer is unknown. However, thousands or even tens of thousands of birds may be present, and the majority may stage in the vicinity of Icy Cape where appropriate habitats appear to be more abundant than along other areas of the coast. Late summer densities on salt marshes at Icy Cape in 1980 reached up to 53 semipalmated sandpipers/km^2, 170 western sandpipers/km^2, and 287 dunlins/km^2 (Lehnhausen and Quinlan 1981). Small concentrations in similar densities may also frequent sections of Peard Bay, the remainder of Kasegaluk Lagoon, and the Point Hope spit.

Large numbers of *Calidris* sandpipers may continue to use salt marshes, mud flats, and beaches until about mid-September in some years. Few birds are likely to remain along the coast adjacent to the Barrow Arch beyond late September.

Prominent prey of *Calidris* sandpipers in salt marsh habitats adjacent to the Barrow Arch include chironomid larvae, adult chironomids, and oligochaetes (Connors and Riseborough 1977).

5.2.6 Larids

Eighteen species of larid (jaegers, gulls, and terns) have been recorded on the Arctic Slope of Alaska. Nine of these species are regular breeders along the eastern Chukchi Sea coast and at least four others regularly visit the Barrow Arch. Information on the principal species frequenting the planning area are provided as follows.

Pomarine, Parasitic, and Long-tailed Jaegers

Pomarine, parasitic, and long-tailed jaegers (*Stercorarius pomarinus, S. parasiticus* and *S. longicaudus*) migrate and breed along the eastern Chukchi Sea coast (Williamson *et al.* 1966; Maher 1974). Pomarine jaegers are abundant migrants in the coastal zone of the Barrow Arch (Timson 1976; Lehnhausen and Quinlan 1981) but they tend to breed only at low densities except in years when microtine populations are high (densities at Barrow during 1951–54 ranged from 0 birds/km^2 to about 15 birds/km^2; *see* Pitelka *et al.* 1955). Parasitic and long-tailed jaegers are less abundant in the planning area, but both species probably nest at low densities in most years (1 bird/km^2 or less). Parasitic jaegers usually nest in wet tundra, and are more commonly found along the coast north of Cape Beaufort. Long-tailed jaegers usually nest in drier tundra habitats, and are more commonly seen along the coast of the Lisburne Peninsula.

Spring and fall migrations of jaegers probably occur over broad fronts, including over sea and over land in the Barrow Arch (Watson and Divoky 1972; Williamson *et al.* 1966; Lehnhausen and Quinlan 1981). Spring migration usually begins in late May and is complete by early July. Fall migration begins most often in late August and is complete by late September.

Large numbers of pomarine jaegers have been observed migrating westward along the Beaufort Sea coast and southward along the eastern Chukchi Sea coast during some springs (Pitelka 1974; Johnson and Richardson 1981). Relatively large numbers of pomarine jaegers are also present on the ice front in the central Chukchi Sea during July in certain years (Divoky, pers. comm.). Such movements and flocks at sea probably represent unsuccessful adults and nonbreeders leaving the Arctic in years of low microtine populations (Maher 1974). In 1980 relatively large numbers of pomarine jaegers were also observed migrating northward along the Chukchi Sea coast in summer (Lehnhausen and Quinlan 1981). These birds may have included failed breeders from more southern areas.

Jaegers tend to be scattered widely throughout the nearshore and offshore zones of the Barrow Arch at low densities during most of the open-water season. Pomarine jaegers are the most abundant; the largest number may be present during late summer.

Breeding jaegers tend to forage in terrestrial habitats (Maher 1974; Martin and Barry 1978; Cramp 1983). On the breeding grounds, pomarine jaegers feed heavily on lemmings and voles, and take some small birds. Long-tailed jaegers also feed heavily on lemmings and voles, and also eat small birds, eggs, invertebrates (including insects and snails), and berries (especially blueberries). Parasitic jaegers tend to rely heavily on small birds, but also consume various other prey.

All three species often pirate fishes (and occasionally invertebrates) from other seabirds. In marine waters, jaegers feed on small fishes and invertebrates which they seize at the surface, and rob alcids and other larids of similar prey (Divoky and Good 1979; Cramp 1983).

Glaucous Gull

Glaucous gulls (*Larus hyperboreus*) are circumpolar in distribution and breed from Kuskokwim Bay, Alaska northward and eastward across arctic North America, and from Anadyrland northward and westward across arctic Asia (A.O.U. 1983). The total world population size is unknown.

About 30,000 glaucous gulls may inhabit Alaskan waters (Sowls *et al.* 1978). Abundance is highest in the northern Bering and southern Chukchi seas.

Several thousand glaucous gulls probably breed along the eastern Chukchi Sea coast, and several thousand subadults summer there (Childs 1969; Sowls *et al.* 1978, unpubl. data; Springer and Roseneau 1978; Lehnhausen and Quinlan 1981; Springer *et al.* 1982). Relatively few birds nest adjacent to the Barrow Arch. Only a few hundred are present at small headlands between Kilikralik Point and Cape Lisburne, including Capes Dyer and Lewis, less than 100 are usually present at Cape Lisburne, about 20 nest at Sapumik Ridge, about 100 may nest a few miles inland from Corwin Creek Bluff, and a few hundred more are scattered between Cape Beaufort and Point Barrow. The remainder are located south of the planning area at Cape Thompson (about 300 birds) and in Kotzebue Sound (a minimum of about 2,000 birds).

Small numbers of glaucous gulls probably overwinter in the Barrow Arch wherever open water is present (Swartz 1966). Numbers increase in April and spring migrants are prevalent in both the offshore lead system (Woodby and Divoky 1982) and along the coast (Lehnhausen and Quinlan 1981). Pairs begin arriving at nesting locations as early as late April. Eggs are laid from mid-June to early July in the northern sector of the Barrow Arch, and from about mid-May to early June in the southern sector (Swartz 1966; Lehnhausen and Quinlan 1981; Springer *et al.* 1982). Hatching at northern nests occurs during mid-July to late July, and at southern nests from about mid-June to early July. Fledging at northern nests is probably completed by about late August, and at southern nests by about mid-August.

Large numbers of subadult glaucous gulls enter the coastal zone of the Barrow Arch during late summer. Throughout August, mixed flocks containing adults, juveniles, and hundreds of these subadults forage and loaf along the shoreline of Ledyard Bay (Springer *et al.* 1982), and similar large mixed flocks frequent Kasegaluk Lagoon and the vicinity of Icy Cape (Lehnhausen and Quinlan 1981). Fall migration tends to occur coastally over several months' time. In the northern sector of the planning area southward movements begin in September and probably continue throughout October (Lehnhausen and Quinlan 1981). However, many birds may still be present during November and early December (Swartz 1966).

Glaucous gulls are scavengers and predators. They tend to forage throughout the coastal zone, including nearshore waters, lagoons, and nearby terrestrial habitats, commonly feeding on marine mammal and bird carcasses, and human refuse (Bailey 1948; Swartz 1966; Woodby and Divoky 1982). However, they also consume a wide variety of small mammals, birds and their eggs, fishes, freshwater and marine invertebrates, and even berries and marine plants (Swartz 1966; Johnson and Richardson 1981; Strang 1982; Divoky 1983). Common food sources in the southern sector of the planning area include murre and walrus carcasses. Principal prey include murre eggs and chicks, and a variety of fishes including cods, herring, and sand lance (Swartz 1966; Springer and Roseneau, pers. comm.).

Productivity of glaucous gulls nesting adjacent to the Barrow Arch is relatively low. The lowest levels have been reported at Icy Cape where fledging success was only about 0.55 young per pair (Lehnhausen and Quinlan 1981), but this low success was probably due mainly to heavy predation by arctic foxes. Fledging success at Cape Thompson near the southern sector of the planning area has ranged between about 0.8 and 1.3 young per pair (Swartz 1966; Springer *et al.* 1982).

Black-legged Kittiwakes

Black-legged kittiwakes (*Rissa tridactyla*) are circumpolar in distribution and breed from the vicinity of Glacier Bay to Cape Lisburne, Alaska in western North America, and from the Kurile Islands to the New Siberian Islands in eastern Asia (Terres 1980; A.O.U. 1983). The world population is large, probably several million individuals.

The Alaskan population of black-legged kittiwakes is estimated at about 1.7 million birds (Sowls *et al.* 1978). Abundance is highest in the western Gulf of Alaska and southeastern Bering Sea.

The number of black-legged kittiwakes inhabiting seabird colonies in the eastern Chukchi Sea may fluctuate in response to environmental factors (Springer *et al.* 1982). At present, the population comprises about 60,000 birds and appears to be increasing (Sowls *et al.* 1978, unpubl. data; Springer *et al.* 1982). Nearly half of the population nests at colonies adjacent to the Barrow Arch: at least 20,000 birds at Cape Lisburne where about 14,000 nests have been counted, and perhaps 6,000–7,000 birds at Cape Lewis where approximately 4,500 nests have been counted (Fig. 5.4). The remaining kittiwakes are located south of the planning area at Cape Thompson, with at least 20,000 birds and about 14,000 nests, and in Kotzebue Sound with a minimum of about 8,000 birds.

Black-legged kittiwakes are also found commonly in the northern region of the Barrow Arch and in the western Beaufort Sea during summer and fall (Kessel and Gibson 1979). Kittiwakes were seen moving southward past Icy Cape almost daily by Lehnhausen and Quinlan (1981), and 9,873 were estimated to have moved past that point in the fall.

The spring migration of kittiwakes in the Barrow Arch follows the lead system between the Bering Strait and Point Barrow. Birds begin arriving in the vicinities of the nest cliffs in May, but nest building does not begin until about mid-June (Swartz 1966). Fledged young usually do not depart from nests until late September or early October. Departure from the cliffs is usually complete by about mid-October.

Black-legged kittiwakes nesting adjacent to the Barrow Arch may forage more than 120 km offshore of the Lisburne Peninsula (Swartz 1967). However, most birds tend to stay closer to land. Summer foraging patterns are relatively well known (Springer and Roseneau 1978; Springer *et al.* 1982). In most years the majority tend to forage northeast of Cape Lisburne in Ledyard Bay during June and July. After late July foraging intensifies along the coastline of Ledyard Bay and near Cape Lisburne in response to nearshore, near-surface schooling of juvenile sand lance and spawning capelin.

Kittiwakes obtain their food from surface waters at depths of 1 m or less by dipping, plunging, and hovering. Kittiwakes nesting adjacent to and near the Barrow Arch feed heavily on small fishes, but take some invertebrates (Swartz 1966; Springer *et al.* 1982). Surface schools of fish often attract feeding melees of thousands of plunging birds. The fishes

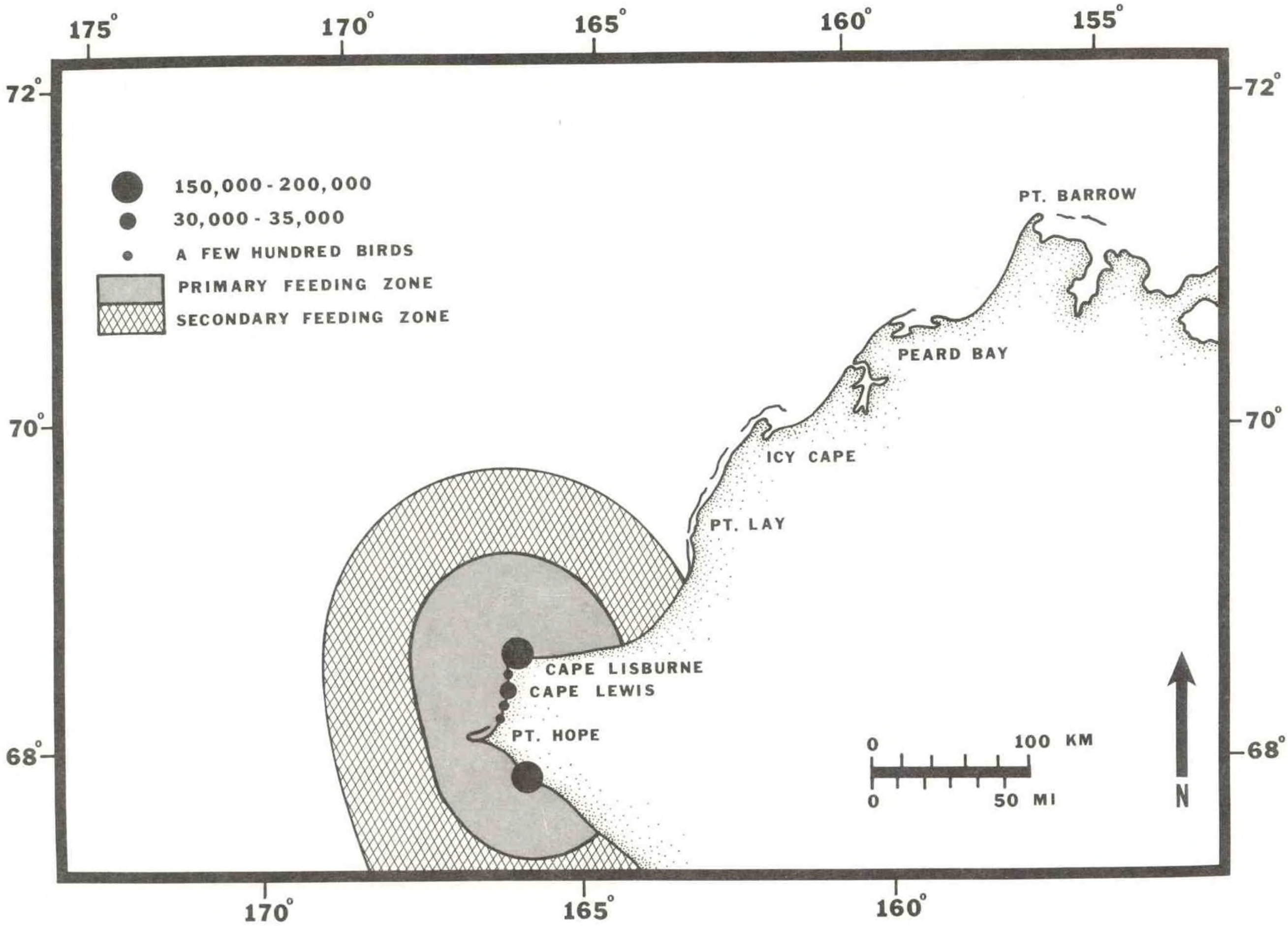

FIGURE 5.4—Cliff-nesting-seabird nesting colonies and feeding zones in summer in and near the Barrow Arch.

most frequently taken in the planning area are cods (especially Arctic cod), sand lance, and capelin. Diets vary seasonally. Arctic cod are eaten primarily during spring and early summer when they are abundant in surface waters near ice. Sand lance and capelin become increasingly important during July and August, and their availability in nearshore surface waters can strongly influence the nesting success of the kittiwakes (Springer *et al.* 1982).

Productivity of kittiwakes nesting adjacent to the Barrow Arch is generally low and tends to vary considerably over the years in response to environmental factors (Springer *et al.* 1982). Fledging success at Capes Lisburne and Thompson is often less than one chick per pair.

Ross' Gull

Ross' gulls (*Rhodostethia rosea*) may be present in Arctic waters throughout the year, but their winter range is unknown (A.O.U. 1983). The majority breed in northeastern Siberia between the Khroma and Kolyma rivers, inland to about 67° N., and on the southern Taymyr Peninsula (Cramp 1983). A few pairs have also nested in Greenland; near Bathurst Island, N.W.T., Canada; and in northern Manitoba, Canada (A.O.U. 1983). Total population size is unknown; however, it may not exceed several tens of thousands of individuals (Divoky, pers. comm.).

Ross' gulls may be present in the southern sector of the Barrow Arch in spring: large numbers were reported in loose ice about 110 km northwest of Point Hope on 10 June 1883 (Murdoch quoted in Bailey 1948). During summer, scattered individuals have been seen in the northeastern sector of the planning area, and in nearby coastal areas (Watson and Divoky 1972; Lehnhausen and Quinlan 1981; R. E. Gill, unpubl. data).

After mid-August, larger numbers of migrant Ross' gulls enter the northern Chukchi Sea to feed. During late fall, they are often seen in the nearshore and littoral zones between Wainwright and Point Barrow (Bailey 1948; Watson and Divoky 1972), and a large segment of the world population may concentrate near Barrow, especially in waters surrounding the Plover Islands (Divoky 1983, pers. comm.). Ross' gulls have also been observed as far south as Cape Lisburne during late September and October, generally in flocks ranging up to 120 birds each (Watson and Divoky 1972).

Fall migration routes of Ross' gulls are generally unknown. It has been assumed that the majority move eastward to winter over the Arctic Ocean (Bailey 1948; Watson and Divoky 1972). However, they may winter southwest of Anadyr Strait. The people of St. Lawrence Island are quite familiar with them (Fay and Cade 1959; Sealy *et al.* 1971), and in most years some are noted passing Gambell, St. Lawrence Island, in late November and December (R. Slwooko, pers. comm.).

Ross' gulls feed by hovering and picking items from the water, dipping, wading, and plunging onto the surface of the water where they remain for brief periods (Divoky 1976, pers. comm.). Feeding activities are especially prevalent around ice floes, along the ice edge, and near grounded, rotting ice. The predominant prey taken in the eastern Chukchi Sea are ice-associated amphipods (*Apherusa glacialis*) and juvenile Arctic cod (Divoky 1976).

Sabine's Gull

Sabine's gull (*Xema sabini*) also has a circumpolar distribution (A.O.U. 1983; Cramp 1983), but is generally uncommon over much of its Alaskan range, including the eastern Chukchi Sea. A small number breeds along the coast adjacent to the Barrow Arch on coastal tundra lakes (Bailey 1948). A few pairs have nested on the barrier islands near Point Lay (Divoky 1978); some potential nesting habitat, including the deltas of the Utokok and Kukpowruk rivers, has not been surveyed.

Sabine's gulls begin to arrive in the planning area in May and migration appears to continue through mid-June, but few birds appear to follow the coast (Lehnhausen and Quinlan 1981). The majority of spring migrants may fly overland or at high altitudes and thus escape detection by ground-based observers (Divoky, pers. comm.). Thousands of Sabine's gulls have been reported at Barrow in early August (Bailey 1948), and the fall migration follows the coast: they are especially evident at Icy Cape and Point Franklin where movements along the nearshore zone peak in late August and early September (Bailey 1948; Lehnhausen and Quinlan 1981).

In nearshore waters, Sabine's gulls are associated with productive zones around rotting ice where they feed on amphipods (primarily *Apherusa glacialis*) and mysids (*Mysis* sp.) (Divoky 1983). They also forage at low densities offshore and near the ice edge, where they prey heavily on amphipods and take some euphausiids (*Thysanoessa* sp.), Arctic cod, and other invertebrates (Divoky 1983).

Ivory Gull

In summer the ivory gull (*Pagophyla eburneas*) is restricted to the polar basin, where it nests on rocky shores in northern Siberia, Greenland, and the Canadian high Arctic (A.O.U. 1983; Cramp 1983). In winter these birds range as far south as the ice front in the Bering Sea (Divoky 1981). Nonbreeders, mostly immatures, may wander widely over the Arctic Ocean during summer. The world population size is unknown, but presumed to be relatively small.

Ivory gulls are rarely sighted from land in the Barrow Arch, but they may be widespread over offshore regions of the planning area whenever pack ice is present (Watson and Divoky 1972), and they are probably most common during fall and spring (Divoky 1983). When present, they usually occur as individuals or small groups foraging over pelagic waters, across the ice, and near the ice edge.

Carcasses and feces of a variety of marine mammals were considered by Divoky (1976) to be major food sources of ivory gulls. Recent studies have shown that fish and invertebrates are also important in their diet (Divoky, pers. comm.).

Arctic Tern

Arctic terns (*Sterna paradisaea*) breed throughout the holarctic and return to antarctic waters during the boreal winter (A.O.U. 1983). Their long migrations are made over the open oceans and they are commonly seen over land only during the breeding season. World population size is unknown.

An estimate of the Alaskan population of arctic terns is unavailable; however, some 25,000 birds may breed in coastal Alaska in summer (Sowls *et al.* 1978). The total number of arctic terns breeding adjacent to the Barrow Arch is relatively small, probably only several hundred pairs (Sowls *et al.* 1978; Lehnhausen and Quinlan 1981; D. Herter, unpubl. data). The primary nesting areas are the small islands and spits in Peard Bay and Kasegaluk Lagoon. The islands are especially important nesting habitat because they tend to be free of foxes. The largest numbers of terns appear to nest between Point Lay and Icy Cape, where a series of 10–15 small islets in Kasegaluk Lagoon support colonies from 10 to more than 100 birds each (Lehnhausen and Quinlan 1981; D. Herter, unpubl. data). At least one of these islets also supported a small colony of 10–15 Aleutian terns (*S. aleutica*) in 1983. (Aleutian terns appear to be expanding their range in Alaska, but have a small worldwide population that is restricted in distribution to Alaska and eastern Siberia (Sowls *et al.* [1978]; Connors and Risebrough [1979].)

A few pairs of arctic terns have nested on a small spit at the delta of the Pitmegea River (Childs 1969), and 50 pairs previously nested on another small spit near Corwin Creek Bluff in Ledyard Bay (Bailey 1948). The latter location may have been altered over time; no equivalent concentration of nesting terns has been seen at that vicinity in recent years (Springer and Roseneau, pers. comm.).

Only a relatively small number of arctic terns appear to migrate along the northeastern Chukchi Sea coast in spring (Lehnhausen and Quinlan 1981). They probably start arriving in late May (Williamson *et al.* 1966). Numbers tend to peak in early June, northward movements end by late June, and nesting begins in late June or early July (Lehnhausen and Quinlan 1981). Fall migration is abrupt, tends to be concentrated in the coastal zone (including lagoons), and includes more than 10,000 Arctic Slope migrants. Numbers of migrants tend to peak in mid- and late August or early September and the migrants are gone from the Barrow Arch by mid-September (Bailey 1948; Timson 1976; Lehnhausen and Quinlan 1981).

Nesting terns feed primarily in nearshore and lagoonal waters where there may be up to 25–100 birds/km^2 in summer (Divoky and Good 1979). Densities tend to be very low offshore, not more than 0.1 birds/km^2 (Divoky 1978; Divoky and Good 1979). Terns obtain their food at and just below the surface by plunging from the air. Primary prey include Arctic cod and euphausiids (*Thysanoessa* sp.) in pelagic waters, and amphipods (*Apherusa glacialis*), euphausiids (*Thysanoessa* sp.), mysids (*Mysis* sp.), Arctic cod, and sand lance in nearshore waters (Divoky 1983).

5.2.7. Alcids

Alcids (auks and their relatives, including murres, guillemots, puffins, auklets, and murrelets) are confined to the Northern Hemisphere. Fifteen of the world's 22 living species breed in Alaska. Diversity and abundance are highest in the western Gulf of Alaska and Bering Sea, and lowest north of the Bering Strait where several species reach the northern limits of their breeding range (Sowls *et al.* 1978). Only one species nests along Alaska's coast north of Cape Lisburne.

Nine species of alcid regularly visit the eastern Chukchi Sea during the open-water season (generally May through October), and a tenth is an uncommon year-round resident. Seven of the ten species are known to breed within or near the Barrow Arch (Springer and Roseneau 1978; Murphy *et al. In press*). Common and thick-billed murres are emphasized in the following summary because they are the principal species breeding in the Chukchi Sea and Barrow Arch, and have historical and current uses as secondary subsistence resources. Black guillemots also are emphasized because they both breed and winter in the eastern Chukchi Sea and Barrow Arch, and also have a history of use by subsistence hunters.

Common and Thick-billed Murres

Common and thick-billed murres (*Uria aalge and U. lomvia*) have widespread, circumpolar distributions and both species are abundant in the Pacific Ocean. Common murres breed from southern California to Cape Lisburne, Alaska in western North America, and from Korea to the eastern Chukchi Peninsula in eastern Asia (Terres 1980; A.O.U. 1983). Thick-billed murres nest from Middleton Island, Alaska to Cape Parry, N.W.T. in western North America, and from northern Japan to the New Siberian Islands in eastern Asia (Terres 1980; A.O.U. 1983). The world populations of both species are large, comprising several tens of millions of individuals (Tuck 1960), but probably declining (Gaston and Nettleship 1981).

The Alaskan populations of common and thick-billed murres are about equal in size and may total more than 10 million individuals (Sowls *et al.* 1978; Hunt *et al.* 1981b). As many as 4.9 million birds of each species are estimated to inhabit the eastern Bering Sea alone (Hunt *et al.* 1981b).

Murres are the most abundant alcids breeding in the eastern Chukchi Sea, but numbers have declined markedly since the early 1960's (Swartz 1966; Springer *et al.* 1982). The current population is estimated at about 400,000 individuals of which about 67% are thick-billed murres and 33% are common murres (DeGange and Sowls 1978; Sowls *et al.* 1978, unpubl. data; Roseneau *et al.* 1982; Springer *et al.* 1982). Nearly half of the total nest at colonies adjacent to the Barrow Arch: about 150,000 birds at Cape Lisburne and about 25,000 at Cape Lewis (Roseneau *et al.* 1982; Springer *et al.* 1982) (Fig. 5.4). Both colonies comprise about 30% common murres and 70% thick-billed murres. A second major, similarly composed concentration of about 150,000 murres is located about 50 km south of the planning area at Cape Thompson. The remaining concentrations, totaling about 23,000 individuals of which about 70% are common murres and 30% are thick-billed murres, are located well south of the planning area in Kotzebue Sound (DeGange and Sowls 1978; Sowls *et al.* 1978, unpubl. data).

The spring migration of murres into the Barrow Arch follows the system of open leads between the Bering Strait and Point Barrow. Birds begin arriving in April, but occupation of colonies usually does not commence until May (Swartz 1966). Attendance at nesting cliffs is irregular for several more weeks. Large flocks visit the cliffs to prospect for nesting sites, then depart to rest and feed in offshore leads.

Occupation of the nesting cliffs begins to stabilize in June.

Nesting phenology varies from year to year (Springer *et al.* 1982). Single eggs are usually laid in late June or early July, hatching occurs in late July or early August, and flightless chicks go to sea in mid- or late August. Departure from the cliffs is usually complete by late September (Swartz 1966; Springer and Roseneau, unpubl. data). Fall migration occurs predominantly on the water. Prevailing northward currents may carry large numbers of Cape Thompson, Cape Lewis, and Cape Lisburne murres well into the Barrow Arch before ice cover begins to force birds south toward the Bering Strait. The majority of murres are absent from the planning area by late October (Divoky, pers. comm.). However, small numbers of thick-billed murres may remain to winter in open leads and polynyas in some years (Swartz 1966).

Murres nesting adjacent to the Barrow Arch may forage more than 120 km offshore of the Lisburne Peninsula. However, the majority probably remain within 60 km of land (Swartz 1966; Springer *et al.* 1979). The feeding areas are relatively well known (Springer *et al.* 1982). The majority of Cape Lisburne and Cape Lewis birds feed northeast of Cape Lisburne and in Ledyard Bay during June and July. After late July, daily flight patterns shift north and west of Cape Lisburne, possibly in response to a drifting, maturing food web carried northward past the colonies by the prevailing currents, and to changes in the position of frontal systems between Bering Sea water masses. Many murres nesting south of the Barrow Arch also appear to respond to the same phenomena. Most murres nesting at Cape Thompson typically feed south of their colony until mid- or late July, then shift efforts northward to forage in what appears to be a common late-season feeding ground west and north of Cape Lisburne.

Murres dive deeply for food (over 100 m) and can travel considerable distances under water (100 m or more). Their food habits in and near the Barrow Arch are well known (Swartz 1966; Springer *et al.* 1982). Both species rely heavily on small fishes, but consume some invertebrates. The fishes preyed on most frequently by murres in the planning area are Arctic cod, saffron cod, sand lance, capelin, and sculpins. Thick-billed murres take sculpins, a variety of other demersal fishes, and invertebrates more frequently than do common murres. Diets of both species vary seasonally. Consumption of invertebrates tends to be higher in spring and early summer, and fishes assume greater dietary importance later in the breeding season. Among the fishes, cods and sculpins tend to predominate in early-season diets, and sand lance and capelin increase in importance after midsummer.

The productivity of murres nesting adjacent to the Barrow Arch is not well known (Swartz 1966; Springer and Roseneau 1977, 1978; Springer *et al.* 1979, 1982; Murphy *et al.* 1980; Roseneau *et al.* 1982). However, it probably does not often exceed about 0.5 chicks per pair, and varies considerably over the years in response to environmental factors (Table 5 of Springer *et al.* 1982).

Both species of murre and their eggs have served as important secondary subsistence resources in many parts of the Northern Hemisphere. Past use by subsistence hunters from villages along the eastern Chukchi Sea coast, including the Barrow Arch, is well documented (Saario and Kessel 1966; Swartz 1966; Nelson 1969; Burch 1981). Today adults and eggs remain an important, although not necessarily annual, secondary source of food for many residents of several local villages including Kivalina and Point Hope (Springer and Roseneau 1978).

Black Guillemot

Black guillemots (*Cepphus grylle*) are circumpolar in distribution and breed from Little Diomede Island, Alaska northward and eastward across arctic North America and Greenland, and from Wrangel Island westward across arctic Asia (Terres 1980; A.O.U. 1983). The total world population size is unknown; however, 20,000 individuals may inhabit the eastern Canadian arctic (Brown *et al.* 1975), and many thousands reside in other polar regions (Storer 1952).

Black guillemots are not numerous in Alaska. Fewer than 400 individuals may have nested north of Cape Thompson in the mid-1970's (Divoky 1978; Sowls *et al.* 1978). The majority were located in the eastern Chukchi Sea, primarily in the Barrow Arch, and the remainder in the Beaufort Sea. Since the mid-1970's, ongoing experiments have provided additional nesting habitat near Point Barrow. These experiments have increased the population and shifted the center of abundance to the western Beaufort Sea. Annual increases on Cooper Island in the Plover Islands have been especially significant: between 1972 and 1983, importation and placement of man-made debris, including plywood, boards, and wooden boxes, expanded the local population from 10 nesting pairs to about 185 nesting pairs and 200 subadults; and on one occasion in 1982, as many as 700 subadults were present (Divoky 1978, unpubl. data). As a result, the Alaskan population may now total about 1,400–1,500 birds (Divoky 1982, unpubl. data; Springer *et al.* 1982, unpubl. data).

Currently, about 500 black guillemots may frequent locations scattered along the coast between Point Barrow and Point Hope (Divoky 1982; Springer *et al.* 1982). About 300 individuals may be present between Corwin Bluff and the Kukpuk River, a section of coast containing some of the most suitable, natural cavity-nesting habitat in the region (Springer *et al.* 1982, unpubl. data). Up to 150 or more of these birds are concentrated at Cape Lisburne. A smaller number frequent the coast between Corwin Bluff and Point Barrow; about 20 pairs nested on the Seahorse Islands in Peard Bay in 1983 (Divoky, pers. comm.), but only 49 sightings and no nests were reported from Icy Cape in 1980 (Lehnhausen and Quinlan 1981). A relatively small, but unknown, number of additional birds also reside offshore along the ice edge in the planning area during the summer (Divoky, pers. comm.).

Black guillemots are year-round residents of the eastern Chukchi Sea. They winter in relatively small numbers in open leads and polynyas (Bailey 1948). An estimate of the wintering population is unavailable; however, it may be larger than the summering population, especially if birds are forced southward out of the Beaufort Sea by severe ice conditions.

The spring migration of black guillemots wintering south of the planning area follows the spring lead system. Nesting phenology varies from year to year, but up to two eggs are usually laid in late June or early July. Hatching begins in late July or early August, and chicks fledge in late August or early September (Divoky *et al.* 1974; Divoky, unpubl. data).

Black guillemots dive for food. Birds nesting adjacent to the Barrow Arch forage primarily in the nearshore waters, especially at ice edges. They feed predominantly on Arctic cod and under-ice amphipods, but snailfish and sand lance also are important prey (Divoky, unpubl. data; Springer and Roseneau, pers. obs.).

Considerable data on productivity of black guillemots have been collected at Cooper Island near the Barrow Arch. Clutch size has averaged 1.8 eggs, and hatching and fledging success about 60% each over several years' time (Divoky *et al.* 1974; Divoky, unpubl. data).

Hunters from coastal villages adjacent to the planning area historically harvested black guillemots in winter, but the practice apparently declined by the late 1960's (Nelson 1969). A few birds are occasionally harvested in summer on the Seahorse Islands and Peard Bay, but winter and summer dependence on this local resource currently is probably low (Divoky, pers. comm.).

Other Alcids

Other alcids using the resources of the Barrow Arch include horned and tufted puffins (*Fratercula corniculata* and *F. cirrhata*); Kittlitz's murrelet (*Brachyramphus brevirostris*); crested, least, and parakeet auklets (*Aethia cristatella, A. pusilla,* and *Cyclorrhynchus psittacula*); and, rarely, pigeon guillemots (*Cepphus columba*). The two puffins and Kittlitz's murrelet nest adjacent to the Barrow Arch in relatively low numbers; pigeon guillemots nest south of the planning area from Cape Thompson southward; and the three auklet species are mid- and late summer visitors.

About 20,000 pigeon guillemots breed in Alaska, but few venture north of the Bering Strait (Sowls *et al.* 1978). A few individuals have been seen at Capes Lisburne and Dyer, but nesting has never been documented north of Cape Thompson (Swartz 1966; Springer *et al.* 1982, unpubl. data).

Fewer than 3,000 horned puffins (of about 1.5 million in Alaska; Sowls *et al.* 1978) frequent nesting colonies adjacent to the Barrow Arch; about 2,000 nest at Cape Lisburne and a few hundred at small headlands between Niak Creek and Kilikralik Point, including Cape Lewis (Fig. 5.4). Horned puffins forage widely, often far offshore from their nest sites, diving for fishes such as cods, sand lance, and capelin.

Of the few million tufted puffins that nest in Alaska, fewer than 200 are estimated to frequent colonies adjacent to the Barrow Arch. Cape Lisburne hosts up to 100, Noyalik Peak has about 50, and a few occur at Corwin Creek Bluff and small headlands between Kilikralik Point and Niak Creek. Similar to horned puffins, these birds forage widely offshore (west, north, and east) from their nest sites, diving for cods, sand lance, and capelin.

The majority of Alaska's population of perhaps several tens of thousands of Kittlitz's murrelets breed in the Gulf of Alaska and the Aleutian Islands. A very few birds and only two nest sites (both >20 km inland) have been found anywhere near the Barrow Arch. The birds that use the planning area presumably forage widely offshore.

Nonbreeding crested, least, and parakeet auklets visit and forage in the Barrow Arch, mostly well offshore, but none nest north of the Bering Strait. Numbers of foragers probably peak in the planning area in August or September and most depart by late October. Densities of foraging birds are low, 0–3 birds/km^2. These birds dive after zooplankton, primarily crustaceans (copepods, euphausiids, amphipods); parakeet auklets may also feed on polychaetes and larval fishes.

5.3 POTENTIAL EFFECTS OF OCS DEVELOPMENT

Development of offshore petroleum reserves in the Barrow Arch presents three kinds of hazards to birds: (1) contamination of the environment by oil pollution, (2) disturbance by humans, and (3) habitat loss by construction of land-based support facilities. The susceptibility of birds to petroleum-related hazards and activities is greatest in areas traditionally used for concentration of nesting, molting, staging, and feeding birds, especially where large numbers of birds are confined to limited areas of habitat (e.g., nesting cliffs, islets, salt marshes).

5.3.1 Petroleum Spills

Oil spills are likely to pose the greatest danger to birds in the Barrow Arch. Large-scale events could (1) contaminate large areas of coastal and offshore habitats for relatively long periods of time, especially if oil were driven ashore in areas of wetlands and peat soils, or entrained in ice; and (2) result in the deaths (or at least lowered productivity) of large numbers of birds, if spills coincided with times and places of concentrated bird activity. Large-scale losses of long-lived, slowly reproducing species, including the alcids and larids breeding in the Barrow Arch, are of particular concern because such losses might affect local and regional populations for decades (Wiens *et al.* 1978; Samuels and Lanfear 1982).

Large-scale mortality of birds as a result of major oil spills has been well documented (Clark 1969; Vermeer and Vermeer 1975; Sopuck *et al.* 1979; Thomson *et al.* 1981; and others). Small-scale events may also cause considerable mortality of birds if they coincide with areas of high bird use. For example, a 250-gallon spill killed a minimum of 1,400 birds of 27 species in England (Campbell *et al.* 1978), and a series of five relatively small spills over a 3-year period caused a minimum of 60,000 birds to die along the coast of Denmark (Joensen 1972). Chronic pollution as a result of small intentional and unintentional discharges from vessels at sea and small accidental discharges from oil platforms, pipelines, terminals, storage facilities, and tankers may also cause mortality of birds. Mortality from these events may be equal to or greater than that associated with well-publicized large-scale events involving major tanker accidents and oil well blowouts (Hawkes 1961; Clark 1969; Holmes and Cronshaw 1977; Barrett 1979; McKnight and Knoder 1979).

Oil pollution has occurred in Alaska. Oil-laden ballast discharged from tankers entering Cook Inlet may have caused the deaths of an estimated 100,000 birds, mostly alcids and waterfowl, near Kodiak Island during February and March 1970 (Bartonek *et al.* 1971). Chronic discharges of oil and refined petroleum products from oil-related activities in Cook Inlet and from barging operations at remote coastal villages, U.S. Air Force outposts, and at sea may occur annually, but mortality of birds associated with these spills may not be noticed or reported (Bartonek *et al.* 1971).

Direct contact with oil can affect birds in a variety of ways. Oiling of plumage can destroy waterproofing, insulation, and buoyancy (Nye 1964). Heavily oiled birds may drown; lightly oiled birds may die from hypothermia even if they are in good physical condition (Hartung 1967; Choules *et al.* 1978). Oiled birds can also starve to death; increased metabolic rates, decreased feeding times and intakes of food, and interference with nutrient uptake in the intestines may all contribute to mortality (Hartung 1967; McEwan and Koelink 1973; Holmes *et al.* 1978).

Breeding birds that have been oiled may transmit oil to their eggs. Very small quantities of oil (e.g., 5–10 μl) can cause significant decreases in the hatchability of eggs (Szaro and Albers 1977; Albers 1978; Patten and Patten 1978; Coon *et al.* 1979; McGill and Richmond 1979; White *et al.* 1979; Macko and King 1980). Very small quantities of oil (1–5μl) have also caused abnormalities, including stunted growth, deformed bills, and incomplete ossification of bones, in a significant number of hatching and surviving chicks (Hoffman 1979; Stickel *et al.* 1979).

Oiled birds also attempt to clean themselves by preening, which is often the primary way birds ingest oil (Clark 1969). Oil may also be ingested during feeding, either by swallowing bits of oil along with prey or by consuming previously contaminated prey. The amount of oil individual birds can ingest and still survive may depend on several factors, including the species and physical condition of the birds, the length of time over which oil is consumed, and the toxicity of the particular oil.

Ingested oil has been reported to interfere with absorption of food and water in birds (Crocker *et al.* 1974, 1975; Holmes *et al.* 1978; Miller *et al.* 1978; Peakall *et al.* 1980), and to cause fatty changes in the liver, gastric irritation, hyperplasia of the adrenal cortex, and lipid pneumonia (Hartung and Hunt 1966; Austin-Smith 1968; Gorman and Milne 1971). Oil ingested by breeding adults may also reduce rates of oviposition and fertilization, affect egg shell thickness, and reduce the viability of chicks (Szaro and Albers 1977; Holmes *et al.* 1978; Stickel *et al.* 1979; Vangilder and Peterle 1980, 1981). Oil ingested by nestlings may affect their growth rates and feather development (Stickel *et al.* 1979; Peakall *et al.* 1980; Ainley *et al.* 1981).

The members of the bird workshop at the Barrow Arch Synthesis Meeting assessed the potential levels of impact to birds as a result of large-scale oil spills in the planning area. Spills were assumed to be major events involving thousands of barrels of oil lost during tanker accidents, subsea pipeline ruptures, or well-head blowouts. Definitions of the levels of impact used in the assessments were provided by the

Minerals Management Service. These definitions were as follows:

Major impact: A regional population or species declines in abundance, distribution, or both to a point beyond which natural recruitment would not return it to its former level within several generations.

Moderate impact: A portion of a regional population changes in abundance, distribution, or both over more than one generation, but the regional population is not likely to be affected.

Minor impact: A specific group of individuals of a population in a localized area and over a short time period (one generation) is affected.

Negligible impact: No measurable change.

Loons

Loons are considered to be highly vulnerable to oil spills because they spend a great deal of time on the water, dive for food, and may unknowingly surface in oil slicks. However, the potential magnitude of impacts on loons as a result of oil spills in the Barrow Arch was ranked from negligible to moderate (Table 5.1) because, in general, loons typically do not assemble in large flocks or in large concentrations and they disperse to breed over broad areas at relatively low densities.

The spring lead system and the nearshore waters between Cape Beaufort and Point Barrow were considered to be the marine areas within and adjacent to the planning area where oil spills would present the greatest danger to loons. A moderate level of impact was assigned to loons in the spring lead system because spring migrants may be present at higher densities in the confines of the open leads. Potential impacts on yellow-billed loons were judged to be somewhat higher than for arctic or red-throated

TABLE 5.1—Summary of potential levels of impact on birds as a result of oil pollution in the Barrow Arch.

Habitat	Alcids	Larids	Shorebirds	Waterfowl	Cormorants	Procellarids	Loons
Winter							
Leads and polynyas	Low	—*					
Spring							
Lead system	High	Moderate		High	—		Moderate
Sea cliffs	High	Moderate			Moderate		
River overflow				Low	—		Low
Summer							
Offshore (depth >20 m)	Moderate to high†	Low	—	—	—	Low	—
Nearshore (depth <20 m)	High	Low	Moderate	High	Moderate	Low	Low
Lagoons		Moderate	Low	High			Low
Salt marshes and mud flats		—	Low	—			
Sea cliffs	High	Moderate			Moderate		
Fall							
Offshore (depth >20 m)	Moderate to high†	Low	—	—	—	Low	—
Nearshore (depth <20 m)	High	Low	Low	High	Moderate	Low	Moderate
Ice edge	Moderate	High	—			—	
Lagoons		Low	Low	High			—
Salt marshes and mud flats		—	Moderate	High			
Sea cliffs	High	Moderate			Moderate		

* Indicates the presence of some birds, but a negligible level of impact.

† A high level of impact applies only to murres within 60 km of Cape Lisburne (see text).

loons because a relatively high proportion of the Alaskan breeding population may utilize the lead system in spring. Oil spills in the lead system would almost certainly result in the deaths of some loons.

A moderate level of impact was also assigned to loons in the nearshore zone during fall, when the highest densities of migrants are present along the coast. Oil spills at this time would probably result in the deaths of more loons than would oil spills in summer. But even in fall, flock sizes are relatively small and migrants tend to be scattered along the entire coast, so losses are unlikely to be of sufficient size to seriously affect regional or migrant populations over the long term.

Procellarids

Northern fulmars and short-tailed shearwaters, nonbreeding visitors in the Barrow Arch, are vulnerable to oil spills because they spend much time on the water and feed at or near the surface. However, both species may avoid diving into oil slicks and both have a scant history of oiling (Vermeer and Vermeer 1975). The potential magnitude of oil spill impacts was ranked from negligible to low for both species (Table 5.1).

Both species were considered to be at some risk of oiling during August to October, and risks of oiling were judged to be highest in September when numbers of both species may peak in the planning area. Spills in offshore areas would be somewhat more likely to contact these species than spills in nearshore waters. Risks were judged to be somewhat higher for short-tailed shearwaters than for northern fulmars because shearwaters often occur in large concentrations (>1,000 birds).

Low levels of impact were assigned these species because (1) fulmars are widely dispersed at low densities; (2) shearwaters have a patchy distribution that may change rapidly at irregular intervals; and (3) neither species appears to occur in the planning area in sufficient numbers that even large losses from one or more coincidental events would seriously jeopardize their breeding populations, or prevent their reappearance in following years.

Cormorants

Cormorants are quite vulnerable to oil spills because they spend a great deal of time on the water and dive for food. They are frequent victims of oil spills (Bourne 1968; Tanis and Bruijins 1968; Campbell *et al.* 1978). The potential magnitude of impacts to pelagic cormorants as a result of oil spills in the Barrow Arch during the open-water season was ranked from negligible to moderate (Table 5.1).

Pelagic cormorants were considered to be at risk of oiling from May to October. The nearshore waters between Point Hope and Thetis Creek and sea cliffs between Point Hope and Corwin Creek Bluff were judged to be the general area within and adjacent to the Barrow Arch where oil spills would present the greatest danger to this species. These sea cliffs and nearshore waters may contain over 50% of the pelagic cormorants found in the eastern Chukchi Sea, and major events occurring at the sea cliffs or in the nearshore zone would have the greatest probability of oiling these birds. However, the potential magnitude of impacts was ranked moderate overall, because (1) the local nesting and roosting concentrations are small and widely scattered over about 100 km of shoreline, (2) the birds typically disperse and forage at sea in low densities, and (3) in the majority of cases losses are unlikely to be of sufficient size to seriously affect the regional population over the long term.

Waterfowl

Sea ducks (e.g., eiders, oldsquaws, scoters) are especially vulnerable to oil spills because they spend the greater portions of their lives at sea, dive for food, and undergo flightless molting periods that are spent largely in saltwater areas. Some sea ducks may be attracted to oil slicks because they may mistake them for calm water or food sources (Curry-Lindahl 1960; Clark 1969). They are frequent victims of oil pollution (Vermeer and Vermeer 1975).

The potential magnitude of impacts on waterfowl, especially eiders and oldsquaws, as a result of oil spills in the Barrow Arch was ranked as high during most of the open-water season (Table 5.1). The spring lead system, Ledyard Bay, and the nearshore waters between Cape Lisburne and Point Barrow were judged to be the marine areas within and adjacent to the planning area where oil spills would present the greatest danger to waterfowl. The species judged to be at greatest risk of oiling in these areas were common and king eiders, and oldsquaws.

A high level of impact was assigned to waterfowl in the lead system during spring because virtually the entire Alaskan and northwestern Canadian populations of king eiders (estimated at over 1 million birds) and thousands of common eiders and oldsquaws migrate in the leads (Woodby and Divoky 1982), and especially large numbers of them may become even more concentrated in these areas of open water during periods of inclement weather.

A high level of impact was also assigned to the nearshore zone and lagoons in summer. These areas are host to concentrations of eiders and oldsquaws, including breeding colonies of common eiders on barrier islands in Peard Bay and Kasegaluk Lagoon, molting concentrations of thousands of oldsquaws in most of the major lagoons, and molting concentrations totaling tens or even hundreds of thousands of common and king eiders in the nearshore waters off Point Lay and in Ledyard Bay. Brood rearing of common eiders and some oldsquaws also occurs along the coast where they would be vulnerable to oil spills.

A high level of impact was also assigned to waterfowl in the nearshore zone and lagoons throughout the planning area during fall because these areas are host to large concentrations of migrating eiders and oldsquaws, which frequently stop to rest on the water (Timson 1976).

Large oil spills occurring in the spring lead system could directly oil many thousands of common and king eiders and oldsquaws. Spilled oil combined with inclement weather and restrictive ice conditions might have long-term effects on their regional and perhaps even western North American populations.

Similarly, single major oil spills occurring in the nearshore zone at Point Lay or in Ledyard Bay in summer could directly oil many thousands of molting male common and king eiders. Losses of sufficient size to have long-term effects on their regional and western North American populations are possible. Large amounts of oil driven ashore at Icy cape and Kasegaluk Lagoon in summer could affect the majority of the northeastern Chukchi breeding population of common eiders, and large numbers of molting male oldsquaws. Losses of large numbers of male oldsquaws might not seriously affect oldsquaw populations, but losses of nesting common eiders could have long-term effects on their regional populations.

Large oil spills in the nearshore zone or driven ashore at Icy Cape and Kasegaluk Lagoon in fall could also directly oil and kill many thousands of migrating adult female and juvenile eiders, and adult male, adult female, and juvenile oldsquaws. In this case, losses of common eiders and oldsquaws might have long-term effects on their regional populations.

The salt marsh and mud flat habitat of brant at Icy Cape was judged to be vulnerable to wind-driven oil spills. A high level of potential impact was assigned to brant at Icy Cape during fall because the cape contains the majority of salt marsh and mud flat habitat adjacent to the planning area, and serves as an important fall staging area for thousands of brant migrating through the Barrow Arch between Alaskan and Canadian Arctic Slope breeding grounds, and Izembek Lagoon in the Bering Sea (Lehnhausen and Quinlan 1981). Brant, traditionally attracted to these salt marshes to feed, might become oiled, ingest oil, or lose this important food source for several years. Losses of brant, salt marsh habitat, or brant and salt marshes combined might have relatively long-term effects on this species' regional population.

Shorebirds

Shorebirds, in general, are considered to be much less vulnerable to oil spills than are other groups of water birds (Vermeer and Vermeer 1975). However, oil can contaminate coastal feeding and roosting habitat and prey (Smith and Bleakney 1968; Clotuche and Schaeken 1982). Among the shorebirds, phalaropes are considered the most vulnerable to pollution because they feed and roost on the surface of the water in nearshore and offshore areas.

The potential magnitude of impacts to shorebirds as a result of oil spills in the Barrow Arch was ranked from negligible to moderate (Table 5.1). A moderate level of impact was assigned to shorebirds in the nearshore zone in summer because of the presence of feeding and staging red and red-necked phalaropes; other species are less vulnerable. Thousands of red phalaropes are present during August in the vicinity of Point Barrow, Peard Bay, and Icy Cape; this species is especially vulnerable here. The nearshore zone between Point Lay and Point Hope is the area where oil spills would present the greatest danger to feeding and staging flocks of red-necked phalaropes. Thousands of red-necked phalaropes, in flocks of hundreds, are present outside the surf zone from Ledyard Bay to Point Hope during August.

Major oil spills occurring in either of these nearshore zones in August might contaminate or kill phalaropes and the marine organisms eaten by them, but the phalaropes tend to be broadly distributed over relatively large areas and such losses are unlikely to seriously affect regional populations over the long term. Major oil spills occurring at Point Barrow, Peard Bay, or Icy Cape would affect red phalaropes more than currently predicted, because the extent to which the Arctic Slope population of this species uses these specific areas is unknown.

A moderate level of impact was assigned to shorebirds in salt marsh and mud flat habitats during fall because of the presence of thousands of feeding and staging *Calidris* sandpipers (especially dunlins, but including semipalmated sandpipers, western sandpipers, and others). The vicinity of Icy Cape was judged to be the area most vulnerable to wind-driven oil spills, in terms of the greatest danger to these fall migrants. Oil spills here could contaminate the salt marsh and mud flat feeding habitat. However, the level of impact was not expected to exceed the moderate category in most cases because (1) risks of oiling sandpipers would be relatively low, even if an event occurred in fall; (2) staging and migrating sandpipers also use a variety of other habitats, including beaches, spits, and lake shores; and (3) staging and migrating sandpipers are likely to also frequent mud flats and salt marshes not vulnerable to oiling.

Larids

Larids, including jaegers, gulls, and terns, are less vulnerable to oil spills than are many groups of water birds. They are infrequent victims of oil pollution (Vermeer and Vermeer 1975). Some species feed in terrestrial habitats as well as marine habitats. Larids tend to become less highly oiled than diving species, and some oiled birds may successfully clean themselves (Birkhead *et al.* 1973). Also, larids may actively avoid oil slicks (Bourne 1968b). Nevertheless, large numbers of larids may sometimes succumb to oil spills; e.g., oil spills at night in roosting areas (Harrison and Buck 1967).

The potential magnitude of impacts to larids as a result of oil spills in the Barrow Arch was ranked from negligible to high (Table 5.1). Larids that concentrate for nesting or feeding are at greater risk of oiling in the planning area than are others. Waters in the spring lead system, coastal lagoons, and near sea cliffs and ice edges were judged to be the areas where oil spills would present the greatest danger to larids. The species of greatest concern in the first three areas were black-legged kittiwakes, glaucous gulls, and arctic terns, and the species of greatest concern along the ice edge was the Ross' gull.

Larids were judged to have a moderate level of potential impact in the lead system during spring because thousands of black-legged kittiwakes concentrate in southern parts of the leads for several weeks before nesting at Capes Lisburne and Lewis. The leads provide the only early-season feeding habitat available to them.

A moderate level of impact was also assigned to larids in the nearshore zone during summer and fall, when the density of kittiwakes is consistently high on the water near their nesting colonies at Capes Lisburne and Lewis. Furthermore, thousands of feeding kittiwakes concentrate on the water near the Cape Lisburne colony during late summer, and thousands of adults and newly fledged young congregate near the nesting cliffs at both colonies in fall.

A moderate level of impact was assigned to larids in lagoons during summer and fall. The lagoons and stream deltas in Ledyard Bay are intensively used by thousands of bathing and resting kittiwakes during both seasons, and several thousand subadult glaucous gulls often congregate at them after early August. Further, the majority of arctic tern colonies are located between Icy Cape and Point Lay in Kasegaluk Lagoon, and several thousand staging terns are present in the lagoon during fall.

Oil spills occurring in the lead system in the southern sector of the planning area during spring might (1) kill kittiwakes by direct oiling, (2) contaminate or kill their prey organisms, or (3) exclude pre-nesting adults from important early-season feeding habitat. A reduction in the prey base or the loss of large areas of feeding habitat could possibly decrease breeding success during the nesting season immediately following an oil spill. Oil in water near the nesting cliffs would result in near-maximum contact between kittiwakes and oil pollution. Spills driven ashore in Ledyard Bay might contaminate regularly used lagoons and stream deltas and also expose many thousands of kittiwakes and concentrations of glaucous gulls to oil. Spills driven ashore between Icy Cape and Point Lay might affect breeding colonies of terns. In all of these events the level of impact was not usually expected to exceed the moderate category because (1) perching, bathing, and foraging larids, including kittiwakes, glaucous gulls, and terns are likely to avoid oil slicks; (2) loss of reproduction at the kittiwake colonies in one year, although serious, is not likely to be combined with large-scale losses of breeding adults; and (3) tern colonies are small and distributed over a relatively long section of the coast. Selected instances of spills, such as those at night in the spring lead system or at the nesting cliffs, could result in effects greater than moderate.

A high level of potential impact was assigned to Ross' gulls at the ice edge in fall because a major portion of their world population is thought to feed in that area during September and October. Though the feeding flocks tend to be dispersed, large numbers of birds are loosely concentrated in a relatively narrow zone. Major spills occurring at the ice edge in fall might contaminate or kill prey organisms or expose relatively large numbers of Ross' gulls to floating oil. Though these birds can feed on the wing and may avoid oil, little is known about their activities and behavior. Furthermore, losses of a relatively small number of birds might have relatively long-term effects on their northeastern Chukchi Sea and world populations.

Alcids

Alcids are very vulnerable to oil in water because they spend most of their lives on the water and dive for food. If they unknowingly surface within oil slicks they become coated with oil (Clark 1969). They may attempt to avoid slicks by diving under them, further increasing the chances of serious oiling (Bourne 1968). They are among the most commonly observed victims of oil pollution (Clark 1969; Vermeer and Vermeer 1975).

The potential magnitude of impacts to alcids as a result of oil spills during the open-water season was ranked from moderate to high (Table 5.1). The spring lead system, offshore and nearshore waters, and sea cliffs were all judged to be areas where oil spills would present considerable danger to alcids. The specific areas of concern were the spring lead system between Point Hope and Point Lay, the nearshore and offshore waters within 60 km of Cape Lisburne during summer and fall, and the sea cliffs at Capes Lisburne and Lewis during spring, summer, and fall. The species of greatest concern within these areas were common and thick-billed murres.

A high level of impact was assigned to alcids in the spring lead system because several hundred thousand murres are concentrated in its southern sector in limited areas of open water for up to 2 months. These concentrations include the entire nesting populations at Capes Lisburne and Lewis, and possibly large parts of the Wrangel Island and Cape Parry populations. The leads provide the only early-season feeding habitat for these murres.

Oil spills occurring in the southern sector of the planning area during spring might contaminate or kill early-season prey organisms, and are likely to directly oil and kill many thousands of feeding murres. These losses might normally be only moderate, but in some situations (e.g., those involving large volumes of oil combined with restrictive ice conditions and inclement weather) losses might have relatively long-term effects on the Cape Lisburne and Cape Lewis populations, and on regional populations of both species.

A high level of impact was also assigned to alcids at the sea cliffs during spring, summer, and fall. Oil spills driven ashore at the nesting cliffs would result in contact between feeding alcids and oil pollution. If oil covered large areas, many alcids would probably be killed by oiling. Such events would have the most serious consequences at Cape Lisburne where large losses of murres might have relatively long-term effects on their regional populations.

A high level of impact was also assigned to alcids in the nearshore and offshore waters within 60 km of Cape Lisburne during summer and fall. The majority of murres and other alcids breeding at Capes Lisburne and Lewis regularly feed there during the nesting season. Large numbers of murres from Cape Thompson also feed in the western portion of this area during the latter part of the breeding season in some years. Large concentrations of molting, post-breeding murres and flightless chicks are also present in this area in fall. Oil in large portions of this area would cause extensive oiling of alcids. In such events, large numbers of alcids would probably be oiled and killed. The consequences to murres are likely to be the most profound; resultant losses might have long-term effects on regional populations of both species.

5.3.2 Disturbance

Human activities were considered as another potential source of impact to birds. Disturbance to bird populations by human activities was of less concern than oil pollution because (1) sensitive areas and periods can be more easily avoided by planning, developing, and enforcing appropriate stipulations and guidelines that limit potentially disruptive activities; and (2) many of the expected activities (*see* Chapter 1) are judged to cause less severe and less long-lasting effects on bird populations than will oil spills.

The vulnerabilities of birds to human disturbance vary, depending on bird distribution patterns, life history stages, species, nest type, nest location, and type of disturbance (Manuwal 1978; Burger 1981). In general, colonial species are the most vulnerable because they are concentrated. Ground-nesting colonial species, including some gulls, terns, and waterfowl, are especially vulnerable because they are often easily accessible to people. Responses of birds to many potentially disruptive activities in terms of productivity, abandonment of habitats, and survival rates are not well documented.

Examples of potentially disturbing activities include people on foot near nests (Burger 1981); aircraft, boat, and other vehicular traffic near nesting, molting, and staging birds (Hume 1976; Batten 1977; Owens 1977; Sopuck *et al.* 1979); and operation of other equipment or facilities near these areas that may generate high noise levels (Gollop *et al.* 1974a, 1974b, 1974c; Wisely 1974).

The productivity of some species of birds, notably gulls, terns, cormorants, and some alcids, has decreased at some nesting colonies (not in the Barrow Arch) frequently disturbed by humans (Hawksley 1957; Hunt 1972; Gillett *et al.* 1975; Robert and Ralph 1975; Trapp 1977; Ellison and Cleary 1978; Bart 1979; Wehle 1980; Burger 1981). These decreases in productivity have resulted from predation on exposed eggs and chicks by large gulls (including within their own colonies), thermal stress, injury of eggs, injury of chicks by startled adults, and nest abandonment.

Murres are particularly vulnerable to human disturbance during the breeding season because they nest on cliffs and lay their eggs directly on rock (sometimes soil) ledges. When approached by aircraft, boats, or humans, they often flush from their nesting cliffs in large numbers, frequently dislodging eggs and small chicks (Hunt *et al.* 1981a). Unattended eggs and chicks which do not fall are often taken by glaucous gulls (Springer and Roseneau, pers. obs.). Repeated disturbance increases these losses. Other species of cliff-nesting seabirds, including nest-building species (e.g., kittiwakes, cormorants) and burrow- or crevice-nesting species (e.g., puffins, guillemots), tend to eject fewer eggs and chicks from their nests during panic flights. However, if the adults are flushed, eggs and chicks are exposed. Unattended kittiwake and cormorant nests are vulnerable to predation. Also, human disturbance at kittiwake nests may cause some chicks to leave their nests and enter others where they are less likely to survive (Burger 1981), or prematurely fledge, in which case they usually die (Springer and Roseneau, pers. obs.). Puffin nests tend to be less vulnerable to predation; however, puffins appear to be sensitive to human disturbance during egg laying and incubation, and they may abandon their nests (Hunt *et al.* 1981a). Again, repeated disturbance tends to increase losses.

Waterfowl are also vulnerable to human disturbance, although they tend to remain on their nests unless activities occur in immediate proximity to them. However, common eiders may be especially sensitive to disturbance during egg laying, early incubation, and hatching (S. R. Johnson, pers. comm.). Waterfowl nests disturbed by humans may be plundered by jaegers and large gulls (Strang 1980).

Waterfowl are considered to be especially susceptible to human disturbance during the flightless molting period and while staging. Disturbance of molting concentrations by aircraft and ground activities might cause abandonment of safe molting areas (which may be essential to survival) or unnecessarily increase the energy expenditure of the molting birds (Sterling and Dzubin 1967; Ward and Sharp 1974). Any human activities that serve to reduce feeding times and increase flight times of staging waterfowl might lower the physical condition of the migrants, thereby reducing survival rates during migration (Cooch 1958; Wiseley 1974).

In the Barrow Arch, disturbance to bird populations might result from a variety of human activities. In nearshore and offshore zones these activities may include placement and operation of drilling platforms in foraging, molting, or staging areas, and in major migratory pathways; ship traffic through these areas; aircraft traffic over these areas; and possibly, construction and maintenance of offshore pipelines through these areas. In the coastal zone, including lagoons and terrestrial habitats, activities that may be sources of disturbance include construction, operation, and maintanance of shore-based facilities near bird nesting, feeding, molting, and staging areas; aircraft traffic over these areas; and the general presence of humans in these areas.

Members of the bird workshop considered human activities to be a greater potential danger to birds in the coastal zone adjacent to the Barrow Arch than in the nearshore and offshore zones of the planning area proper. In the coastal zone, large numbers of birds concentrate in relatively limited areas of specific habitat for purposes of breeding, molting, and staging (sea cliffs, islands, salt marshes, mud flats, lagoons). If birds are disturbed in these areas they have few alternatives; comparable alternate-use areas are not or may not be present. Two areas within the coastal zone where human activities could have the greatest effects on bird populations are the northern half of Kasegaluk Lagoon and the cliffs at Cape Lisburne. Human activities during May through September within the northern sector of Kasegaluk Lagoon (including Icy Cape) might interfere with large portions of the region's nesting populations of common eiders and arctic terns, and large numbers of molting and staging waterfowl, including black brant. Human activities during May through September at Cape Lisburne might interfere with large segments of the region's nesting populations of common and thick-billed murres, and black-legged kittiwakes.

Human activities were considered to be of less potential danger to birds in the nearshore and offshore zones of the Barrow Arch than in the adjacent coastal zone because, in spite of large numbers of birds being present at certain times and places, these zones (1) are not used for nesting, (2) are relatively uniform in character, and (3) have bird use dispersed over larger areas. In general, these zones tend to offer a greater availability of nearby similar habitat for birds, if they encounter and avoid fixed or moving sources of potential disturbance (e.g., drilling platforms, ships, aircraft). However, one exception may exist: a high level of human activity in the spring lead system during April through mid-June might interfere with large numbers of the region's migrants at times when they are restricted to relatively limited areas of open water.

5.3.3 Habitat Loss

The direct loss or alteration of habitat adjacent to the Barrow Arch as a result of exploration and development of offshore oil reserves was considered to be of minor consequence to birds. Virtually all planned coastal facilities would be restricted to the Point Belcher vicinity (McCrea and Roberts 1984). Point Belcher is located more than 12 km southwest of the southern edge of one sensitive coastal bird area, Peard Bay, and about 48 km northeast of another major sensitive area, Kasegaluk Lagoon.

The construction of an oil storage and loading facility or a pump station and associated road and pipeline approaching from the east will result in direct losses of some bird habitats and cause the displacement of some breeding birds. However, direct losses of habitat will be limited to a relatively small amount of coastal acreage in an area that likely supports only low densities of a few species of passerines, shorebirds, waterfowl, larids, and ptarmigan (*Lagopus lagopus*). As a consequence, resultant losses of these birds will be relatively small, and the level of impact on their regional populations will be low.

Construction of the coastal facilities also might alter nearby habitats by creating graveled areas and impoundments (the result of blocked drainages), and elevating dust levels. These changes would also affect surrounding bird communities. For example, impounding water may affect the local distribution of some species by flooding of breeding habitat (Troy *et al.* 1983). Other species may be attracted to these impoundments, but usually not for breeding purposes. However, alteration of breeding habitats is expected to be local in extent, and the overall levels of impact on populations of birds in the vicinity of the Barrow Arch are likely to be low.

Shore-based facilities could also alter the distribution of some species of birds, or affect surrounding breeding populations. Solid wastes and food handouts may attract large gulls, common ravens (*Corvus corax*), and arctic foxes (*Alopex lagopus*). Glaucous gull populations especially may increase as a result of artificial food supplies (Kadlec and Drury 1968; Patten 1982). Increases in local populations of these predators could affect the total numbers or breeding success of local populations of other breeding birds. However, creation and enforcement of stipulations regarding waste disposal and feeding of wildlife can effectively minimize these problems. Therefore, overall levels of impact are expected to be low.

5.4 SITES VULNERABLE TO IMPACT

The members of the bird workshop identified several areas of great concern with respect to birds in the Barrow Arch. The members agreed that these areas should receive the highest possible levels of protection when exploration and development of petroleum resources are undertaken. The areas are shown in Figure 5.5 and are briefly described here.

5.4.1 Coastal Environments

Cape Lisburne

Cape Lisburne is the northernmost large seabird colony in western North America, and one of only two major concentrations of colonial-nesting seabirds in the eastern Chukchi Sea. The cape provides essential cliff-nesing habitat for about 40% of all alcids and larids breeding in the region, and about 80% of all alcids and larids breeding in the Barrow Arch.

Cape Lewis

Cape Lewis, about 18 km south of Cape Lisburne, supports the third largest concentration of colonial-nesting seabirds in the eastern Chukchi Sea. This cape provides essential cliff-nesting habitat for about 7% of all alcids and larids breeding in the region, and about 14% of all alcids and larids breeding in the Barrow Arch.

Kasegaluk Lagoon

Kasegaluk Lagoon, including associated wetlands and nearby nearshore waters, is the most important coastal lowland habitat for non-cliff-nesting birds in the northeastern Chukchi Sea and Barrow Arch. The Icy Cape area serves as a natural focal point for many of the region's spring, summer, and fall migrants and contains the largest concentration of mud flat and salt marsh habitats found between Point Barrow and Kotzebue Sound. The mud flats and salt marshes, beaches, and protected waters of the entire lagoon provide essential summer and fall feeding, molting, and staging habitat for thousands of waterfowl, shorebirds, gulls, and terns. The salt marshes may be especially vital to Alaskan and Canadian Arctic Slope populations of black brant; thousands of these geese are attracted to Icy Cape in the fall where the salt marshes provide the species' only known major fall feeding and resting stop between Teshekpuk Lake in the Beaufort Sea and Izembek Lagoon in the southeastern Bering Sea. Wetlands adjacent to the lagoon also provide nesting habitat for large numbers of a variety of shorebirds and waterfowl. The small islands in the lagoon between Icy Cape and Point Lay are essential predator-free nesting habitat for colonial-nesting common eiders and arctic terns; as many as a few thousand eiders and hundreds of terns nest on them, and together these colonies compose the majority of the known breeding populations of both species in the planning area.

Point Hope

The Point Hope spit and associated wetlands compose another noteworthy area of coastal lowland habitat for non-cliff-nesting birds in the Barrow Arch. The spit serves as a natural focal point for many of the region's migrants, and the beaches, lagoons, ponds, and wetlands almost certainly provide significant nesting, feeding, molting, and staging habitat for large numbers of a variety of regionally and locally important species. The spit and beaches especially may attract staging shorebirds, including large late-summer flocks of dunlins. However, actual densities and seasonality of use of this area by birds remain undocumented.

Peard Bay

Peard Bay, including the associated spit, islands, and nearby nearshore waters provides important molting and staging habitat for concentrations of old-

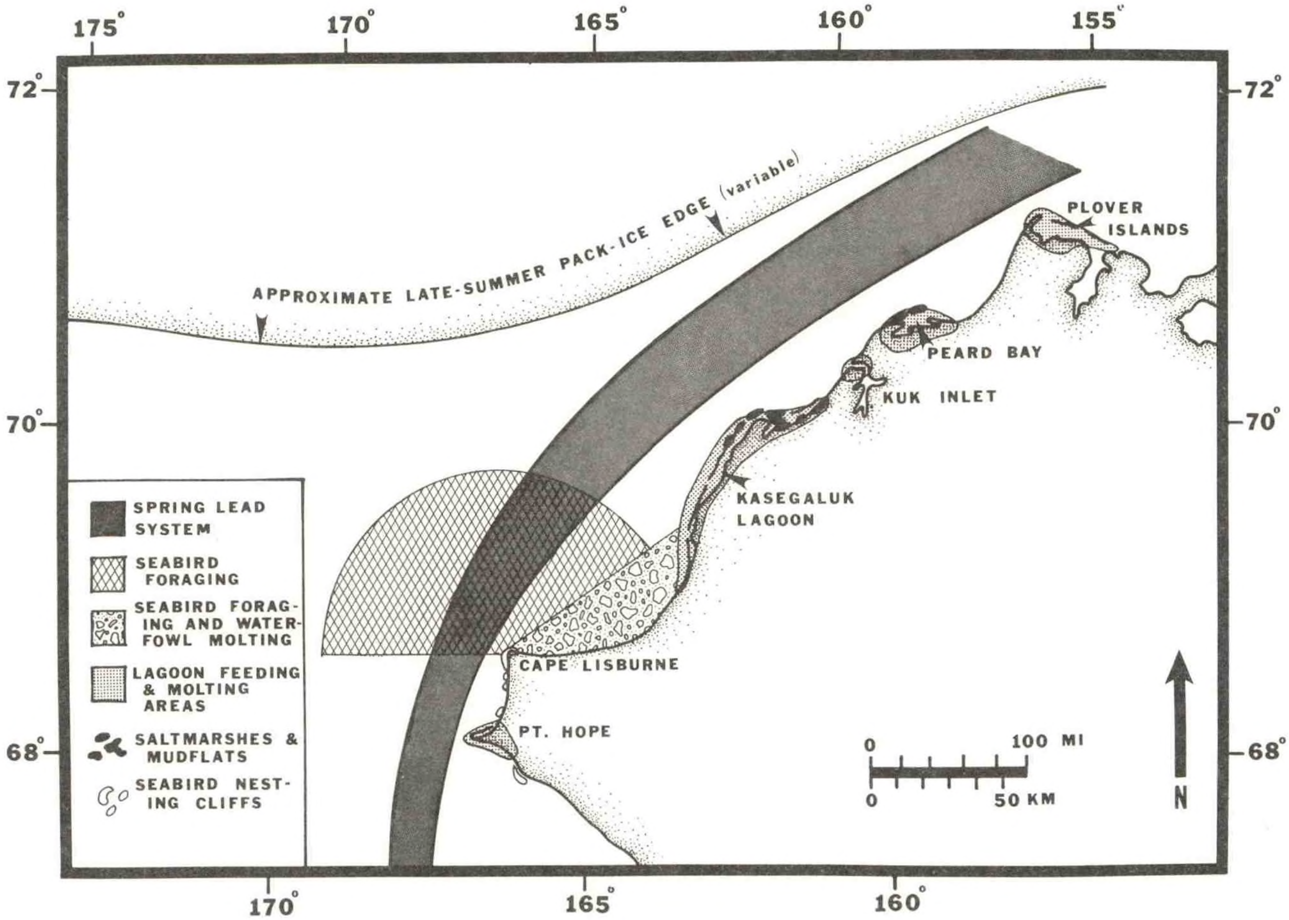

FIGURE 5.5—Places in the Barrow Arch where birds are particularly vulnerable to impact from oil and gas activities.

squaws, and feeding and staging habitat for what may be a significant portion of the Alaskan Arctic Slope population of red phalaropes. The spit and islands—especially the Seahorse Islands—provide essential nesting habitat for several small but locally important populations of colonial-nesting arctic terns, black guillemots and, in some years, common eiders.

Pitmegea River and Thetis Creek Deltas

The deltas of the Pitmegea River and Thetis Creek serve as summer-long, daily resting and bathing habitat for thousands of black-legged kittiwakes that commute from Cape Lisburne to feed in Ledyard Bay. The deltas may also serve as annual, late-summer staging areas for several thousand subadult glaucous gulls.

5.4.2 Marine Environments

Ledyard Bay

Ledyard Bay is a highly productive area of the eastern Chukchi Sea, perhaps the most important in the Barrow Arch for seabirds and waterfowl. Relatively shallow water and annually abundant marine fauna combine to provide rich spring, summer, and fall feeding habitats for many of the region's birds. The bay is especially significant to regional and local populations of seabirds; almost all alcids and larids nesting at Capes Lisburne and Lewis feed there throughout June and July every year, many thousands of them continue to forage there in August in some years, and several thousand subadult glaucous gulls feed and stage there in August of most years. Ledyard Bay is also especially significant to Alaskan and Canadian populations of common and king eiders; tens of thousands, or perhaps hundreds of thousands, of these regionally and locally important sea ducks stage and molt there in July and August.

Waters Off Cape Lisburne

The nearshore and offshore waters west, north, and northeast of Cape Lisburne provide significant late summer and fall feeding habitat for the majority of alcids and larids nesting at Capes Lisburne and Lewis. In some years these waters also provide significant late-summer and fall feeding habitat for the majority of murres nesting at Cape Thompson. The feeding area is generally defined as all waters within about 120 km of shore between the entrance to Ledyard Bay and 270° (true heading) from Cape Lisburne; however, most concentrations of feeding birds generally occur within about 60 km of shore.

Open Leads and Polynyas in Winter

The leads and polynyas that develop annually in the pack ice of the Barrow Arch provide vital resting and feeding habitat for an unknown but possibly significant portion of the region's wintering population of black guillemots. The areas of open water may also provide vital winter habitat for small local populations of glaucous gulls and thick-billed murres.

Offshore Spring Lead System

The offshore lead system in the Barrow Arch is part of a major spring migration route taken by birds entering the eastern Chukchi and western Beaufort seas from the Bering Sea. The open leads provide essential early-season resting, staging, and feeding habitat for large numbers of alcids, larids, waterfowl, and loons during late April–late June (very large concentrations using the lead system may be the result of inclement weather "short-stopping" migrants). The open leads are especially significant to local and regional populations of alcids and larids; tens of thousands of murres and kittiwakes from the nesting colonies at Capes Lisburne, Lewis, and Thompson regularly commute between the nesting cliffs and the leads for several weeks before laying eggs, and thereby remain concentrated in limited areas of open water for long periods of time. It is likely that the majority of the murres and kittiwakes from these colonies may be concentrated near Point Hope and in the southern sector of the planning area for as long as 4 to 6 weeks in the spring. It is also possible that significant numbers of murres and kittiwakes from nesting colonies at Wrangel and Herald islands in the northwestern Soviet sector of the Chukchi Sea may be present in the leads in the planning area for similarly long periods in the spring.

Seasonal Ice Edge

The seasonal ice edge of the eastern Chukchi Sea and Barrow Arch is a productive zone providing essential fall feeding habitat for migrating Ross' and ivory gulls. The feeding flocks of Ross' gulls may compose a significant part of the world population of this uncommon species. The seasonal ice edge also provides resting and feeding habitat for nonbreeding and post-breeding black guillemots, thick-billed murres, jaegers, black-legged kittiwakes, glaucous gulls, ivory gulls and, possibly, red phalaropes.

5.4.3 Recommended Mitigative Measures

The members of the bird workshop emphasized the need to (1) mitigate disturbance to the areas of concern, especially those containing breeding birds; (2) prevent habitat loss in terrestrial areas of concern wherever possible, especially those areas containing breeding, staging, molting, and feeding birds; (3) prevent oil spills of any kind or magnitude in the areas of concern, especially in nearshore and offshore leads in winter and spring, in nearshore and offshore areas used for feeding and molting, and near breeding colonies—especially colonies at Cape Lisburne and Cape Lewis; and (4) provide for means to rapidly and effectively clean up oil spills, if they do occur.

The members of the bird workshop agreed that the placement of shore-based facilities should be avoided in the terrestrial areas of concern. Offshore facilities would be highly undesirable in bird concentration areas, such as molting areas of eiders in Ledyard Bay, or near seabird colonies at Capes Lisburne and Lewis. The members also agreed that oil spills must be avoided at all costs, and oil spills near Cape Lewis, Cape Lisburne, Icy Cape, or in Ledyard Bay would be particularly detrimental. Spills at or near those locations would be, in all likelihood, major disasters, and spills in Ledyard Bay might have long-lasting effects on seabird food webs.

In conclusion, it is suggested that contingency plans be developed to mitigate and clean up oil spills in the planning area. It is also suggested that the most efficient containment and cleanup devices be stationed at Point Hope, Point Lay, and Point Barrow.

5.5 INFORMATION NEEDS

The members of the bird workshop identified several areas and topics that require further study before firm conclusions can be drawn on the potential impacts of oil and gas development in the Barrow Arch. These data gaps are briefly outlined below.

1) Few data are available on the winter bird use of open leads and polynyas. Therefore, it is difficult to accurately predict what effects oil entering open-water areas in winter may actually have on resident seabirds, especially wintering populations of black guillemots. Potential sources of wintertime oil were assumed to include accidental ruptures of offshore pipelines and incidents involving icebreaking tankers, if either technique is employed in the lease area.

2) Few data are available on bird use in the regularly occurring offshore lead system between Bering Strait and Point Barrow during spring migration. Information on actual use (other than as a general migration corridor) by loons, waterfowl, and larids is especially lacking. Therefore, it is difficult to accurately predict what effects oil entering the lead

system may have on populations of these birds as they migrate through the Barrow Arch. Potential sources of oil were assumed to include those mentioned in 1) above, and the release of previously entrained oil from melting sea ice.

3) Few data are available on the basic life histories of the principal prey species of seabirds in the eastern Chukchi Sea and Barrow Arch. Spawning, rearing, and overwintering areas have not been identified. Therefore, it is difficult to predict what effects potential nearshore or offshore oil spills, including major single events, or chronic leaks may have on seabird food webs, and ultimately, on seabird populations. Potential sources of oil were assumed to include tanker accidents, accidents at coastal storage facilities and gathering systems, ruptures of coastal and offshore pipelines, and blowouts at offshore well heads.

4) Few demographic data have been collected on northern marine bird species, and information on age structure, mortality rates, and recruitment rates is not available from the breeding populations of long-lived but slowly reproducing species in the eastern Chukchi Sea. Therefore, it is difficult to accurately predict the response of local marine bird populations to varying levels of direct mortality associated with potential oil spills in the planning area. Potential sources of oil were assumed to be the same as those given in 3) above.

5) Systematic surveys to determine the pelagic distribution of birds have not been made in the eastern Chukchi Sea, including the Barrow Arch. Most data that are available were obtained incidental to other shipboard work during passages between the Bering and Beaufort seas, or from a limited number of aerial transects. As a result, fewer quantitative data are available on the pelagic distribution of birds in the eastern Chukchi Sea and Barrow Arch than for the Bering or Beaufort seas. Therefore, it is difficult to fully assess the significance of offshore areas to regional bird populations, or to predict what effects offshore oil spills or other development-related activities may have on these populations. Potential sources of oil were assumed to be the same as those given in 3) above.

6) Information on eider populations in Ledyard Bay is incomplete. Large concentrations of molting eiders have been seen there in late summer, but arrival and departure dates, extent of occupied area, species composition, population structure, and other uses, including feeding, are poorly documented. Therefore, it is difficult to fully assess the significance of Ledyard Bay to migrating eiders, or to predict what affects potential oil spills or potentially disturbing activities may have on the summer migration and molting of eiders in the planning area. Potential sources of oil were assumed to be the same as those in 3) above, and potential coastal facilities were assumed to include exploration camps and airfields equipped to support offshore activities, marine terminals and gathering systems, pipelines, causeways, and communication towers.

7) Information on resident and transient bird populations in Kasegaluk Lagoon is incomplete. Although data on bird use are available from the vicinity of Icy Cape, little information is available from the southern sector where some migratory species may pause in spring, summer, and fall, and where colonies of eiders, gulls, and terns have been recently noted. Therefore, it is difficult to completely assess the significance of the lagoon to regional bird populations, or to predict what effects potential oil spills, disturbing activities, or habitat loss may have on local bird use. Potential sources of oil were assumed to be the same as those given in 6) above.

8) Few data are available on bird use of the Point Hope spit and adjacent wetlands. Therefore, it is difficult to completely assess the significance of this area to regional bird populations, or to predict the consequences of oil spills that may be driven ashore there. Potential sources of oil were assumed to be the same as those given in 3) above.

9) In general there have been few intensive studies, particularly long-term studies, of bird use of coastal salt marshes and other terrestrial habitats where birds concentrate. Better documentation of the extent and nature of bird use in salt marsh and other heavily used habitat on the coastal fringe would contribute to a better understanding of the potential impacts of oil and gas development.

5.6 SUMMARY

The Barrow Arch has a bird fauna that is relatively abundant and diverse in comparison with that of the Beaufort Sea. Because of the availability of open water in spring and coastal cliffs in the southern parts of the area, large populations of cliff-nesting seabirds (including larids and alcids) inhabit the area from spring through fall; this avian component is nearly absent from the Beaufort Sea. Other abundant groups, most of them well represented in the Beaufort Sea as well, include loons, waterfowl, shorebirds, and larids not requiring cliff nesting sites. Nearly all species arrive in spring and leave in fall, but small numbers of a few species may also be present in winter.

Three loon species breed near the Barrow Arch. Arctic and red-throated loons are the most common, and yellow-billed loons are the least abundant. Large numbers of these three species also migrate through the planning area, on their way to nesting areas farther north and east. The loons nest locally in tundra and frequently visit coastal waters to feed on fish. Red-throated loons are the most common coastal feeders.

Procellarids using the planning area include northern fulmars and short-tailed shearwaters. Neither species breeds there, but both use the area for foraging in late summer and early fall. During the open-water period they usually feed in offshore waters of the planning area, mainly on invertebrates and small fishes which they catch on or just below the surface.

Only one cormorant species, the pelagic cormorant, breeds in the vicinity of the Barrow Arch. About 300 (of an Alaskan population of about 90,000) breed on coastal headlands from Cape Lisburne southward. These forage in adjacent nearshore waters, diving for small fishes.

One of the most abundant and (to humans) important components of the Chukchi Sea bird fauna is waterfowl. The most abundant species are brant, common and king eiders, and oldsquaw. Up to a few thousand brant migrate along the coast adjacent to the Barrow Arch in spring, and are followed by several tens of thousands of molt migrants. Scattered nests occur in coastal tundra adjacent to the planning area, and some brant may molt in the area. However, the major use occurs in early fall, when thousands stage and feed in coastal salt marshes during fall migration on their way to wintering areas. Like brant, common and king eiders and oldsquaws occur in greatest numbers in the Barrow Arch as migrants, but the eiders and oldsquaws also nest and molt there. In spring, many of these sea ducks (about one million eiders, mostly king eiders, and several hundred thousand oldsquaws) pass along the nearshore lead system on their way to breeding grounds north and east of the planning area. A few thousand common eiders, and perhaps a few tens of thousands of oldsquaws, remain to nest in early summer adjacent to the Barrow Arch. From late June through October, nearshore waters host varying numbers (in the hundreds of thousands at most times) of molting, staging, and feeding eiders and oldsquaws. Relatively small numbers of other waterfowl use the Barrow Arch. These species include pintails; white-winged, surf, and black scoters; spectacled and Steller's eiders; and harlequin ducks.

About 15 species of shorebirds regularly breed in tundra adjacent to the Barrow Arch; several additional species forage in coastal habitats as migrants. Red and red-necked phalaropes are relatively abundant, and are the only shorebirds to use habitats seaward of the coastal margin. Both species nest in wet coastal tundra adjacent to the planning area; red phalaropes are generally more common north of Point Lay and red-necked phalaropes south of Point Lay. Their main concentrations come in July and August when thousands move to the coast, where they feed on invertebrates at the water's surface in bays, lagoons, and even farther offshore. Other shorebirds, like phalaropes, nest in tundra. But unlike phalaropes, the other birds feed mainly in salt marshes and other tundra areas in July and August. Late summer densities of these species may reach several hundred per square kilometer along selected beaches and in salt marshes and mud flats.

Nine species of larid (jaegers, gulls, and terns) are regular breeders adjacent to the Barrow Arch, and four additional species regularly visit the area. Three species of jaeger (pomarine, parasitic, and long-tailed) breed on the tundra and feed in terrestrial habitats and, to a limited extent, in marine environments on prey at the surface or robbed from other birds. Several hundred glaucous gulls breed on coastal spits and barrier islands in the planning area; several thousand forage along coastal environments in summer and fall for carrion and various vertebrate and invertebrate prey; and a few even overwinter in the area. About 30,000 black-legged kittiwakes nest on coastal cliffs at Capes Lisburne and Lewis. These generally forage for fish and invertebrates at or near the water's surface within about 120 km of the cliffs, but often congregate nearshore to feed on schooling sand lance and capelin. Ross' gulls forage for amphipods and small fishes in the area, mainly from late summer to late fall along the ice edge and (in late fall) near the coast. Sabine's and ivory gulls are two other species that frequently feed along the ice edge in the area during spring and fall; a few Sabine's gulls nest adjacent to the planning area. A few hundred arctic terns nest on barrier islands adjacent to the planning area; thousands feed in coastal waters in late summer and early fall before moving southward in late September.

Seven species of alcid breed adjacent to the Barrow Arch; all but one are restricted to the extreme southerly portion where nesting cliffs are available. Common and thick-billed murres are by far the most abundant breeders; about 175,000 (30% common, 70% thick-billed) nest at Capes Lisburne and Lewis. Murres arrive in April and May, feeding in the nearby lead system until open water prevails everywhere. The majority feed within about 60 km of land, but many go as far as 120 km. They eat small fishes and (secondarily) invertebrates, which they take by diving. A few hundred black guillemots nest adjacent to the Barrow Arch at coastal locations where cavity nests are available at cliffs, and along beaches where driftwood and man-made debris provide nest sites. This species is one of the few year-round avian residents of the planning area. Pigeon guillemots; horned and tufted puffins; Kittlitz's murrelets; and crested, least, and parakeet auklets also occur adjacent to the Barrow Arch. Small numbers of both species of puffins, Kittlitz's murrelets, and perhaps a few pigeon guillemots nest there, in the sea-cliff colonies at Cape Lisburne and vicinity; the auklets are nonbreeders from more southerly areas that visit the region to feed in summer and fall.

The potential adverse effects of oil and gas development on birds in the Barrow Arch are of three types: contamination by oil, disturbance by human activity, and loss of habitat. The greatest hazard is expected to be that presented by petroleum spills, for oiling of birds has frequently caused large-scale mortalities.

Adverse effects would be the greatest if large quantities of oil were spilled at times and in areas where large proportions of the regional species populations congregate. Included would be (1) oil in spring leads, particularly near Cape Lisburne, (2) oil in Ledyard Bay, Kasegaluk Lagoon, Peard Bay, or other semi-enclosed and adjacent coastal water body from mid-summer to fall, or (3) oil in coastal salt marshes. Offshore areas in general are not areas where birds are particularly vulnerable. Birds most susceptible to adverse effects of oil pollution are alcids, waterfowl, cormorants, loons, procellarids, and larids, in approximately that order of potential level of impact. Long-lived species with low reproductive rates, especially alcids, would be particularly susceptible because of long population recovery times.

Activities of humans and machines are, next to oil spills, the most likely source of important adverse effect. In general, colonial-nesting species are the most vulnerable to human activity because large proportions of populations could be affected by a single localized activity. Ground-nesting birds (some gulls, waterfowl, and terns) are highly vulnerable because of their accessibility. Cliff-nesting species (alcids, kittiwakes, and others) tend to be less vulnerable because they are relatively inaccessible to people, but they nest in dense concentrations on cliffs where panic flights can cause loss of eggs and young of some species, especially murres. Birds such as oldsquaws, eiders, and brant that congregate to molt or feed are also vulnerable to adverse effects of human activity. Similar to effects of oil, effects of human activity have much more potential to cause adverse effects in the coastal zone than offshore.

The potential loss or alteration of habitat in or adjacent to the planning area presents a relatively minor threat to birds. In most cases, habitat disruption is not expected to occur in a very large proportion of important habitats available to the birds.

Areas within or adjacent to the Barrow Arch in which birds are highly vulnerable to potential adverse impact include Cape Lisburne and vicinity including nearshore and offshore waters and Ledyard Bay (spring to fall), Cape Lewis and vicinity (spring to fall), Kasegaluk Lagoon (summer and early fall), Point Hope (late summer and early fall), Peard Bay (summer and fall), Pitmegea River and Thetis Creek deltas (summer), and the lead system offshore of the fast ice (winter and spring). Mitigative actions recommended in relation to these areas include (1) preventing oil from reaching the areas, (2) minimizing human activity in the areas at times when birds congragate in them, and (3) preventing habitat loss or degradation where applicable (e.g., when sites are terrestrial).

Important research needs relative to potential impacts of OCS development on birds in the Barrow Arch include the following:

1. Acquire more data on bird use of open leads and polynyas in winter and in spring.
2. Acquire data on spawning, rearing, and overwintering requirements and sensitivities of forage fish species consumed by seabirds.
3. Investigate age structure, natural mortality rates, and recruitment rates of alcids and other long-lived species.
4. Conduct systematic surveys to evaluate the pelagic distribution of birds at selected times in the planning area.
5. Determine the timing and spatial use of Ledyard Bay by eiders.
6. Document the seasonal and spatial use of Kasegaluk Lagoon and of the Point Hope wetlands by birds.

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6

Fish Resources

by Peter C. Craig

With contributions from R. R. Emerson, R. G. Fechhelm, C. George, J. D. Hall, J. P. Houghton, C. Johnson, T. K. Newbury, and D. R. Schmidt. Meeting Chairman: P. C. Craig.

Until recently, fish resources of the northeastern Chukchi Sea (Barrow Arch OCS Planning Area) had received little scientific attention, largely because the area lacked commercial quantities of fish or other resources which are often the stimuli for research. Consequently, the data base prior to 1983 was very limited (reviewed by Morris 1981; Moulton and Bowden 1981, Craig and Skvorc 1982; MP–WCC 1983). In 1983, the forthcoming oil and gas lease sale (Sale 85) prompted a considerable research effort in the area and this recent information provides much of the basis for this review. It is important to note that the degree to which 1983 is representative of annual conditions in the Barrow Arch is not known.

The data base for offshore waters of the northeastern Chukchi Sea consists primarily of trawl or gillnet surveys near Barrow (Frost and Lowry 1983), Point Lay (Fechhelm *et al.* 1984), and Ledyard Bay (Alverson and Wilimovsky 1966; Quast 1972, 1974). Nearshore studies have been conducted near Point Lay (Fechhelm *et al.* 1984; Schmidt and Craig 1984) and Peard Bay (Kinnetic 1983), and supplementary information is available from a variety of other sources (summarized by Craig and Skvorc 1982). Several rivers flowing into the planning area have been examined by Bendock (1979) and Schmidt and Craig (1984). At the time of this writing, analysis of data from studies by Kinnetic (1983) and Schmidt and Craig (1984) has not been completed.

6.1 SETTING

Water mass characteristics and exchange patterns in the Barrow Arch area are extremely important to fish populations. Though these characteristics were discussed earlier (*see* Chapter 2), factors particularly important to fish are summarized here as background for the discussions of fish distribution and abundance in following sections.

There are three major aquatic environments in the northeastern Chukchi Sea, each characterized by a somewhat distinctive water mass: (1) the cold offshore and bottom waters, composed variously of Bering Sea Water, the relatively cold, offshore portions of Alaskan Coastal Water, and on occasion, Arctic Ocean Water; these cold, offshore waters are called herein "outer shelf water"; (2) the nearer shore, warmer waters dominated by relatively warm, inshore portions of the Alaskan Coastal Current; and (3) the still warmer brackish waters adjacent to the coast; these persist for long periods only in lagoons. The locations and interactions of these water masses are important factors influencing the distributions of fish species and their use of the study area.

The outer shelf water of the Barrow Arch is cold (<3°C) and saline (~31 ppt). It is normally located several tens of kilometers or more offshore, but may move nearer shore in the deep layers during periods of wind-induced upwelling.

Nearshore shelf waters are dominated by nearshore parts of the Alaskan Coastal Current. The average summer current flows parallel to shore toward the northeast (this northeasterly flow is frequently in the face of the prevailing northeasterly and easterly winds); its core is found seaward of the shore from 20 to 30 km along most stretches of coast to as far as 100 km off Ledyard Bay. The main water mass of the Alaskan Coastal Current tends to remain at the surface, usually above ~30 m. Temperatures of this water mass can reach 5–10°C in summer;

salinities are usually less than 31.5 ppt. Although it is a persistent nearshore feature, its position is subject to some onshore–offshore movement by winds. An offshore movement of this water mass is accompanied by the onshore transport (upwelling) of deeper, cold outer shelf water.

The warmest and least saline aquatic habitats occur very near the coast, particularly in the three largest lagoons—Peard Bay, lower Kuk River (Wainwright Inlet), and Kasegaluk Lagoon. These waters in summer are warmed by the sun and freshened by stream discharge and *in situ* ice melt. Under southerly winds, they are held against the coast and moved northeastward. Strong and persistent northeasterly and easterly winds move these coastal waters southeastward along the coast, and at the same time move them seaward at the surface, to be replaced by upwelled shelf water that is colder and saltier.

Lagoons retain their warm, brackish waters under these upwelling conditions much more effectively than do open coasts, because the lagoons have low flushing rates and, consequently, limited exchange with adjacent marine waters. Lagoon waters generally remain warm, brackish, and turbid throughout summer, although conditions are highly variable. For example, in Kasegaluk Lagoon in summer, measurements of temperature were 5–13°C, salinity 1–26 ppt, and turbidity 1–140 NTU (Fechhelm *et al.* 1984). In addition, lagoon waters may become stratified with a layer of warm brackish water overlying cold marine water when winds push surface waters offshore. Coastal waters outside lagoons are frequently marine-like in their qualities, because of prevailing wind conditions that promote upwelling effects at the coast.

6.2 CHUKCHI SEA FISH FAUNA

The Chukchi Sea represents a transition zone between fish communities of the Arctic Ocean (Beaufort Sea) and northern Pacific Ocean (Bering Sea). However, it is, perhaps, more appropriate to view the Chukchi fauna as basically an arctic one which has continual input of southern species through the Bering Strait (Fig. 6.1). This view is especially appropriate for the northeastern Chukchi Sea where there is a strong resemblance to the fish fauna in the western Beaufort Sea. Both areas have a very low diversity of fish species, amounting to only about 20% of the number of species present in the Bering Sea and northern Pacific Ocean (Fig. 6.2). Only 72 species have been recorded to date in (or near) the northeastern Chukchi Sea and 74% of these species are common to the Beaufort Sea (Walters 1955; Alverson and Wilimovsky 1966; Quast 1972; Quast and Hall 1972; Frost and Lowry 1983; Fechhelm *et al.* 1984; and others). Chukchi Sea waters south of Point Hope are more directly influenced by the northward flow from the Bering Sea; an additional 25 species occur there. However, at least some of the marine species in the Chukchi Sea are believed to maintain their populations only through a continual recruitment of eggs and larvae transported north from the Bering Sea (Pruter and Alverson 1962); it is hypothesized that population levels of these fishes are kept low due to cold water temperatures in winter and resultant high mortalities.

A comparison of the principal fish species (arbitrarily defined as comprising 5% or more of total catches) in the southeastern Chukchi, northeastern Chukchi, and Beaufort seas demonstrates the faunistic transition between oceans (Table 6.1). The overall composition of demersal fishes is considerably different among the three areas—only a single major species, the Arctic cod, is common to all three offshore regions. (It is unlikely that the unidentified species of snailfish in the three regions are the same.)

Fish species composition differs between nearshore and offshore waters of the northeastern Chukchi Sea. Principal species in offshore waters consisted of nine marine fishes: four sculpin species, Arctic cod, polar eelpout, sand lance, snailfish, and Pacific herring (Table 6.2). Bottom trawls in offshore waters caught demersal species such as Arctic cod, sculpins, and eelpouts (Frost and Lowry 1983; Fechhelm *et al.* 1984). At surface and midwater depths, Quast (1972, 1974) found that juvenile Arctic cod (mostly young-of-year) and sand lance were virtually the only species collected in Ledyard Bay. Sand lance were usually taken at the surface, but numbers of Arctic cod tended to increase with depth. In view of the abundance of Arctic cod (28/1,000 m^3 or 0.7 t/km^2 of ocean surface), Quast described them as "a key element in the ecosystem of the Arctic Ocean." Gill nets were also used in offshore waters in an attempt to catch larger fishes (Fechhelm *et al.* 1984); however, herring was the only species caught in waters 5–100 km offshore and the catch per unit effort (CPUE) was extremely low in both surface and bottom sets (1.5 fish/gillnet-day). No salmon or other anadromous species were caught, although it should be noted that this gillnet survey was conducted in late summer (24 August–15 September 1983) when anadromous fishes may have already returned to fresh water to spawn or overwinter.

Principal species in nearshore habitats consisted of two species that were also common in offshore waters—herring, Arctic cod—and six others: rainbow smelt, least cisco, capelin, saffron cod, fourhorn sculpin, and Arctic flounder (Table 6.3). It is noteworthy that most of these fishes are marine rather than anadromous species. Relatively few anadromous

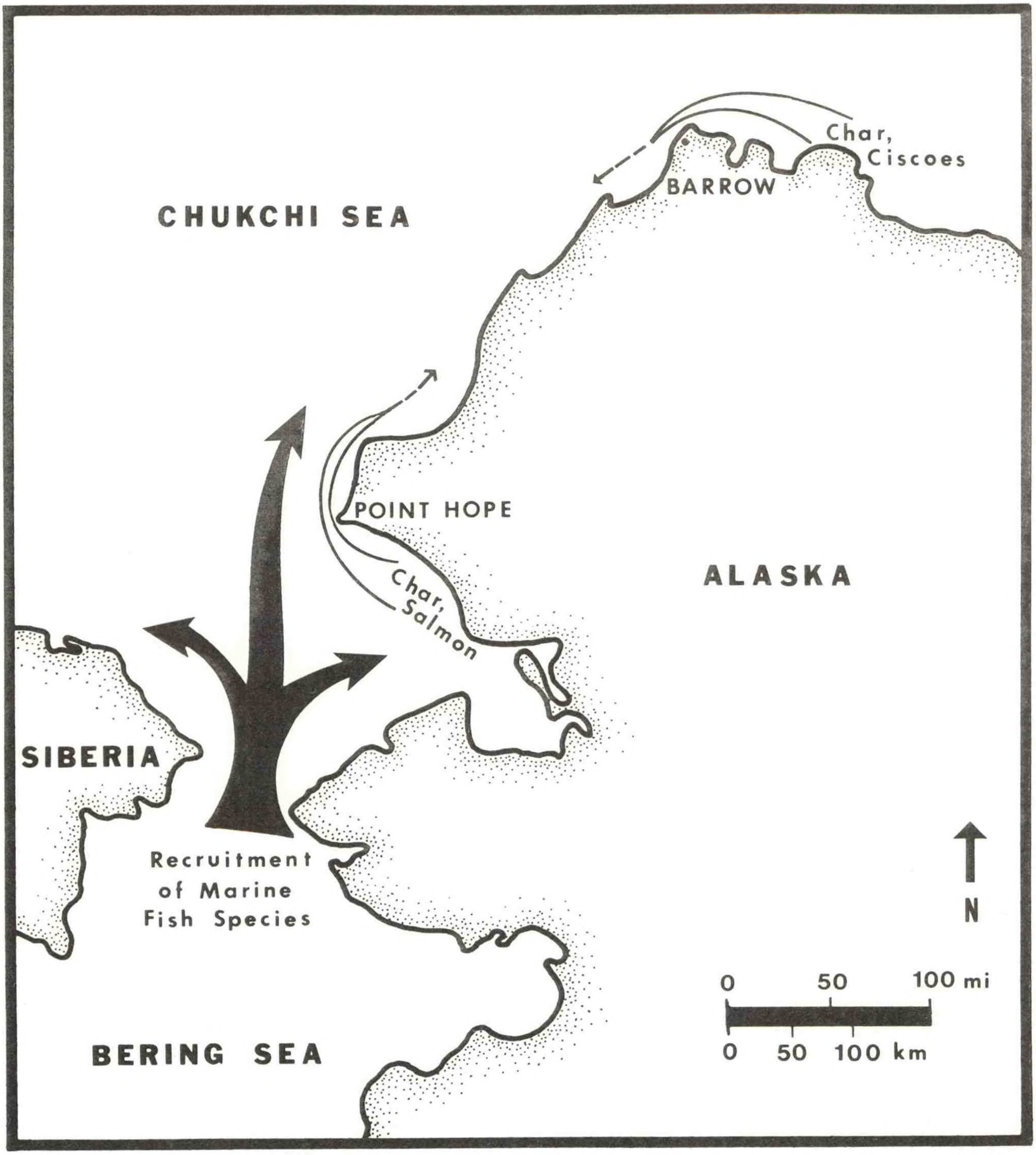

FIGURE 6.1—Schematic view of fish dispersals to the northeastern Chukchi Sea from adjacent regions.

fishes were caught even in gill nets, which are effective at capturing these fishes. Rainbow smelt was the most abundant anadromous species collected, and least cisco were common at one location (lower Kuk River). Additional anadromous species were also taken but in very small numbers: Arctic and Bering ciscoes, pink and chum salmon, and Arctic char.

The low representation of anadromous fishes in catches along the northeastern Chukchi Sea coast is in direct contrast to the abundance of these species along the Beaufort Sea coastline. A comparison of catches at several locations (where a similar gear type

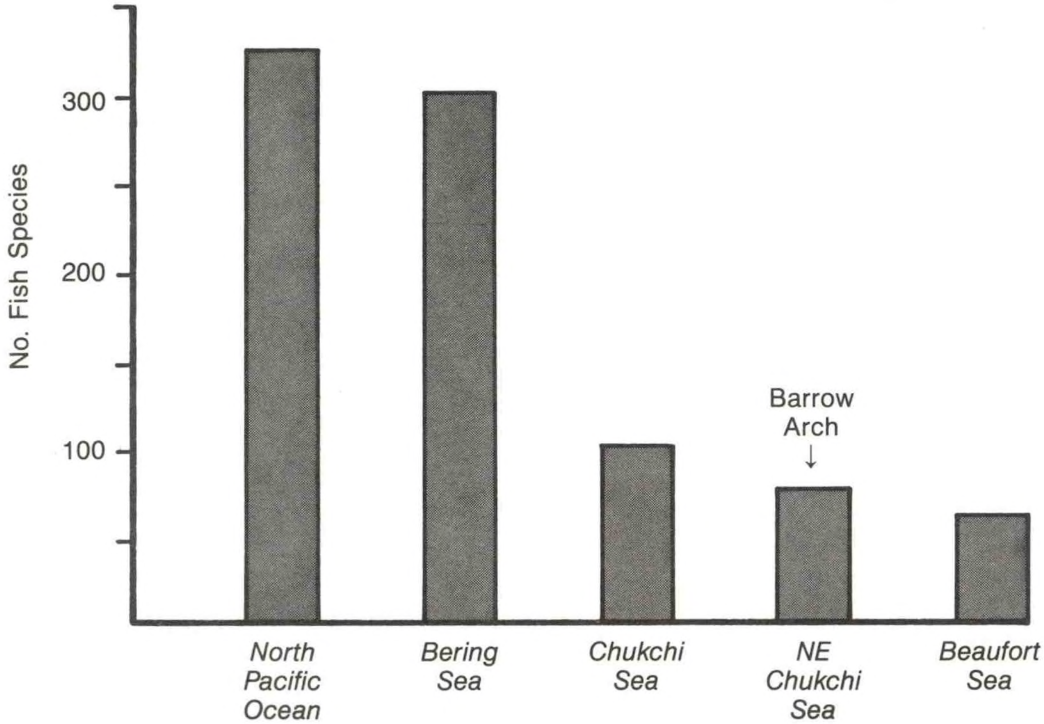

FIGURE 6.2—Number of fish species in Alaskan seas and the North Pacific Ocean. (From Hart 1973; Pereyra *et al.* 1976; Craig 1984.)

was used) shows that the CPUE for anadromous fishes was only 2–5 fish/net-day along the Chukchi coastline and 11–225 fish/net-day along the Beaufort coastline; the reverse trend occurred with the marine species (Table 6.4).

The southern Chukchi Sea also has a considerably larger anadromous fish component than occurs in the Barrow Arch. For example, many thousands of pink and chum salmon from the Noatak, Kobuk, and Selawik rivers and Arctic char from the Wulik and Kivalina enter coastal waters and are harvested in both commercial and subsistence fisheries.

It therefore appears that the anadromous fish community of the northeastern Chukchi Sea is, in some ways, different from those occurring in the Beaufort Sea, the southern Chukchi Sea, or even some combination of both. This apparent difference may be, in part, an artifact because virtually all Chukchi Sea data used in these comparisons were gathered during a single summer (1983) and thus may or may not be representative of typical conditions.

Two factors probably contribute to the observed scarcity of anadromous fishes in the Barrow Arch:

1) *Small local stocks of anadromous fishes.* Streams flowing into the northeastern Chukchi Sea are relatively small drainages which have marginal significance as anadromous fish streams, and thus they do not contribute many fishes to the coastal waters of the Barrow Arch. For example, the seasonal average CPUE for combined fish species in the lower Kokolik River was only 1.5 fish/net-day (Schmidt and Craig 1984). These streams support small runs of pink salmon with some chum salmon, rainbow smelt, and least cisco, and incidental catches of Arctic char, Arctic cisco, and Bering cisco (Table 6.5). Fish use of these drainages is thought to be restricted by a limited availability of overwintering habitat. In addition, Salonius (1973) suggests salmon are, in general, unable to make use of these arctic drainages because their juvenile stages have a marked intolerance to the low water temperatures occurring in these streams. The salmon species that do occur are relatively independent of freshwater life history stages (pink and chum salmon).

2) *Cold-water barrriers to coastal dispersal.* Another source of anadromous fishes to the Barrow Arch is their dispersal from adjacent coastal regions, the Beaufort Sea, and the southern Chukchi Sea. The distance from adjacent regions to the Barrow Arch is within the fishes' migratory ability, based on tagging data derived from Beaufort Sea studies, but cold water along the coast may hinder their dispersal.

In the Beaufort Sea, the coastal dispersal of anadromous fishes appears to depend on the occurrence of a narrow band of relatively warm, brackish water (5–10°C, 10–25 ppt salinity) which lies immediately adjacent to the shoreline in summer. This band serves as a migratory corridor because these species tend to avoid the colder offshore waters of the Beaufort Sea (reviewed by Craig 1984). There are physiological advantages, and probably requirements, for anadromous species to remain in these warm nearshore waters (Fechhelm *et al.* 1983).

A similar warm-water band apparently is not as persistent along the northeastern Chukchi Sea coastline (except in isolated pockets—Kasegaluk Lagoon, Kuk River, and Peard Bay). Its absence might, in effect, reduce access to the northeastern Chukchi Sea by anadromous fishes from adjacent coastal regions.

Two factors may account for the apparent intermittent occurrence of a warm-water band in the Barrow Arch: (1) there is less freshwater runoff in the planning area to establish such a band, and (2) a relatively steep slope in the nearshore zone promotes exchange of coastal water with marine water more effectively than occurs in the Beaufort Sea. The first point relates to the contribution to the nearshore environment from terrestrial runoff. Solar radiation warms up the water in streams that discharge into

TABLE 6.1—Principal demersal fish species (≥5% of biomass or numerical catch) in bottom trawl catches from offshore waters of the northeastern Chukchi Sea and adjacent regions (% composition).

Fish Species	SE Chukchi Sea*	Kivalina Area†	NE Chukchi Sea‡	Beaufort Sea§
Starry flounder *Platichthys stellatus*	21			
Pacific halibut *Hippoglossus stenolepis*	12			
Pacific herring *Clupea harengus pallasi*	10			
Saffron cod *Eleginus gracilis*	11	31		
Alaska plaice *Pleuronectes quadrituberculatus*	6	19		
Yellowfin sole *Limanda aspera*		20		
Shorthorn sculpin *Myoxocephalus scorpius*	7		×	
Arctic cod *Boreogadus saida*	8		×	38
Snailfish *Liparis* spp.	5		×	6
Hamecon *Artediellus scaber*			×	6
Arctic staghorn sculpin *Gymnocanthus tricuspis*			×	
Polar eelpout *Lycodes turneri*			×	
Spatulate sculpin *Icelus spatula*			×	
Canadian eelpout *Lycodes polaris*				16
Twohorn sculpin *Icelus bicornus*				14
Leatherfin lumpsucker *Eumicrotremus derjugini*				6

* Wolotira *et al.* 1977. † Blaylock and Erikson 1983. ‡ See text. § Frost and Lowry 1983.

coastal waters; the quantity of this runoff, as estimated by drainage area, in northeastern Chukchi Sea drainages is only about 20% of that entering coastal waters of the Beaufort Sea—even excluding the Mackenzie River discharge which also contributes to the formation of the Beaufort Sea warm-water band. Regarding the second point, the warm water that does occur along the coastline is subject to being rapidly moved offshore by northeasterly winds (*see* Chapter 2). Upwelling, or localized turnover of the water column, would occur in this situation, bringing cold outer shelf water up to shore. The net result of the upwelling would be to produce a more marine environment along the coastline, especially at nearshore locations where the bathymetry drops rapidly and facilitates upwelling. These upwelled waters would in theory reduce the coastal dispersal of anadromous species preferring warm waters (Fig. 6.3). Consequently, we might hypothesize that the abundance of anadromous whitefishes, ciscoes, and possibly char along the northeastern Chukchi Sea coastline is related to the frequency of winds which cause upwelling in the area; i.e., the more upwelling, the fewer anadromous fishes.

Pink salmon presumably are unaffected by the kinds of temperature differences discussed above. Similarly, Arctic char in the southeastern Chukchi Sea are thought not to be as restricted to shallow nearshore waters as they are in the Beaufort Sea (Houghton 1983), or as whitefishes and ciscoes are in either sea.

6.3 HABITAT USE

6.3.1 Nearshore Habitats

Habitats along the northeastern Chukchi Sea coast are less varied than along the Beaufort Sea coastline where there are numerous bays, open and limited-exchange lagoons, large river deltas, and a variety of barrier island systems. The northeastern Chukchi coastline has instead two general types of habitat: protected lagoons and exposed coastline. Fish use

TABLE 6.2—Principal demersal fish species (≥5% of numerical catch) in catches from offshore waters of the northeastern Chukchi Sea (% composition).

Fish Species	Bottom Trawl* Deep (>14 m) $n = 19$	Bottom Trawl* Shallow (<14 m) $n = 10$	Bottom Trawl† $n = 10$	Surface & Midwater Trawls‡ $n = 81$	Gill Net* $n = 16$
Arctic staghorn sculpin *Gymnocanthus tricuspis*	55	55			
Arctic cod *Boreogadus saida*	17	5	54	85	
Shorthorn sculpin *Myoxocephalus scorpius*	9	16			
Hamecon *Artediellus scaber*	7	10	7		
Polar eelpout *Lycodes polaris*			23		
Snailfish *Liparis* sp.		5			
Spatulate sculpin *Icelus spatula*			5		
Pacific sand lance *Ammodytes hexapterus*				10	
Pacific herring *Clupea harengus pallasi*					100
Others	12	9	11	5	
Number of fish caught	20,721	599	192	—	24

* Fechhelm *et al.* 1984; gillnet data are for sets more than 3.2 km offshore.

† Frost and Lowry 1983; Chukchi Sea trawls only.

‡ Quast 1974; values used are estimates (B. L. Wing, NOAA, NMFS, Northwest and Alaska Fisheries Center Auke Bay Laboratory, pers. comm.).

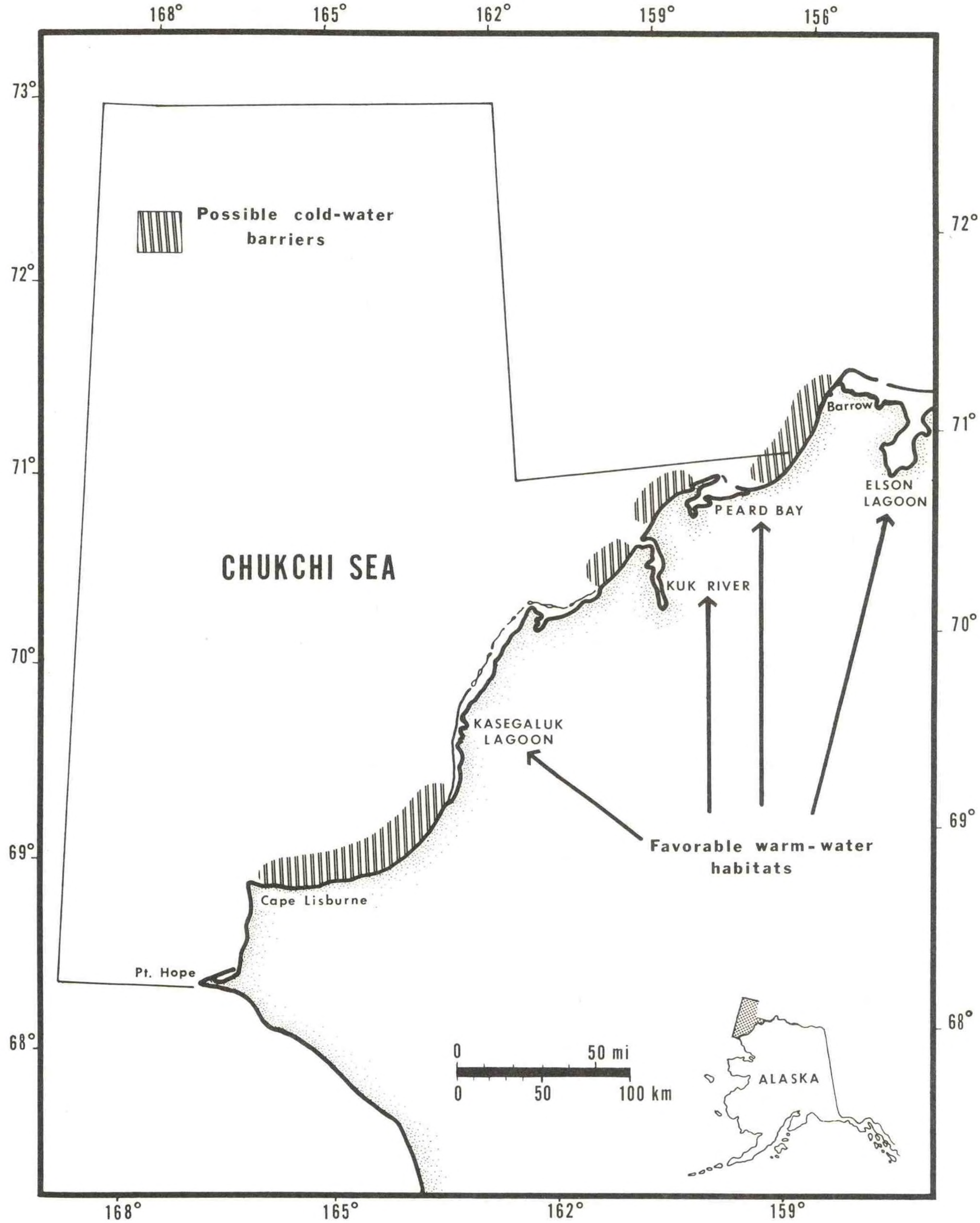

FIGURE 6.3—Postulated cold-water barriers which would hinder the dispersal of anadromous fishes (ciscoes, whitefishes) between areas of favorable warm-water habitats.

of these habitats is generally similar to that occurring in the Beaufort Sea. As in the Beaufort, fish caught by gill net were more abundant in nearshore habitats than in offshore habitats (Fig. 6.4). Anadromous fishes were caught only in nearshore habitats, but as previously discussed, catches were very low (20% of total gillnet catch; Fechhelm *et al.* 1984) and consisted primarily of rainbow smelt (86%), pink salmon (13%), and single specimens of Bering cisco and chum salmon. Abundant marine species in nearshore habitats were Pacific herring, fourhorn sculpin, Arctic flounder, Arctic cod, and capelin (Table 6.3).

Habitat use by nearshore anadromous and marine species can be divided into four broad categories of fish activity: spawning, feeding, migration and dispersal, and overwintering. These categories are discussed below.

Spawning

Although marine species tend to spawn offshore in winter and anadromous species migrate into rivers to spawn in fall, some spawning does occur in nearshore waters during the open-water season. Herring may spawn in the Kasegaluk Lagoon area in spring, and capelin spawners have been collected during early August along the barrier island at Point Lay (Fechhelm *et al.* 1984). Both of these species are abundant in areas of the Bering Sea farther south but their distribution and abundance wane in the northern Chukchi Sea. Spawning populations in the Barrow Arch are probably very small compared to Bering Sea stocks.

Feeding

A primary reason anadromous fishes enter coastal waters is to feed on prey organisms which tend to be much more abundant in coastal waters than in rivers. Anadromous fishes accumulate food reserves during the summer for spawning and overwintering requirements. Marine species likewise may feed in coastal habitats during the open-water season, but the relative importance of various nearshore and offshore habitats as sources of prey to marine species is not known. Details of fish feeding habits are described in Section 6.4.

Migration and Dispersal

Movement patterns of most fishes in the Barrow Arch are not well known. Pink salmon migrate along the northeastern Chukchi coastline from about mid-July to late August, although there is some annual variability in the timing of their run (Craig and Schmidt 1982; Fechhelm *et al.* 1984). Rainbow smelt migrate from coastal waters into the Kokolik River

TABLE 6.3—Principal fish species (≥5% of numerical catch) in catches from nearshore waters of the northeastern Chukchi Sea (% composition).

	Point Lay				Wainwright	Peard Bay
Fish Species	Gill Net*	Fyke Net*	Gill Net†	Misc. Nets‡	Gill Net†	Fyke Net§
Pacific herring *Clupea harengus pallasi*	53		5			
Rainbow smelt *Osmerus mordax*	19		6		9	
Fourhorn sculpin *Myoxocephalus quadricornis*	11	20	29	32	29	24
Arctic flounder *Liopsetta glacialis*	10	13	55	12		
Arctic cod *Boreogadus saida*		39		42		70
Capelin *Mallotus villosus*		25				
Saffron cod *Eleginus gracilis*						6
Least cisco *Coregonus sardinella*					61	
Others	7	3	5	14	1	1
Number of fish caught	1,002	13,335	150	4,684	51	11,896

* Fechhelm *et al.* 1984. † Craig and Schmidt 1982. ‡ Schmidt and Craig 1984. § Kinnetic 1983.

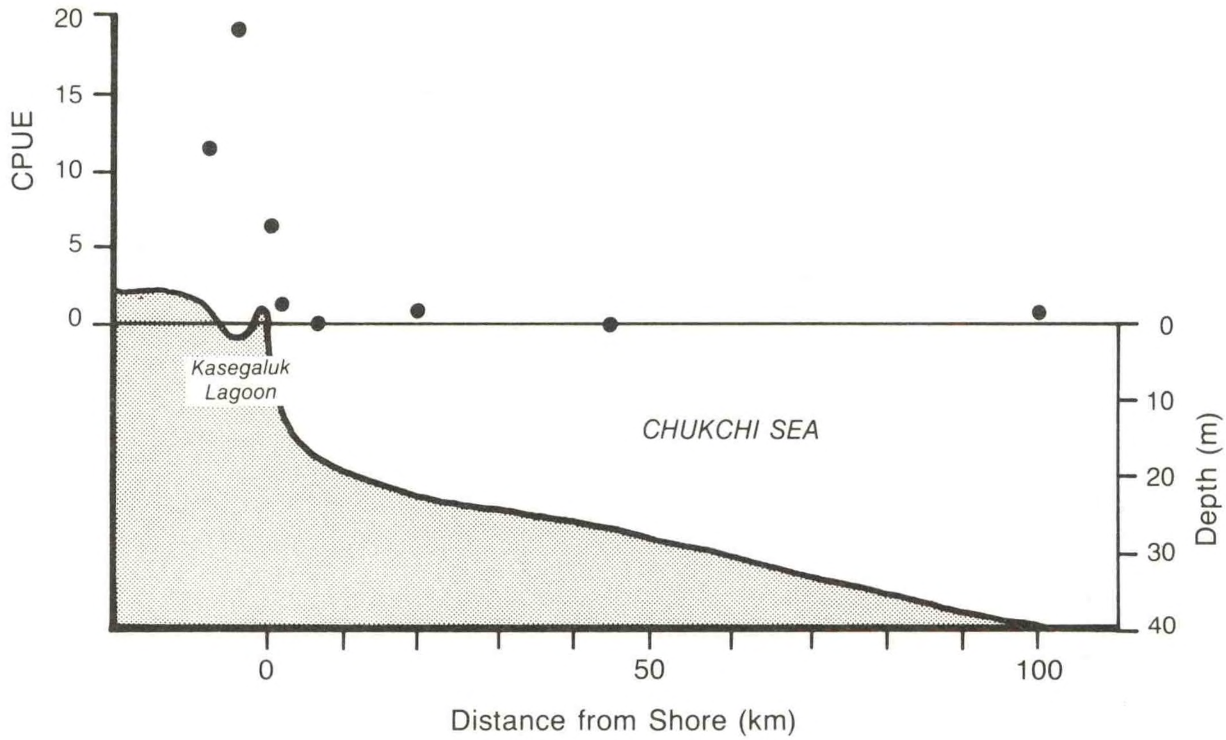

FIGURE 6.4—Cross-section of Chukchi Sea at Point Lay, showing highest catch per unit effort (CPUE) of fishes in Kasegaluk Lagoon and lowest CPUE in offshore waters. CPUE = average number of fish (species combined) in surface and bottom gill nets/24 h. (Data derived from Fechhelm *et al.* 1984.)

to spawn soon after spring breakup (Schmidt and Craig 1984). Capelin were abundant near Point Lay only during their spawning migration in early August (Fechhelm *et al.* 1984). Daily catches of other species were variable, perhaps in response to daily changes in water temperature and salinity as occurs with some species along the Beaufort Sea coastline.

The coastwide dispersal of the anadromous species which prefer warm water may be restricted by cold-water barriers caused by upwelling (*see* Fig. 6.3 and preceding discussions). Pink salmon, however, would presumably be unaffected by such temperature changes as they migrate to their rivers of origin to spawn, because migrating salmon may cue to stimuli other than temperature.

Overwintering

The suitability of nearshore habitats for overwintering fishes is largely a function of water depth. Shallow habitats like Kasegaluk Lagoon (average depth about 1.5 m) probably freeze solid by late winter except in the deepest areas. Habitats appreciably deeper than the maximum extent of ice thickness (about 2 m) can usually be assumed to support overwintering fishes; the lower Kuk River, for example, supports overwintering rainbow smelt and probably other species as well (Craig and Schmidt 1982). In coastal waters about 10 m deep, Fechhelm *et al.* (1984) caught overwintering Arctic cod at three locations: Peard Bay, near Wainwright, and Ledyard Bay. The under-ice CPUE during this late-winter survey was 5 fish/net-day (fyke and gillnet data combined), which is similar to the late-winter CPUE for Arctic cod in the Beaufort Sea (0–11 fish/net-day) (Craig 1981). Additional species presumably are present but not susceptible to capture by the sampling gear used in these studies.

6.3.2 Offshore Habitats

Offshore waters of the northeastern Chukchi Sea are used by pelagic species, particularly Arctic cod and sand lance (Quast 1972, 1974), and a variety of demersal species such as Arctic cod, sculpins, eelpouts, and snailfishes (Table 6.2). These marine species tend to be both numerous and widely distributed; specific patterns of habitat usage are not known.

6.4 TROPHIC RELATIONSHIPS

One of the most significant aspects about fish resources in the northeastern Chukchi Sea is, perhaps, their important position in the marine food web of the region. Forage fishes are the mainstay of large populations of marine mammals and seabirds. For example, Swartz (1966) estimated that as many as 25 million Arctic cod are consumed annually by seabirds at Cape Thompson. Furthermore, a major reason for observed fluctuations in the distribution and reproductive success of these seabirds and marine mammals is thought to be changes in the availability of forage fish species (Springer *et al.* 1979; Lowry *et al.* 1980). Important forage fishes include several pelagic and demersal species: Arctic and saffron cods, sand lance, and sculpins. Details about the diets of predators are given in Chapters 4 and 5.

The fishes, in turn, feed on a variety of foods. Their principal prey (arbitrarily defined as ≥10% by weight in stomach contents) consist primarily of other fishes, mysids, amphipods, and isopods, but also include copepods, cumaceans, and polychaetes (Table 6.6). Statistical analyses of fish diets from the Point Lay area resulted in the following groupings of fish consumers based on the similarity of their diets (Fechhelm *et al.* 1974):

1) *Pink salmon and rainbow smelt.* These species tended to be piscivorous, with fish accounting for 75% and 65% of their diets, respectively. Many of the fishes eaten were Arctic cod.
2) *Pacific herring and capelin.* The diets of Pacific herring and capelin were dominated by *Mysis litoralis,* which accounted for 78% and 95% of their stomach contents, respectively.
3) *Fourhorn sculpin.* This species fed primarily on the isopod *Saduria entomon* in both lagoon (65% of diet) and ocean (81%) habitats.
4) *Arctic flounder.* The benthic nature of this flatfish is reflected in the high incidence of tubular polychaetes (48% of diet) and unidentified worms (35%) in its diet.

6.5 RESOURCE UTILIZATION

Although the overall harvest of fish resources in the Barrow Arch is low, subsistence fishing is an important activity at the villages of Wainwright, Point Lay, and Point Hope (*see* Chapter 9). In summer, members of each community set gill nets along the shore to catch salmon and varying proportions of Arctic char, ciscoes, and whitefishes. In fall, villagers travel inland to fishing camps on the Kuk, Utukok,

TABLE 6.4—Catch per unit effort of fish caught by fyke net at various locations along Chukchi and Beaufort sea coastlines (fish/net-day).

	Chukchi Sea		Beaufort Sea			
	Point Lay (1983)*	Peard Bay (1983)†	Simpson Lagoon (1978)‡	Prudhoe Bay (1981)§	Sagavanirktok Delta (1982)‖	Eastern Beaufort Sea (1982)#
Anadromous fishes						
Least cisco	0.1	1	25	24	13	0.1
Arctic cisco	0	0	17	55	154	6
Arctic char	0.1	0	19	9	28	5
Broad whitefish	0	0	3	3	30	0
Others	5	1	16	?	1	0.1
Total	5	2	80	91	225	11
Marine fishes						
Arctic cod	183	408	390	180	148	80
Fourhorn sculpin	93	142	369	86	147	40
Others	191	39	14	?	3	0.2
Total	467	598	773	266	298	120

* Fechhelm *et al.* 1984.

† Kinnetic 1983.

‡ Craig and Haldorson 1981; large but brief run of Arctic cod omitted.

§ Griffiths and Gallaway 1982.

‖ Griffiths *et al.* 1983.

Griffiths 1983.

and Kukpowruk rivers and catch both anadromous and freshwater fishes. The lower Kuk River (Wainwright Inlet) is particularly well known as a place to catch rainbow smelt in winter. Quantities of fish harvested in subsistence fisheries are not well documented. There is no commercial fishery in the Barrow Arch, and sport fishing is limited to the occasional angler.

6.6 SENSITIVITY OF FISHES TO OCS DEVELOPMENT

Fish sensitivities or vulnerabilities to discharges and spills from OCS petroleum industry operations and accidents were examined according to the Minerals Management Service's definitions for degrees of impact:

Major impact: A regional population or species declines in abundance, distribution, or both to a point beyond which natural recruitment would not return it to its former level within several generations.

Moderate impact: A portion of a regional population changes in abundance, distribution, or both over more than one generation, but the regional population is not likely to be affected.

Minor impact: A specific group of individuals of a population in a localized area and over a short time period (one generation) is affected.

Negligible impact: No measurable change.

Overall, anadromous species were assigned an impact rating of minor to moderate; sensitive areas and times are estuaries and lagoons near salmon-producing rivers in late June–July, and nearshore feeding areas (Kasegaluk Lagoon, Kuk River) in late June–September. Potential impact on marine fishes was considered negligible, and most likely to occur in nearshore feeding areas in late June–September.

The rationale for these ratings is as follows.

6.6.1 Anadromous Species

Pink Salmon

The most vulnerable stage in the life history of pink salmon is when the smolts leave the rivers and reside in estuarine waters for several weeks prior to moving offshore. An oil spill in estuarine waters at this time could theoretically cause a large mortality to a river's production of pink fry, thereby reducing returns of adult salmon. It might take several generations for these small stocks of pink salmon to recover. In a regional sense, however, a reduction of pink salmon in one river would have only a minor to moderate impact because other streams in the Barrow Arch would continue to contribute pink salmon to the region. The impact to returning adult salmon is considered minor in that their migration might be delayed (by their avoidance of oil) but not prevented by an oil spill in their path. There is also a potential for impact of an oil spill on subsistence users if fish flesh becomes tainted by a petroleum flavor and is thus not desirable as food.

Char, Ciscoes, Whitefishes

Arctic char, ciscoes, and whitefishes were not common in the Barrow Arch in 1983, so impact on these species was rated minor. At this time we do not know whether the 1983 data are representative of conditions usually occurring along the northeastern Chukchi coastline, but there are additional reasons for assigning a relatively low impact rating to these species. Their life history characteristics demonstrate a resilience to short-term perturbations: (1) the fish are multiple-year spawners; (2) their fry remain in fresh water for a variable number of years before smolting, unlike pink salmon fry which smolt soon after emerging from the gravel; (3) other vulnerable life stages (spawning, egg incubation, overwintering) also occur in rivers away from coastal areas; and (4) migration patterns tend to result in different segments of the population being in different areas, thus an oil spill would not affect the entire population.

TABLE 6.5—Principal stocks of anadromous fishes in northeastern Chukchi Sea drainages (excluding incidental catches).

Drainage	Pink Salmon	Chum Salmon*	Rainbow Smelt	Least Cisco
Kugrua	×	×		
Kuk	×	×	×	×
Utukok	×			
Kokolik†	×		×	
Kukpowruk†	×			
Pitmegea†	×	×		
Kukpuk‡	×			

SOURCES: Smith *et al.* 1966; Bendock 1979; Hablett 1979; Bendock and Burr 1980; Craig and Schmidt 1982; Schmidt and Craig 1984.

* Stock sizes might be very small.

† No salmon observed during some years (Smith *et al.* 1966).

‡ About 2,600–5,000 spawners (Smith *et al.* 1966); stocks of pink salmon in other drainages are probably much smaller.

Rainbow Smelt

Although rainbow smelt may overwinter in the lower Kuk River and off the mouths of other rivers, fishes in these areas seem fairly safe from an oil spill because (1) they are mobile and could presumably avoid contaminated areas, and (2) the dispersal of oil under ice is limited and its solubility in cold water is low. Even the spawning migration up the river in springtime and spawning itself seem safe because the river discharge at breakup is large and would prevent significant amounts of oil reaching upstream areas. Therefore, the sensitivity of rainbow smelt was rated minor.

6.6.2 Marine Species

Marine species such as Arctic cod, herring, capelin, flatfishes, and sculpins are abundant and widespread, and are thought to accomplish their life history functions (e.g., spawning) over wide areas. The impact of an oil spill on these species would probably be small and difficult to measure and therefore was rated negligible. There is, however, a caveat associated with this rating. If the herring and capelin populations which spawn in the area represent isolated northern populations rather than a continuum with southern stocks, then an oil spill may have a moderate impact on the small northern stocks. Herring and capelin spawn along the shoreline during the open-water period. An oil spill might affect suitability of spawning habitats or cause mortalities among incubating eggs and newly hatched young-of-year.

6.7 INFORMATION NEEDS

1) Probably the most important information needed at present relates to the general limitations of the data base available for the Barrow Arch. It has been necessary to base much of this review upon data gathered during a single year (1983) of study; it is therefore necessary to determine whether this set of data is representative of annual conditions in the northern Chukchi Sea. Synoptic sampling efforts along the coast are needed to test some of the generalized findings presented in this chapter. Specific sampling locations should include the protected warm-water lagoons (Peard Bay, lower Kuk River, Kasegaluk Lagoon) and the exposed shorelines which are presumably characterized by a more cold-water

TABLE 6.6—Principal prey (≥ 10% by weight) of fishes from the Kasegaluk Lagoon area (KL), lower Kokolik River (KR), and offshore waters (O), summer 1983.

	Pink Salmon	Pacific Herring		Rainbow Smelt	Arctic Cod		Saffron Cod	Capelin	Arctic Flounder	Fourhorn Sculpin
Food Item	KL	KL	KR	KL	O	KL	KL	KL	KL	KL
Fishes										
Arctic cod	×			×		×				×
Unidentified	×	×	×							×
Mysids										
Mysis litoralis		×		×		×	×	×		
Mysis spp.					×					
Amphipods										
Onisimus litoralis	×									
Onisimus glacialis									×	
Ampelisca macrocephala					×					
Miscellaneous					×		×			
Isopods										
Saduria entomon							×		×	×
Copepods										
Calanus glacialis					×					
Temora sp.			×							
Cumaceans					×					
Polychaetes									×	

SOURCES: Fechhelm *et al.* 1984; Schmidt and Craig 1984.

marine environment (*see* Fig. 6.3). Specific topics to address include the biological significance of warm-water habitats to fish populations and the relative significance of anadromous fishes in this region.

2) More detailed oceanographic data are needed to understand the dynamic interaction between water masses in the nearshore zone and the effects of these hydrological changes on the distribution and abundance of anadromous and marine fishes.

3) Little is known about the population dynamics and basic biology of the marine forage species (cods, capelin, sand lance) which support large populations of marine mammals and seabirds.

6.8 SUMMARY

The northeastern Chukchi Sea (Barrow Arch area) is a transition zone between major water bodies (Arctic and Pacific oceans) and their associated fish communities. The fish fauna of the Barrow Arch is basically an Arctic one in that it is represented by a low diversty of species and a high degree of species overlap (75%) with the Beaufort Sea fauna. At the same time, the fauna is enriched by a continual input of southern species which probably disperse northward with the Alaskan Coastal Current. The contribution of the relatively warm and productive waters of the Bering Sea, together with other factors such as a longer open-water period and increased hours of sunlight, account for the apparently high standing stocks of marine forage fishes (Arctic and saffron cods, capelin, sand lance) which, in turn, support large populations of marine mammals and seabirds. The abundance and distribution of these consumers probably varies in direct relation to the availability of forage fishes. The pivotal trophic position of fishes in the marine food web is, perhaps, the most significant aspect of fish resources in the Barrow Arch.

In contrast, the fish resources of the Barrow Arch support no commercial fisheries although pink salmon and other species are harvested in small, but locally important, subsistence fisheries at Wainwright, Point Lay, and Point Hope. A primary reason for this overall low level of human utilization is that the Barrow Arch supports a relatively impoverished complement of anadromous fishes, the usual targets of most fishing efforts. For example, the catch per unit effort of anadromous fishes was only 1–45% of that occurring along the Beaufort Sea coast.

Reasons for the low numbers of anadromous fishes are twofold. First, streams flowing into the Barrow Arch are small and have only a marginal significance for fish production. Second, it is also postulated that the dispersal of anadromous species into the Barrow Arch from adjacent coastal regions may, at times, be impeded by "cold-water barriers" caused by the upwelling of cold water against the shoreline. This would apply particularly to species such as whitefishes and ciscoes which prefer warm coastal waters.

Most perceived impacts on fish resources in the Barrow Arch due to petroleum-related activities are judged to be of a localized and short-term nature. However, the area's small stocks of pink salmon might experience a moderate impact if their estuarine nursery areas are affected by an oil spill.

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7

Lower Trophic Levels

by Joe C. Truett

With contributions from A. C. Broad, K. H. Dunton, K. J. Frost, O. Holm-Hansen, and S. Pace. Meeting Chairman: D. M. Schell.

The physical environment of the Barrow Arch planning area strongly influences the structure and productivity of its lower trophic levels. The prevailing northeastward-moving currents that transport water and suspended materials from the Bering Sea to the Chukchi Sea have a strong effect on the area's invertebrate communities and general productivity. The wide, relatively flat and shallow (mostly <50 m) continental shelf and the substrate sediment type distributions exert a large measure of control over benthic communities. The sea-ice regime of retreat and advance, and the water clarity, strongly affect primary production. This chapter discusses the lower trophic levels—benthic invertebrates, zooplankton, primary producers, and other carbon sources—and evaluates important interactions among them and between them and the physical environment.

7.1 BENTHIC INVERTEBRATES

7.1.1 Shelf Infauna

The benthic infauna of the Chukchi Sea shelf in the Barrow Arch area has received almost no detailed investigation (Stoker 1981) despite the importance of the area for such benthic-dependent feeders as walruses and bearded seals (Lowry *et al.* 1980a). The work by Stoker (1981) is essentially the only intensive analysis available. As this author notes, data from stomach sample analyses of benthic-feeding marine mammals probably give a better notion of the abundance of some infaunal species than do results of benthos sampling programs by scientists.

In a series of Van Veen grab samples distributed throughout the eastern Chukchi and Bering seas, but concentrated in the Bering Strait region, Stoker (1981) found 472 species, 292 genera, and 16 phyla of invertebrates. Not all of these were found in the Barrow Arch, or even in the Chukchi Sea, but no regional breakdown was reported. Samples from the offshore shelf in the Barrow Arch area contained the greatest species index of diversity (Brillouin) of any stations in the two seas. In all samples from both seas, polychaetous annelids were most frequent, followed closely by bivalve molluscs, then gastropod molluscs and amphipods.

Stoker (1981) noted that the infaunal compositions of the two seas were, in general, similar; that there was a tendency for faunal assemblages to be repeated. A cluster analysis performed on 176 stations (Fig. 7.1) distinguished eight major station groups, or faunal assemblages (Fig. 7.2). As can be seen, there were two major faunal assemblages in the Barrow Arch area and the Chukchi Sea; both of these also occurred in the Bering Sea (which had several additional assemblages). The dominant species (density/biomass) in these two groups were: (1) (Group VI, Fig. 7.2) the polychaete *Maldane sarsi,* the echinoderm *Ophiura sarsi,* the sipunculid *Golfingia margaritacea,* and the bivalve *Astarte borealis*; and (2) (Group VIII, Fig. 7.2) the bivalves *Macoma calcarea, Nucula tenuis,* and *Yoldia hyperborea,* and the amphipod *Pontoporeia femorata.* The fauna, even in the Chukchi, appeared to be dominated by boreal Pacific forms, though high-Arctic forms were frequent in the northern extremes of the Barrow Arch area. Stoker suggests, and Lowry *et al.* (1980a) report, that diets of the infaunal feeders walrus and bearded seal contain higher percentages of burrowing bivalves than Stoker found; the Van Veen grab is a less effective sampler of those than are their

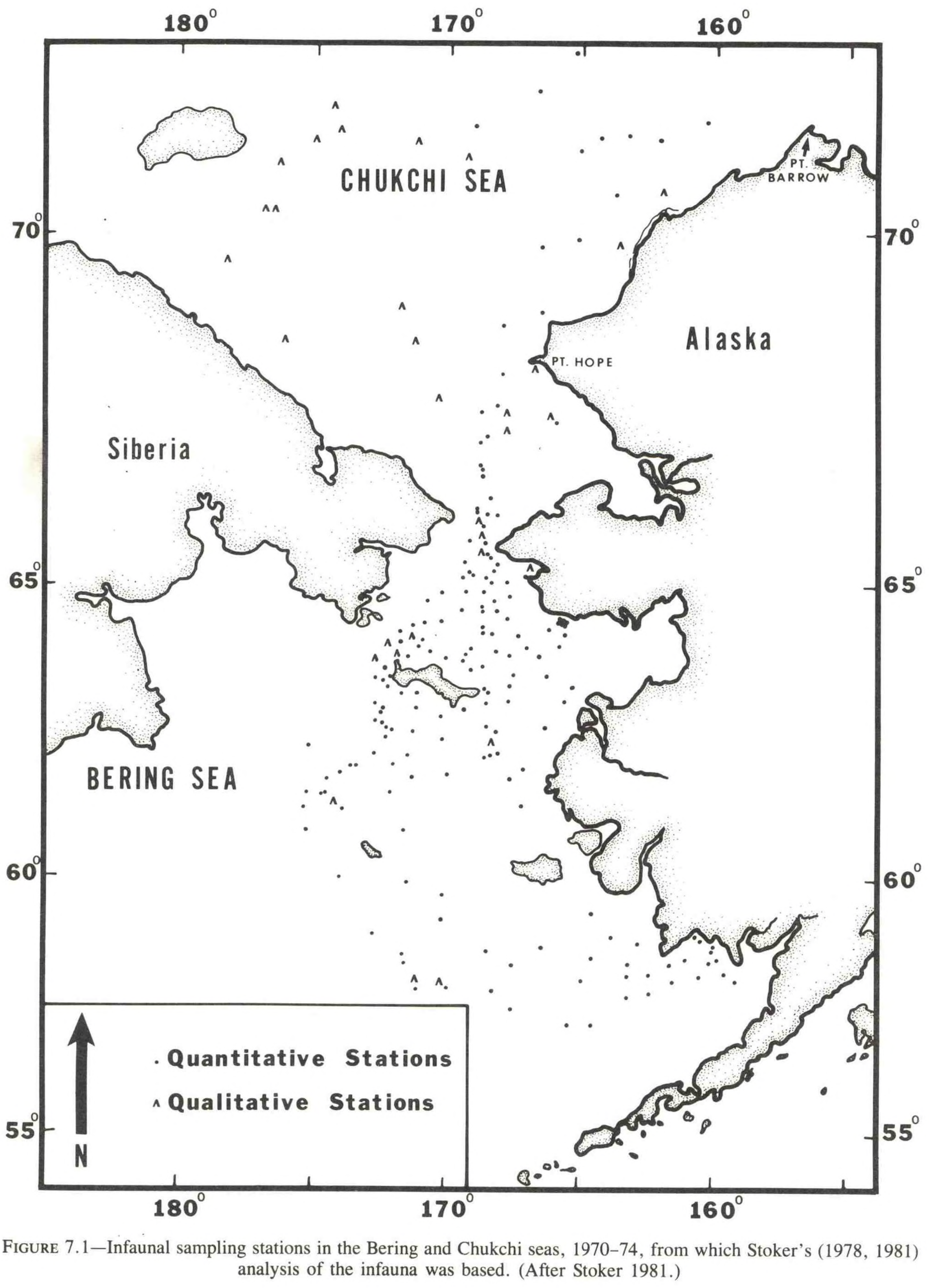

FIGURE 7.1—Infaunal sampling stations in the Bering and Chukchi seas, 1970–74, from which Stoker's (1978, 1981) analysis of the infauna was based. (After Stoker 1981.)

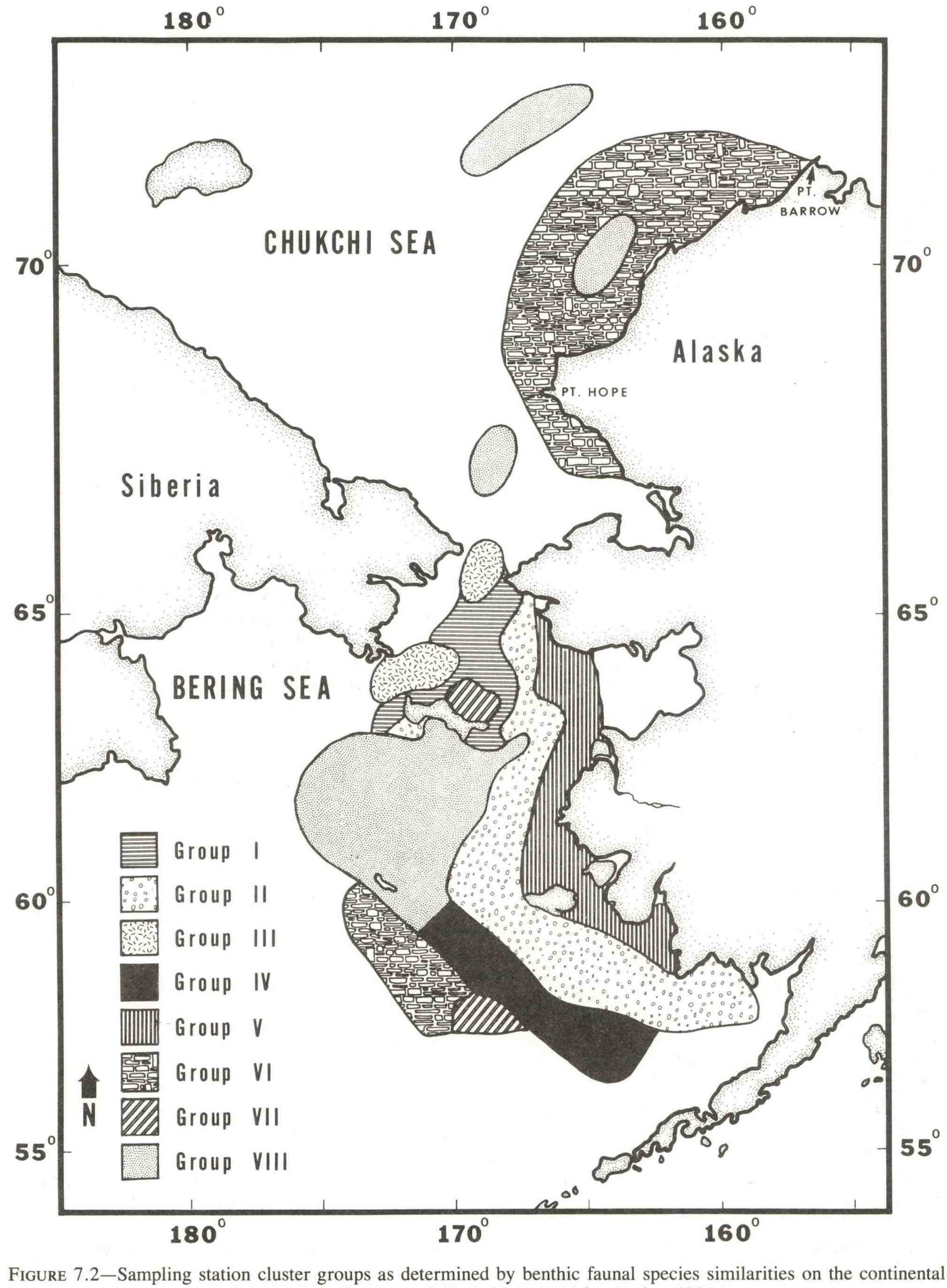

FIGURE 7.2—Sampling station cluster groups as determined by benthic faunal species similarities on the continental shelves of the Bering and Chukchi seas. (After Stoker 1981.)

mammalian predators. Lowry *et al.* (1980a) found that clams (primarily *Serripes* and *Spisula*) were biomass dominants in bearded seal, and probably walrus, diets in the Chukchi Sea.

Somewhat surprisingly, Stoker (1981) found that, when a faunal assemblage was found in both the Chukchi and Bering seas, its standing-stock biomass tended to be higher in the Chukchi. But within the Chukchi, the more northerly areas had lower standing stocks. Dunton (pers. comm.) used Stoker's (1978) data from the Chukchi Sea and Carey's (1979) data from the western Beaufort Sea to compare infaunal biomass estimates (both sampled with Van Veen grabs). He found 332.8 g wet weight/m² (range, 61–838 g/m²; *n,* 13) for the Chukchi, and 42.2 g/m² (range, 3–120 g/m²; *n,* 16) for the western Beaufort. Thus Chukchi Sea infaunal biomasses are probably somewhat higher than those of similar assemblages in the Bering Sea to the south, and probably much higher than those of the Beaufort Sea to the northeast. But as the Chukchi grades toward the Beaufort Sea, in the Barrow Arch, its infaunal biomass diminishes as might be expected based on the low observed biomass in the adjacent western Beaufort.

Stoker (1981) reports the infaunal system of the Chukchi Sea to be dominated by detritus feeders, with a considerable complement of filter feeders. He attributes this to the fact that the dominant system of currents tends to transport suspended material from the northern Bering Sea (into which the Yukon and Kuskokwim rivers discharge large volumes of material) into the Chukchi, where currents slow and suspended material settles. By the time this Bering Sea water reaches northern portions of the Barrow Arch, much of its suspended load has already settled in the southern and central Chukchi Sea; thus the biomass of detritus consumers (the infauna) diminishes to the north.

As noted above, the major predators of the infauna are walruses and bearded seals. A greater diversity of predators of infauna exists farther south in the Bering Sea; Stoker (1981) believes cropping by these predators to partially explain why infaunal biomasses are lower in the Bering Sea than in the southern and central Chukchi Sea.

The general abundance of Barrow Arch infauna appears to be regulated largely by food supply, as noted above. Lowry *et al.* (1980a) speculate that selected groups, particularly clams, might be depleted by predators (bearded seals, walruses). Species distributions, however, appear to be highly correlated with sediment type (Stoker 1981). As pointed out by this author, this correlation does not necessarily imply a causal relationship; sediment type may be determined by current velocity, water depth, or other variables to which the infauna respond directly or indirectly. Species distributions also appear to be affected by latitude and longitude; here again the correlations may not be cause-and-effect but rather mediated by such variables as temperature and primary productivity distributions.

7.1.2 Shelf Epifauna

The epifauna of the shelf waters of the Barrow Arch has, similar to the infauna, been scarcely studied. Frost and Lowry (1983) described epifauna collected in trawl samples in northerly portions of the area. Lowry *et al.* (1980a, 1980b, 1981) describe in some detail the epifaunal organisms in diets of selected marine mammals in the Barrow Arch and other parts of the Chukchi Sea. Lowry and Frost (1981) and Frost and Lowry (1983) list epifaunal species consumed by Arctic cod in the Chukchi.

Immediately outside the Barrow Arch, south of Point Hope in the southeastern Chukchi Sea, several investigators have studied the epifauna. These include Sparks and Pereyra (1966), Feder and Jewett (1978), and Wolotira *et al.* (1977). Given the scarcity of data from within the Barrow Arch area, these studies serve in some cases as useful references.

Frost and Lowry (1983), sampling with semiballoon otter trawls (34 tows), found 238 species or species groups (49 gastropods, 34 amphipods, 28 polychaetes, 27 echinoderms, 25 bivalves, 16 ectoprocts, and 14 shrimps) in samples from the northeastern Chukchi and western Beaufort seas combined (Fig. 7.3). (The data were not separated by area.) In comparison, Feder and Jewett (1978) found 171 species (11 phyla) in 70 otter trawl samples in the southeastern Chukchi Sea–Kotzebue Sound area. Although the results of the two surveys may not be directly comparable because of differences in trawls used, trawling techniques, duration of trawls, and variety of bottom types surveyed, there is an indication that epibenthic diversity may be higher in the more northerly area.

Frost and Lowry (1983) found echinoderms to be by far the most abundant invertebrates in the northern Chukchi and western Beaufort seas. Of the 27 species of echinoderms found, 15 were asteroids, 7 ophiuroids, and 1 each of echinoid, crinoid, and holothuroid. Ophiuroids were the most abundant species in the Chukchi Sea samples; *Ophiura sarsi* was the only species identified. It is noteworthy that Stoker (1981) found this species to be a dominant in the same region in his infaunal grab samples.

Interestingly, Frost and Lowry (1983), sampling from the northern Chukchi to the U.S.–Canadian border in the Beaufort Sea (Fig. 7.3), found the only epifaunal community type change in their samples to occur in the region between, approximately, 154° and 150° W. longitude. This location is some dis-

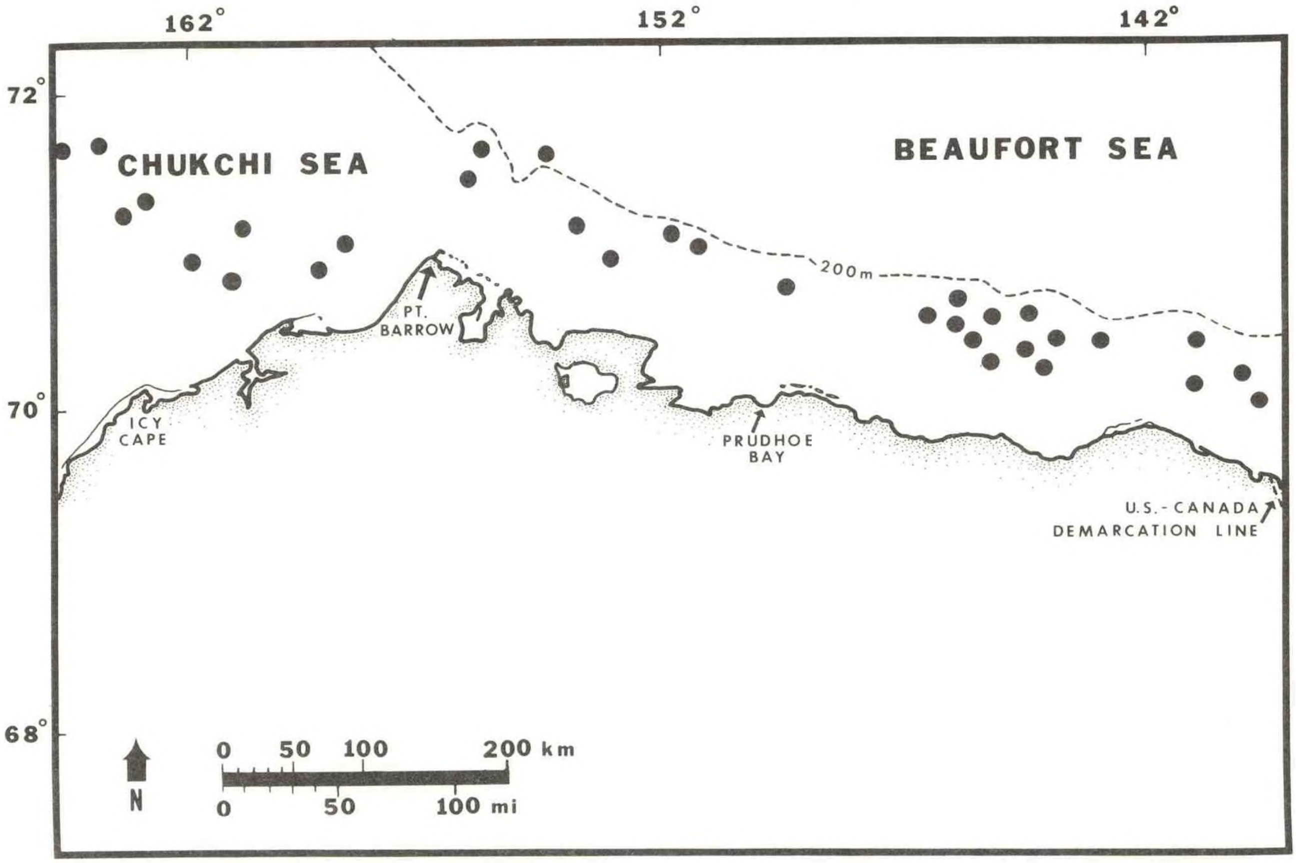

FIGURE 7.3—Benthic epifaunal sampling stations in the Chukchi and Beaufort seas, 1976–77, at which Frost and Lowry (1983) collected samples for analysis. (After Frost and Lowry 1983.)

tance into the Beaufort Sea, and not where the Chukchi and Beaufort seas meet, as one might expect. Reasons for the community change at this point and not elsewhere are unclear, but it is known that the Alaskan Coastal Waters (derived from the Bering Sea and dominating the Chukchi shelf) commonly intrude for some distance onto the western Beaufort shelf (Aagaard 1981). Stoker (1981) noted in his infaunal samples that organisms in the Chukchi shelf communities were mainly of Pacific (Bering) origin and included an appreciable component of high Arctic forms only in the far northern reaches near Barrow. He believed this dominance by Bering Sea fauna to be caused by the dominance of the Chukchi shelf by Bering water.

No estimates of shelf epifaunal biomass are available from the Barrow Arch than can be reasonably compared to estimates from adjacent seas. K. Frost (pers. comm.) believes that biomass levels may be similar between the northern Chukchi and Beaufort seas, but that the Chukchi has a higher percentage of the kinds of epibenthos used as food by vertebrates. For example, the Chukchi shelf seems to have a relatively great proportion of crustaceans in particular, whereas the Beaufort shelf has a large proportion of echinoderms—basket stars, ophiuroids, crinoids, holothuroids, and others—not consumed in quantity by vertebrates.

In trophic importance, the Chukchi Sea epifauna has a further advantage over that of the Beaufort: the Chukchi shelf is wider than that of the Beaufort Sea and not generally covered with ice (and thus inaccessible to some predators) to the extent found in the Beaufort. The epifauna in the Barrow Arch is of importance particularly to bearded seals (shrimps, brachyuran crabs), ringed seals (amphipods, shrimps), gray whales (ampeliscid amphipods), and Arctic cod (benthic amphipods, shrimps, mysids) (Lowry *et al.* 1981). Though no studies of food chains of epibenthic communities in the Barrow Arch are available, studies of similar communities elsewhere (Feder and Jewett 1978) and of infaunal prey of some of the epibenthic species (Stoker 1981) suggest that the community is detritus dependent.

Factors regulating the distribution and abundance of Barrow Arch epibenthos are not known in detail, but existing data provide some suggestions. Frost and Lowry (1983) report several observed associations between species or species groups and substrate type and water depth, especially among the shrimps. As noted by Stoker (1981) for infauna, these associations may not necessarily indicate cause-and-effect relationships. For example, organisms may prefer the colder water that is found at greater depths, or may find detrital food more abundant where the substrate is mud (because organic and fine-grained sediments tend to settle out together). In the Chirikov Basin, the abundance of ampeliscid amphipod prey of gray whales may be correlated with sediment grain size and sorting variables, and to some extent with caloric and carbon content of sediments (Thomson 1983).

7.1.3 Nearshore and Lagoon Benthos

This section addresses benthic communities in the nearshore zone, within approximately the 20-m depth contour. Intensive studies of invertebrates in this zone are scarce. Two studies have been sponsored by OCSEAP in recent years, one as a littoral benthic survey (Broad *et al.* 1978) and one as part of an integrated lagoon study at Peard Bay (complete results not yet available). Studies have been conducted northeast of the Barrow Arch in the western Beaufort Sea (Feder and Schamel 1976; Broad 1977; Carey 1978; Broad *et al.* 1979; Griffiths and Dillinger 1981) and south of Point Hope in the Chukchi Sea (Sparks and Pereyra 1966; Blaylock and Erikson 1983; Blaylock and Houghton 1983).

Given the scarcity of studies in the nearshore zone of the Barrow Arch, results of studies in the nearshore zones of adjacent areas should be examined where applicable. Studies by Broad *et al.* (1978) of the epibenthic and infaunal communities of nearshore areas of the Beaufort and Chukchi seas are the only ones available that suggest which adjacent areas (western Beaufort or Chukchi south of Point Hope) most nearly represent nearshore invertebrate communities of the Barrow Arch. In their studies of the 0–20-m depths of the Beaufort and 0–2-m depths of the Chukchi, these authors made relevant conclusions as follows:

1) The fauna of the Beaufort littoral and nearshore (0–20-m depths) and the Chukchi littoral (0–2-m depths) north of Point Hope are similar in species, diversity, and biomass.
2) South of Point Hope, the Chukchi littoral fauna is much richer in species and biomass than are comparable zones to the north. Twenty-three genera found south of Point Hope were rare or absent from samples north of there.
3) The Beaufort nearshore (2–20-m depths) is a refugium from which the littoral region (0–2-m depths) is repopulated annually. The fauna of the nearshore region is intermediate in species diversity and biomass between the littoral and close offshore region (beyond 20-m depths).
4) The principal forms of the Beaufort littoral and nearshore regions are gammarid amphipods (three species), isopods (one species), mysids (mainly one species), oligochaete worms (unknown species), chironomid larvae (unknown species), polychaete worms (two species), bivalve molluscs (one species), and priapulid worms (one species).

Implications of these conclusions are that, because fauna of the littoral zones of the Beaufort and Chukchi seas north of Point Hope are similar, and littoral and nearshore fauna of the Beaufort are similar, then the infauna and epifauna within 20-m depths in the Barrow Arch are similar to those in similar depths in the Beaufort Sea. Fauna south of Point Hope are considerably more diverse, and biomasses are greater. Tables 7.1 and 7.2 show comparisons between Barrow Arch and south Chukchi fauna and between Barrow Arch and western Beaufort fauna, respectively.

Broad *et al.* (1978) had the following to say about these comparisons:

> The species of the principal genera common to the Beaufort and Chukchi are: *Cyrtodaria kurriana, Chironomus* sp., enchytraeid worms of unknown species; *Gammarus setosa, Halicryotus spinulosus, Mysis relicta, Myoxocephalus quadricornis, Onisimus litoralis, Saduria entomon, Scolecolepides arctius, Pygospio elegans,* and *Pontoporeia affinis.* South of Point Hope, we found 23 principal genera that were not abundant in or absent from the north Chukchi. Among these the bivalve molluscs, *Cryptomya* sp., *Mytilus edulis, Mysella* sp. (an undescribed species); the shrimp *Crangon septemspinosa*; several species of *Neomysis*; and several species of chironomid larvae are particularly abundant in our samples and probably characteristic.

Dropnet samples (four stations) taken in summer 1983 in Peard Bay yielded eight species of annelids, four species of molluscs, and an undetermined number of arthropods. Benthic diver core samples in Peard Bay (three stations) yielded 26 species of annelids, 6 species each of gastropods and bivalves, and an undetermined number of arthropod species. Detailed reports of these analyses are not yet available (S. Pace, pers. comm.).

The trophics of the nearshore epifauna is much more important to the sustenance of coastal vertebrates than is that of the infauna, judging from studies in the Beaufort Sea (*see* Griffiths and Dillinger 1981; Craig and Haldorson 1981; Johnson and Richardson 1981). These authors found that marine and anadro-

TABLE 7.1—Comparison of number of species, species diversity indices, and biomass of littoral benthic and epibenthic fauna of the Chukchi Sea north and south of Point Hope, 1976.

	Chukchi Sea North		Chukchi Sea South			
	s^2	d.f.	s^2	d.f.	F	p
Benthic fauna:						
Number of species	6.927	15	39.038	25	5.636	0.002
Species diversity index	0.200	15	0.612	25	3.060	0.02
Biomass	15.705	15	89.473	25	5.697	0.002
Epibenthic fauna:						
Number of species	10.916	17	80.443	22	7.369	0.002
Species diversity index	0.209	17	0.448	22	2.144	0.40
Biomass	209.757	17	257.074	22	1.226	>0.40

SOURCE: Broad *et al.* 1978.

mous fishes, waterfowl, and shorebirds that fed in the nearshore zone ate mainly epifauna (mysids, amphipods) rather than infauna. No equivalent studies are yet available from the Chukchi Sea. Many of the epifauna are detrital feeders; some (*Gammarus setosa*) ingest terrigenous peat and others presumably feed on plankton that has settled to the bottom. Some (e.g., *Onisimus litoralis*) are at least partly carnivorous, feeding on other invertebrates (Broad *et al.* 1978). The principal infauna (mostly bivalves) are presumably detrital and filter feeders.

Too few data are available to establish patterns of abundance or distribution of invertebrates in a coastwise direction. Perpendicular to the coast, however, distributional zones are marked, influenced largely by annual ice regimes. The littoral zone (Broad *et al.* 1978) is notably scarce in infauna, presumably because most of these areas freeze to the bottom in winter. But species are similar to those found in depths greater than 2 m. Most epifauna exhibit seasonal changes in abundance distributions, becoming scarce in the littoral zone in winter and spring and repopulating it in summer (Broad *et al.* 1978). Apparently the deeper areas of the nearshore act as overwinter refugia (Broad *et al.* 1978; Griffiths and Dillinger 1981).

Too few data are available to determine whether invertebrate communities within coastal lagoons are different from those outside lagoons. Circumstantial evidence from studies in the Beaufort Sea suggests this to be probable (*see* Griffiths 1983; Truett 1983). The relative abundance of some organisms (mysids, amphipods) in Peard Bay (S. Pace, pers. comm.) appears to be lower than that reported by Broad *et*

TABLE 7.2—Comparison of number of species, species diversity indices, and biomass of littoral benthic and epibenthic fauna of the Beaufort Sea, 1975, and the Chukchi Sea north of Point Hope, 1976.

	Beaufort Sea		Chukchi Sea			
	s^2	d.f.	s^2	d.f.	F	p
Benthic fauna:						
Number of species	18.984	50	6.927	15	2.741	0.10
Species diversity index	0.294	50	0.200	15	1.470	>0.40
Biomass	22.438	50	15.705	15	1.429	>0.40
Epibenthic fauna:						
Number of species	41.274	50	10.916	17	3.781	0.002
Species diversity index	0.308	50	0.209	17	1.474	0.40
Biomass	47.088	50	209.757	17	4.455	0.02

SOURCE: Broad *et al.* 1978.

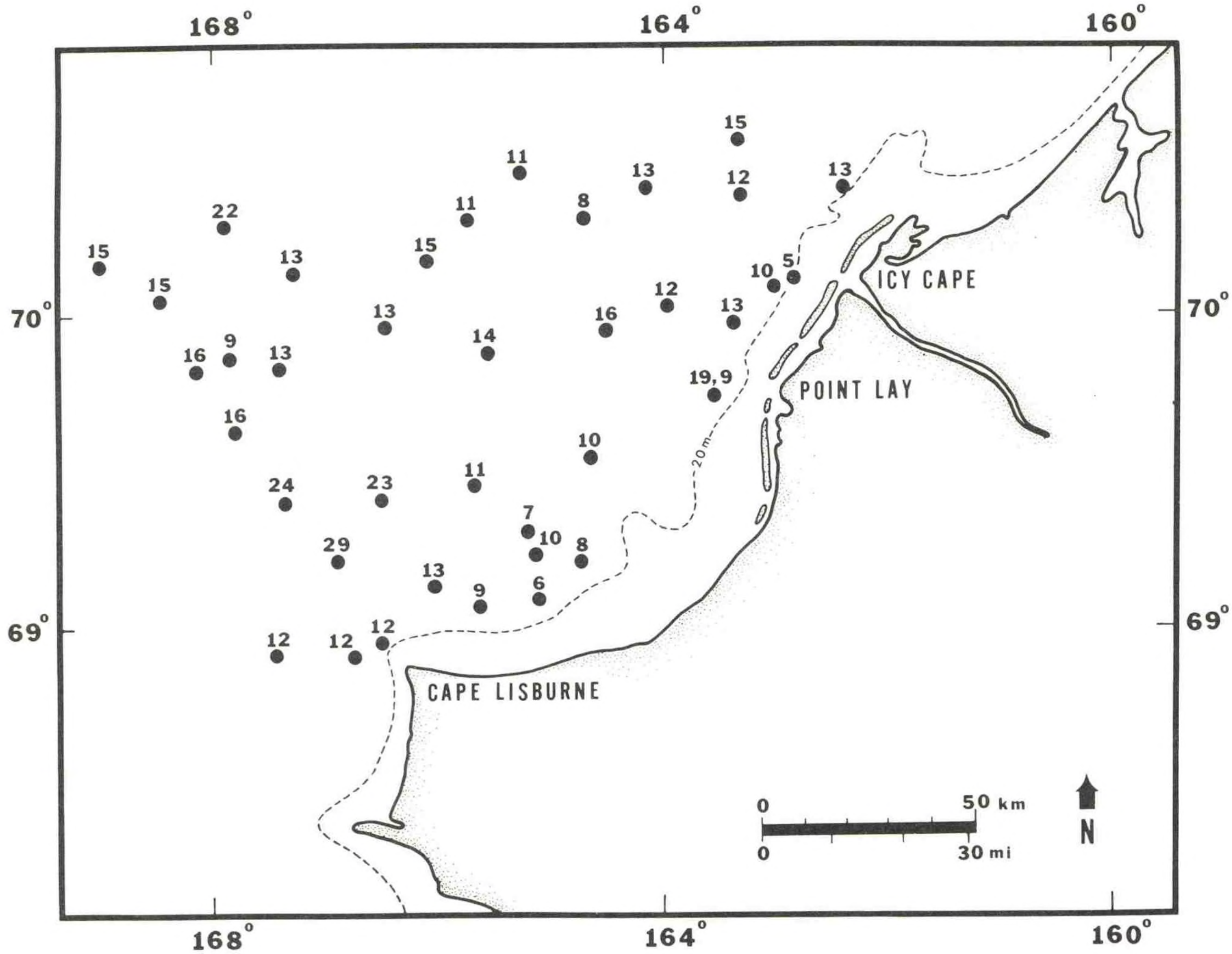

FIGURE 7.4—Zooplankton sampling stations and number of species collected at each station by vertical net tows in the Chukchi Sea in 1970. (After Wing 1972.)

al. (1978) for the north Chukchi coast in general.

7.2 ZOOPLANKTON

The level of investigation of water-column zooplankton in the Barrow Arch area is low, similar to levels of investigations of other invertebrate groups in the area. Two important surveys, however, provide a general picture of the zooplankton community in the open-water period. In September and October 1970, zooplankton were collected at a number of locations in the Barrow Arch from shipboard by vertical net tows, surface net tows, and Isaacs-Kidd midwater trawl (Wing 1972). In September and October of 1980, the U.S. National Marine Fisheries Service and the TINRO Institute of the U.S.S.R. conducted a cooperative sampling effort, including zooplankton sampling, aboard the Soviet whale hunting ship *Razyashchii* (Coyle 1981).

Figure 7.4 shows locations, and number of species at each location, where quantitative samples (vertical tows with #0-mesh plankton net) for zooplankton were taken by WEBSEC-70 in September and October 1970 (other types of sampling were qualitative only). Crustacean arthropods (mainly copepods) dominated the samples; other taxa represented included Coelenterata, Nematoda, Annelida, Mollusca, and Tunicata. Abundance distributions of calanoid copepods showed generally greater densities in the southerly reaches of the area sampled, with particularly high densities off Cape Lisburne (Fig. 7.5) (Wing 1972).

Coyle (1981) described zooplankton concentrations encountered during the cruise of the *Razyashchii* as generally quite low, with the calanoid copepod populations (the dominant group) consisting mainly of *Pseudocalanus* spp. and *Oithona similis*. The larger calanoids of the genera *Metridia* and *Calanus*, com-

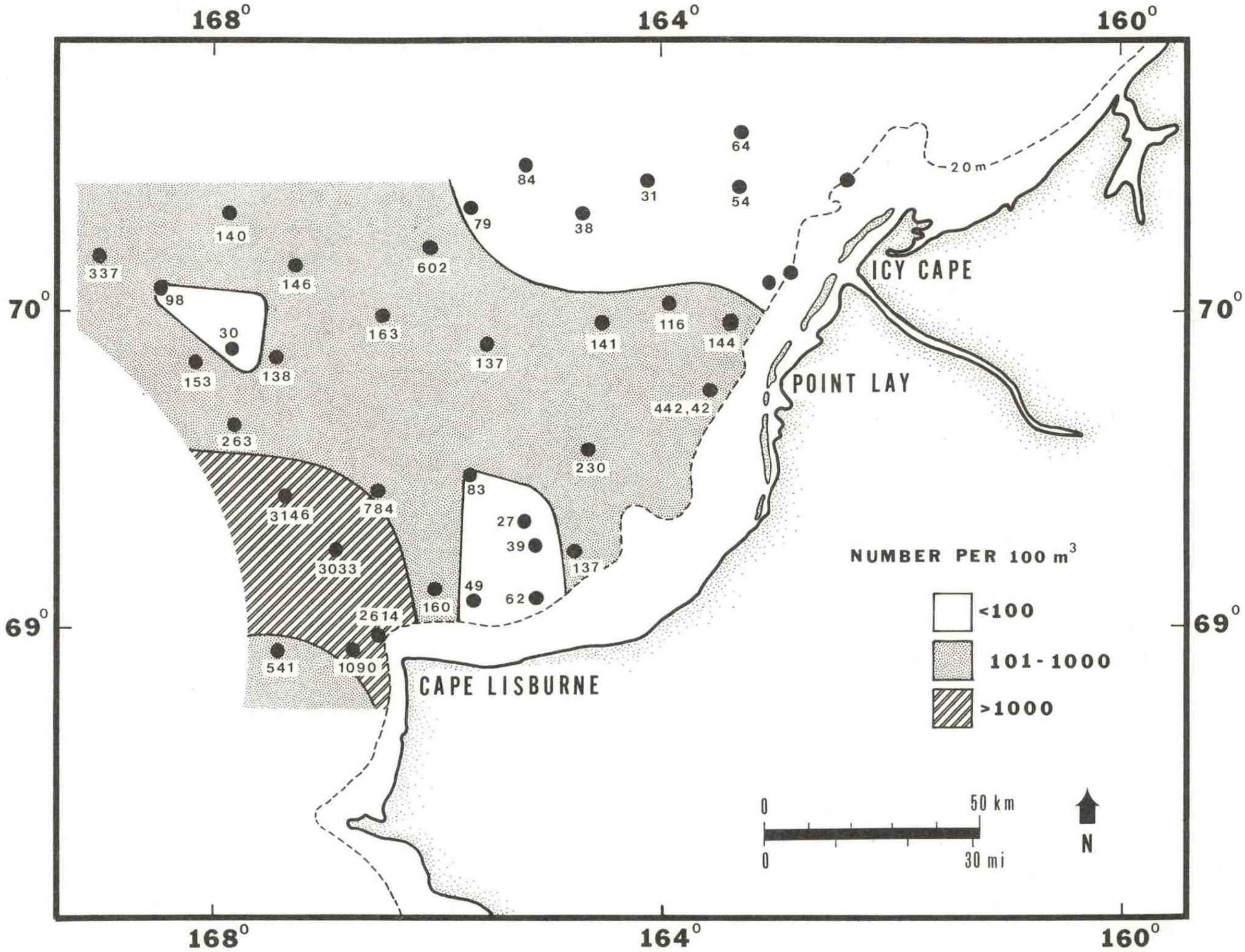

FIGURE 7.5—Densities of calanoid copepods collected by vertical net tows at stations in the Chukchi Sea in 1970. (After Wing 1972.)

mon in places in the Beaufort Sea, were conspicuously absent.

Several important comparisons of zooplankton populations of the Chukchi Sea with those of the adjacent Bering and Beaufort seas have been made. These comparisons are based on analysis of zooplankton and on evaluations of diets of zooplankton predators. Discussions of these comparisons and their implications follow.

Coyle (1981) points out that zooplankton populations he sampled in the Barrow Arch were quite low in abundance (compared to zooplankton communities of more southerly areas) and were composed primarily of the same calanoid copepod species reported from the southeastern Bering Sea. He characterizes these species as mainly small individuals, inefficient phytoplankton grazers, and poor sources of food for whales and other large consumers of zooplankton. In contrast, zooplankton populations in the Beaufort Sea near Barter Island contain an abundance of calanoid copepod species in which individuals are large (Frost and Lowry 1981); these populations appear capable of consuming the majority of primary productivity in the water column (Coyle 1981) (*see* Table 7.3).

The trophic implications of these regional similarities and differences among zooplankton communities are several. Where zooplankton communities are composed of inefficient grazers, logic suggests that much of the phytoplankton production would sink to the bottom and be consumed by benthic communities. Relatively large biomass and production levels of benthos in the Bering and Chukchi seas support this hypothesis. Further logic would suggest that consumers of invertebrates might feed more on benthic invertebrates in areas where more primary production feeds benthic communities, and on water-column invertebrates that were large and efficient grazers (i.e., carnivores would feed on the most abundant food source).

Some examples support this line of reasoning. The Beaufort Sea is the prime feeding habitat for bowhead whales (zooplankton feeders); the Bering and southern Chukchi seas support relatively large numbers of gray whales (benthos feeders). (Table 7.3 shows dominant zooplankters and food habits of the primary cetacean consumers of invertebrates in the two seas.) Lowry and Frost (1981) found that foods of Arctic cod in the *extreme northern* Chukchi Sea and the Beaufort Sea (samples from the two seas not separately analyzed) were primarily calanoid copepods of the genera *Calanus* and *Euchaeta,* and *Apherusa glacialis,* a water-column and under-ice amphipod. Arctic cod foods in the northern Bering Sea were primarily benthic forms. They did not investigate cod foods in the majority of the Barrow Arch area.

In summary, it has been reported that zooplankters of most of the Barrow Arch are mainly small, inefficient grazers, and relatively unimportant in vertebrate food chains. In these ways they appear to be similar to zooplankton in adjacent southerly waters. They are different from zooplankton communities of the Beaufort Sea, which consist mainly of large, efficient grazers and are very important components of the marine food web. (These Beaufort Sea communities may extend into extreme northerly areas of the Barrow Arch.) Reasons for the differences in composition of these major types of zooplankton communities are not known. Some investigators have suggested that each of the two communities is associated with a separate water mass: the Bering Sea water, which typically dominates the Barrow Arch, reaching to Barrow and beyond, and the Beaufort Sea water (Carey 1978).

7.3 PRIMARY PRODUCTION, NUTRIENTS, AND CARBON SOURCES

7.3.1 Macrophytes

Macroalgal densities and community structure within macroalgal beds are virtually unknown in the Chukchi Sea. It is known, however, that macroalgae communities are more widespread in the Chukchi Sea than they are in the Beaufort Sea. Although the total carbon contributed to the Barrow Arch food web by macroalgae is undoubtedly still very small in comparison to that contributed by phytoplankton, they may be significant locally in shallow, coastal habitats.

Attached beds of algae are typically associated with substrates of gravel, cobbles, or boulders. Figure 7.6 demonstrates this by depicting substrates and associated biota in the Barrow Arch coastal region between Skull Cliff and Wainwright. Similarly thorough investigations for other portions of the coast have not been made.

The region of the Barrow Arch between Icy Cape and Barrow has been more thoroughly surveyed for the occurrence of macroalgal communities than has that between Icy Cape and Cape Lisburne (Dunton, pers. comm.). Figure 7.7 is a compilation of reported occurrences of such features in this coastal region. Figure 7.8 shows locations of coastal kelp beds (composed primarily of *Laminaria saccharina* and *L. solidungula*) as currently known in the Barrow Arch.

The presence and characteristics of attached algal communities appear to be strongly associated with substrate type, water depth, and presumably, water clarity. Degree of protection from ice action is also presumably important. Gravel, cobble, or boulder substrates in shallow waters that are relatively free from gouging by moving ice appear to offer the best habitats for macroalgae in the Barrow Arch.

7.3.2 Phytoplankton

The level of investigation of primary production by phytoplankton in the Barrow Arch has been sufficient only to indicate approximate productivity levels and general trends. Similar to production in Arctic seas elsewhere, production in the Barrow Arch takes place both within the lower portions of the ice cover and in the water column. The productivity levels, in general, appear to be higher (in terms of amount of carbon fixed annually) than those in the Beaufort Sea to the northeast, but lower than in the Bering Sea to the south (D. Schell, pers. comm.).

Nearly all the phytoplankton species reported for the Chukchi Sea are widespread in high latitudes (Carey 1978). Some species are characteristic of the sea-ice, or epontic, community; others are typical of the water column community; and some are found in both habitats. Only one, *Nitzschia grunowii,* appears to be a major component of both epontic and pelagic habitats (Carey 1978).

Horner and Alexander (1972) studied production of ice algae in the Chukchi Sea near Barrow. They concluded that, although the algal layer in the ice was restricted to a few centimeters, its potential contribution to the total primary productivity was considerable. Hameedi (1978) also postulated that the contribution of sea-ice algae to productivity in the Chukchi Sea could be substantial for a short period in summer. He found that higher amounts of chlorophyll *a* occurred in the subsurface water near the ice edge than in open water. But he concluded that the stay of these plankton cells in the water column was probably not long following ice melt, and thus the contribution to total productivity was temporally very limited.

Compared to the Beaufort Sea, measurements of primary productivity in the Chukchi Sea are much

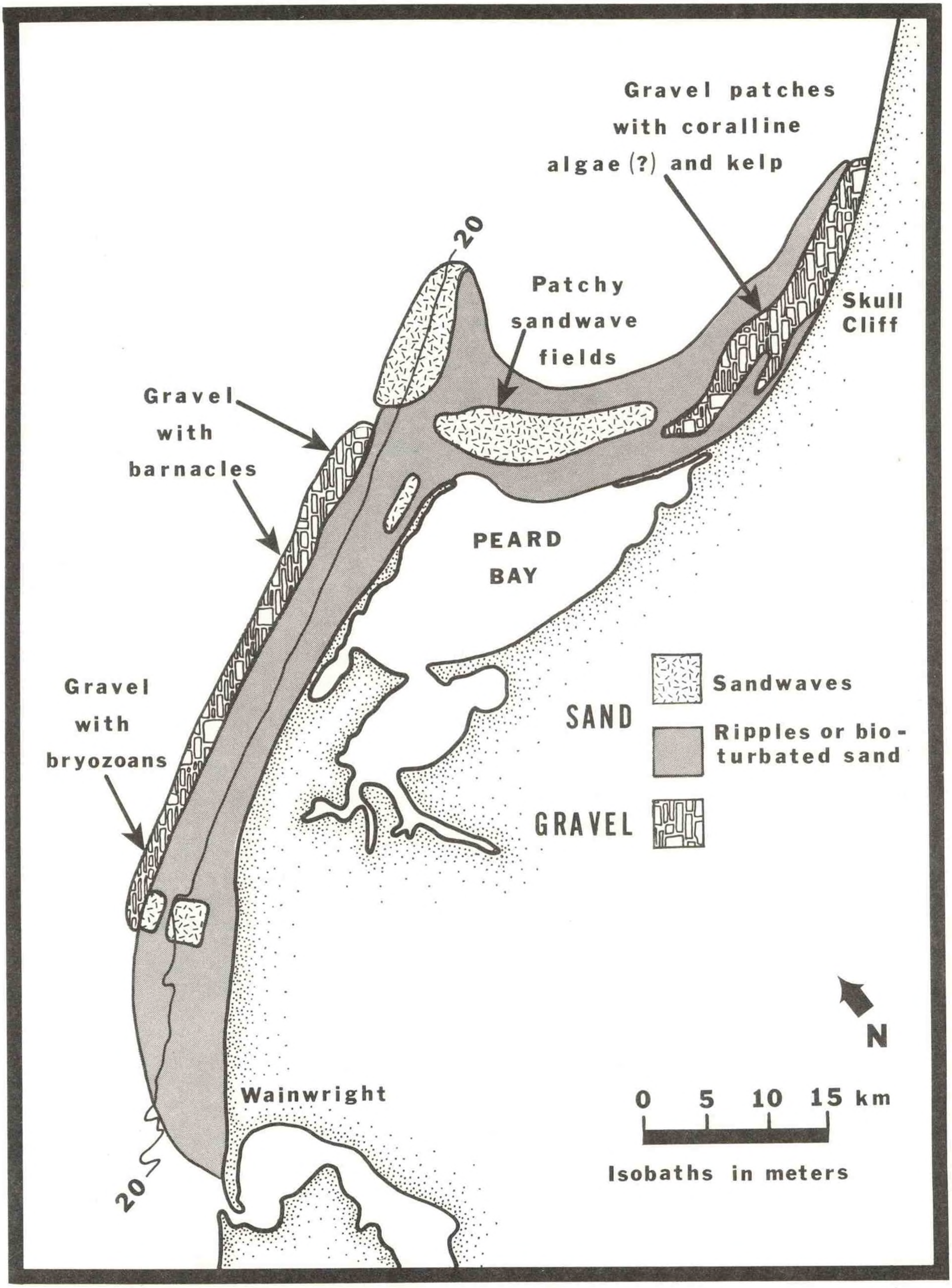

FIGURE 7.6—Substrates and associated biological features in the coastal region between Skull Cliff and Wainwright. (After Phillips *et al.* 1982.)

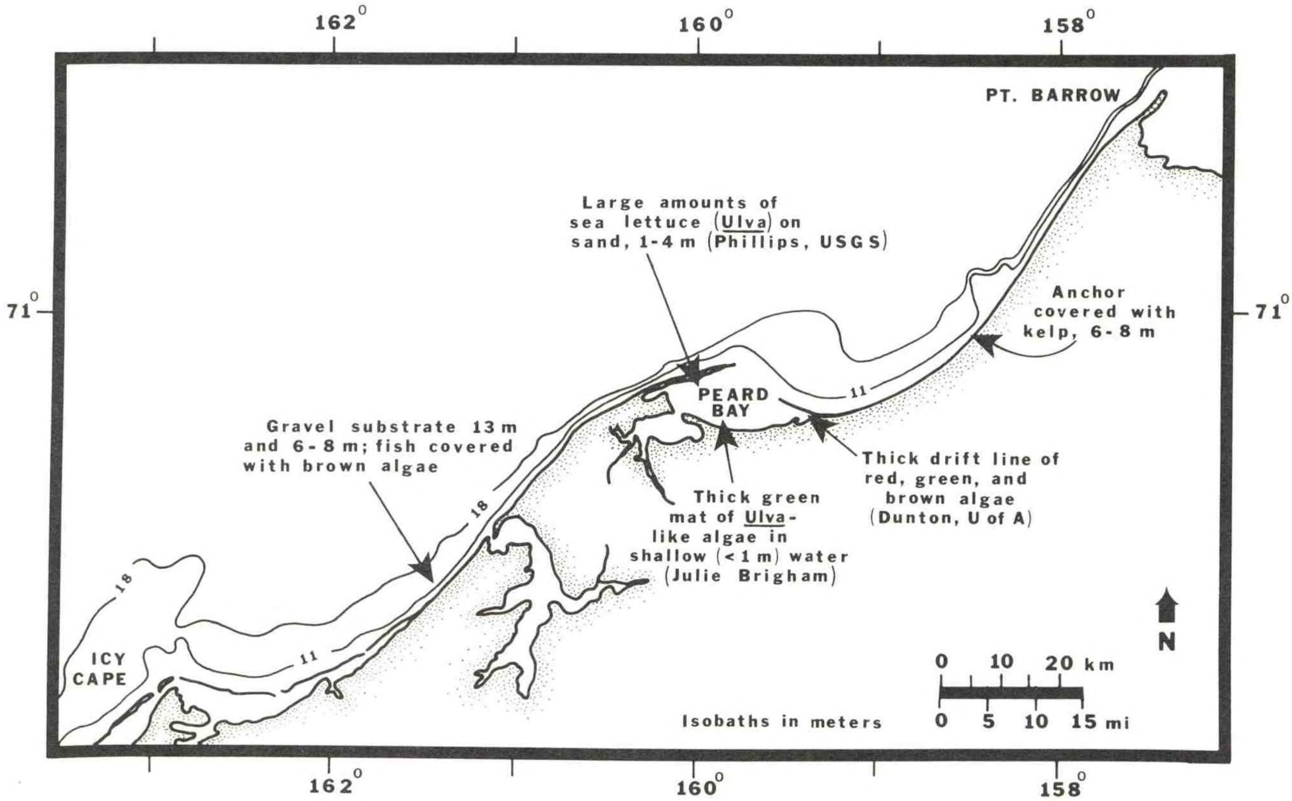

FIGURE 7.7—Reported observations of algal communities between Icy Cape and Point Barrow. (Provided by K. Dunton.)

more extensive on both an areawide and temporal scale. Nevertheless, the presence of ice cover during early summer has limited most measurements to the open-water season and very little information is available on either ice algae productivity or water column production beneath seasonal sea ice in the April through June period.

To provide an overview of regional annual primary production for the Barrow Arch synthesis, D. Schell projected seasonal phytoplankton productivity at arbitrarily chosen locations along transect lines in the Chukchi Sea, using a combination of techniques (detailed in Schell *et al.* 1982). He used NOAA satellite imagery and Navy-NOAA Joint Ice Center data from 1978 to 1980 to determine the average extent of ice cover throughout the "average" summer (Fig. 7.9), and literature data for instantaneous ^{14}C-uptake rates. Light attentuation and water column productivity were taken from the literature or estimated from his under-ice data obtained in the

TABLE 7.3—Species of zooplankton recurrently present in vertical plankton tows and in vertebrate foods of dominant cetaceans in the Chukchi and Beaufort seas.

	Chukchi Sea	Beaufort Sea
Dominant zooplankton species	*Pseudocalanus* *Oithona similis*	*Pseudocalanus* *Calanus hyperboreus* *Calanus glacialis* *Iaschnovia tolli*
Dominant prey of whales	*Ampelisca macrocephala* (90%) Gammarid amphipods (10%)	*Calanus hyperboreus* *Thysanoessa raschii*

SOURCE: Data from Coyle (1981) and Frost and Lowry (1981). Table provided by K. Dunton, Univ. Alaska Inst. Water Resources.

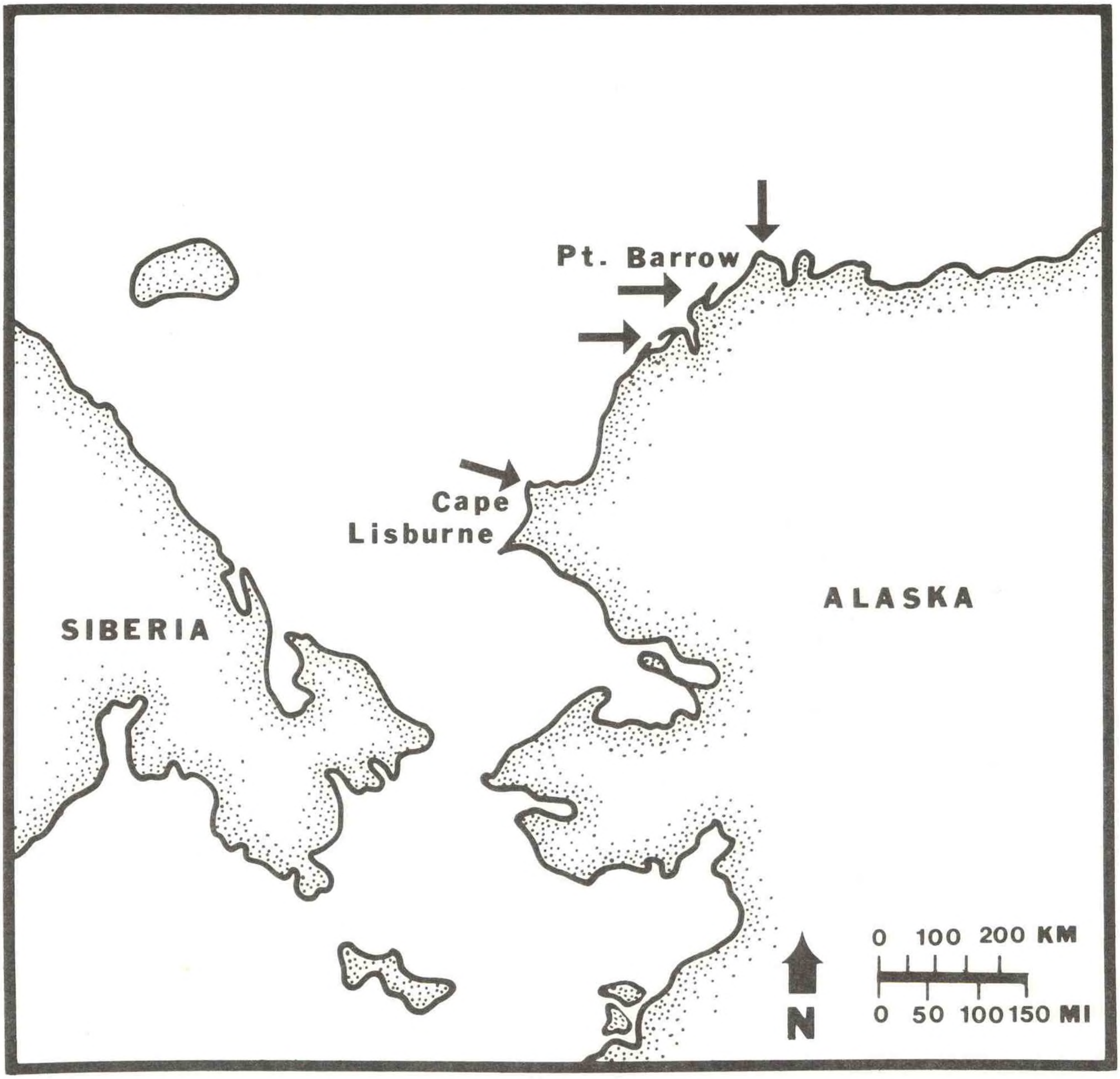

FIGURE 7.8—Known locations of kelp beds (arrows) in coastal waters of the Barrow Arch. (Provided by K. Dunton.)

Beaufort Sea. Primary productivity at the beginning of the season was estimated by extrapolating the new May measurements from the Chukchi Sea (Dawson 1965). Annual productivities calculated for each of the transect points were then contoured to produce Figure 7.10.

The contours in Figure 7.10 are only generally indicative in magnitude and area as to the productivity of the region. The highly variable ice and cloud cover will cause large departures from the situation as shown in a given season. Also, the productivity estimates will undoubtedly be altered as more data become available. But the general patterns and magnitudes of primary production shown are a reasonable approximation of the carbon inputs via primary production in this regional ecosystem.

As discussed earlier, the trophic routes taken by phytoplankton production are probably different between the Chukchi and Beaufort seas, but similar between the Chukchi and Bering seas. In the Chukchi Sea most phytoplankton cells probably sink, to be consumed by the benthic community, because the water-column grazers are relatively inefficient (Coyle 1981; D. Schell, pers. comm.). It is clear, though, that pelagic primary production, and not macroalgae or epontic (ice) algae, contributes the majority of

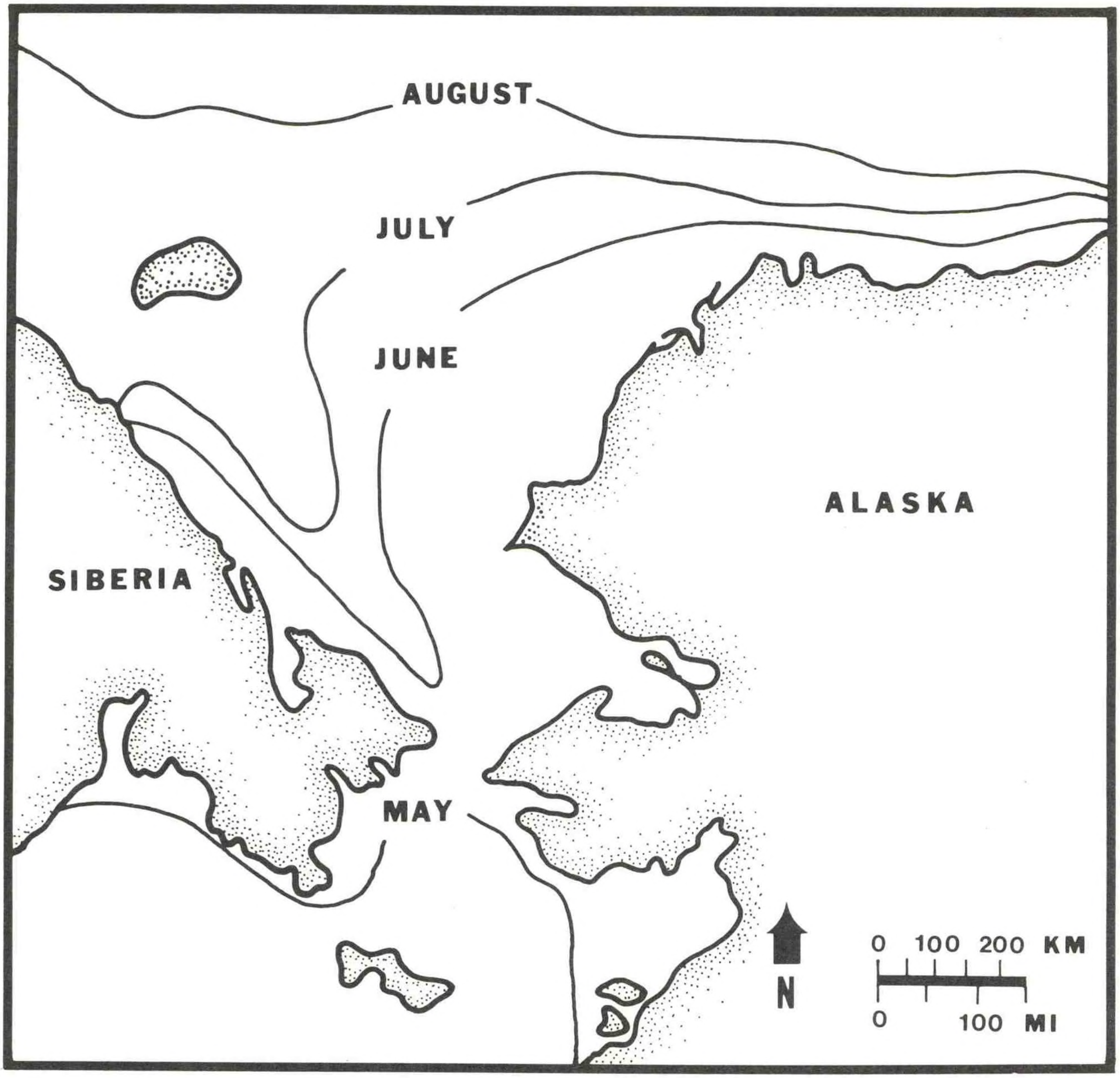

FIGURE 7.9—Average ice edge locations in the Chukchi Sea, 1978–80, from satellite imagery. (Provided by D. Schell.)

carbon to the marine food web (Schell, pers. comm.).

The distributional levels of primary productivity in the Chukchi Sea are probably influenced most strongly by water-column nutrient availability and the availability of open water. Hameedi (1978) found that surface primary productivity in the water was nitrogen-limited at most stations he sampled in the Chukchi Sea. The ultimate source of most Barrow Arch nutrients is presumed to be the Bering Sea, and possibly the major Bering Sea rivers such as the Yukon and Kuskokwim (McRoy *et al.* 1983). Thus nutrient availability in the Barrow Arch would, in general, probably decrease with distance northward.

In terms of spatial variability in productivity caused by variability in sea ice cover, the most obvious feature (in addition to seasonal patterns of sea ice ablation) is the Chukchi Polynya. As discussed in other chapters of this report, this area is open in early spring when other parts of the Barrow Arch are ice-covered. Consequently, total annual primary production may be higher here than elsewhere. Data to confirm this, however, are not available (D. Schell, pers. comm).

7.3.3 Nutrients and Carbon

Several factors relating to the biological produc-

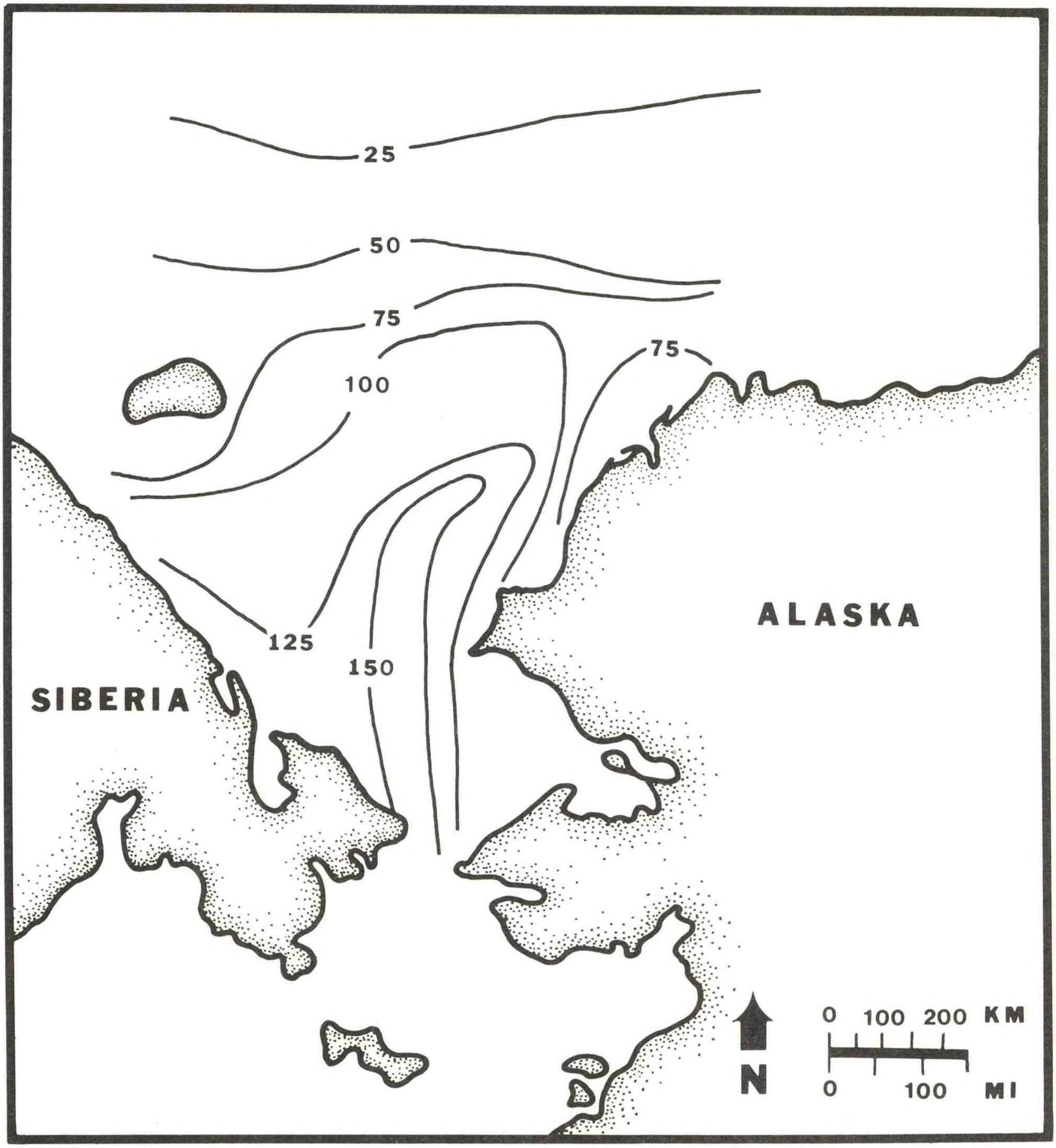

FIGURE 7.10—Synthesized estimates of annual phytoplankton primary production (g C/m^2) in the Chukchi Sea, 1978–80. (Provided by D. Schell.)

tivity of the Barrow Arch region have been discussed. We have seen that many of the vertebrates depend on a benthic food web, as opposed to the situation in the Beaufort Sea, where the pelagic food web is of primary importance. This benthic food web base appears to be productive partly because the zooplankton grazers of water-column productivity are inefficient, allowing much of the production to settle to benthic environments. The annual phytoplankton production itself, which is probably the major contributor to the food base, is intermediate between that of the Beaufort and Bering seas.

Two questions remain: (1) From whence comes the nutrient supply that drives primary production in the Barrow Arch region? and (2) Does carbon fixed outside the Barrow Arch contribute significantly to fueling the food chain?

Nutrients supplied from the land between Point Hope and Barrow are probably limited in abundance, because the land surface drained and the consequent stream input to the Barrow Arch are relatively small. Further, we have seen that the shelf water masses in the area are relatively rapidly moved northward and replaced with water from the Bering Sea to the south. Thus the nutrient supply to the system would seem to come mainly from the south.

McRoy *et al.* (1983) postulate two main sources of nutrients for the northern Bering Sea and (because northern Bering water dominates the Chukchi) for the Chukchi Sea in general. These are (1) nutrients from the deep North Pacific waters that are brought up over the Bering Sea shelf break and eventually supplied to nearshore shelf areas by diffusion (mainly December–April), and (2) nutrients supplied by the fluvial input of the Yukon River (primarily April–November). Regardless of the ultimate source, it seems clear that the nutrients supplied to the Chukchi Sea via Bering Strait largely regulate the productivity of the Barrow Arch shelf area. It is further likely that a significant fraction of this supply comes from discharge of the Yukon (and perhaps Kuskokwim) River (*see* Truett *et al.* 1983). Given this southerly source, the generally diminishing level of primary productivity observed as one proceeds northward through the Barrow Arch appears logical.

Organic carbon appears to be relatively abundant in benthic environments of the Chukchi Sea, in comparison to that in the adjacent Beaufort and north Bering seas (Fig. 7.11) (McRoy *et al.* 1983). Reasons for this have been already discussed: the Chukchi is a depositional, or settling, environment for organic material transported through Bering Strait and, in addition, is an area where much of the carbon from water-column production settles. Whether the major source of this benthic carbon is *in situ* primary production or organic material delivered from the Bering Sea is not known.

Nutrient and carbon sources for shallow coastal and lagoon waters are less clear. It is probable that, where large streams empty into semi-enclosed water bodies, terrigenous sources are important. But also, as discussed in Chapter 2, exchange of nearshore and marine waters augmented by upwelling may contribute nutrients and carbon to nearshore environments.

7.4 POTENTIAL EFFECTS OF OCS DEVELOPMENT

Potential adverse effects of oil and gas development on the lower trophic levels include impacts on benthos, zooplankton, and primary producers. Potential levels of impact are evaluated according to the scale of impact levels used by the Minerals Management Service, Anchorage, Alaska, as follows:

Major impact:	A regional population or species declines in abundance, distribution, or both to a point beyond which natural recruitment would not return it to its former level within several generations.
Moderate impact:	A portion of a regional population changes in abundance, distribution, or both over more than one generation, but the regional population is not likely to be affected.
Minor impact:	A specific group of individuals of a population in a localized area and over a short time period (one generation) is affected.
Negligible impact:	No measurable change.

In addition to impacts at the various lower trophic levels, there is potential for those impacts to have secondary effects at the vertebrate consumer level (e.g., predators are affected by changes in prey populations). The potential for these secondary impacts to occur is noted where applicable.

Among the benthos, the infauna is generally the most vulnerable to impact; the epifaunal organisms are relatively mobile and may be able to avoid localized effects of pollutants or seafloor disturbance. Potential effects on the benthos include consequences of oil or drilling mud and fluid introduction and the effects of subsea dredging or filling such as might accompany pipeline burial or dock construction. We have seen (Chapter 2) that the extent of sea floor that would be affected by drilling muds or cuttings, or even by major oil spills, is very small in comparison to the total shelf area. The same would hold true for the effects of trenching and filling of the sea floor. Thus a very small percentage of the infauna, and an even smaller percentage of the epifauna, would probably perish. The level of impact would be minor according to the above scale. The effects on the consumers of the benthos would undoubtedly be negligible.

Potential impacts to zooplankton populations are somewhat analogous to those on benthos populations in terms of extent in time and space and effects on consumers. Oil spills, drilling muds and cuttings, and water-column turbidities caused by seafloor disturbance would all potentially have localized adverse effects on zooplankton. But the number of organisms affected would be very small when compared to the total Barrow Arch populations, and the level of im-

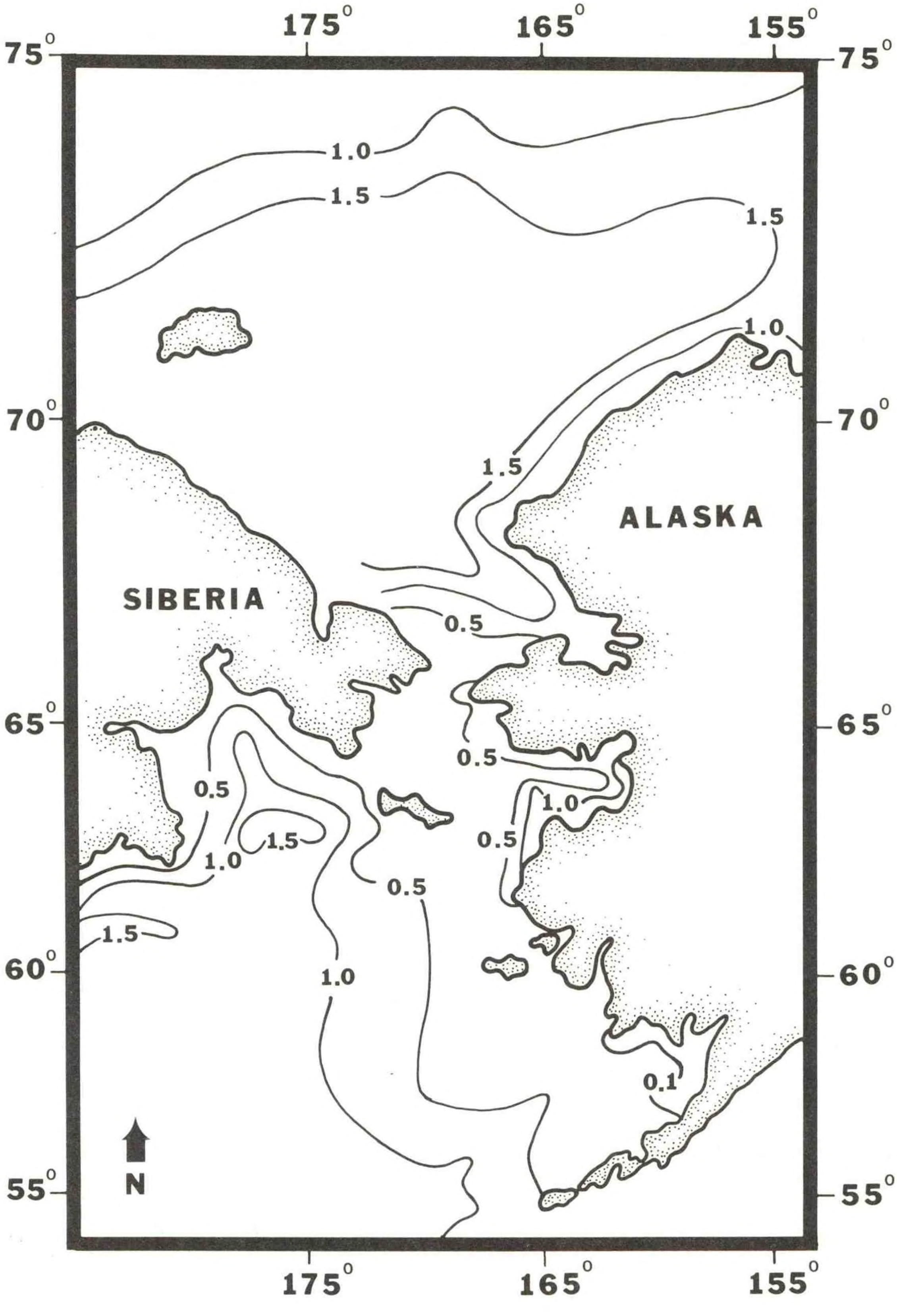

FIGURE 7.11—Distribution of organic carbon (% dry weight) in the surface sediments of the Bering and Chukchi seas. (After McRoy *et al.* 1983.)

pact would be minor. The effects on consumers of zooplankton would be negligible.

The major primary producers (in terms of their contributions to the food web) are ice algae and phytoplankton. Reductions in total ice algae production, potentially caused by oil under ice or by development-spawned sediments becoming incorporated into the ice, would be very small in comparison to the annual total epontic production. Likewise, the potential for pollutants to appreciably diminish the total annual water-column production is essentially nonexistent. Thus the actions related to development might cause local reductions in ice algal or water-column productions, and the impacts would be minor. The effects on total annual production, or on the consumers of that production, would be negligible.

Impacts of oil and gas development on macroalgal communities would depend on what proportion of seabed containing macroalgae came under the influence of oil, drilling muds and cuttings, or suspended sediments caused by development. Very little is known about the probable responses of the macroalgae to these kinds of disturbance but they would probably be proportional to the sediment or pollutant concentration. Should such discharges contact algal beds, some local changes in algal densities and perhaps community structure are likely to occur (K. Dunton, pers. comm.), but the extent of such effects cannot at present be predicted. The level of effects would range from minor to major. Because vertebrates of interest in the lease area are not known to depend on macroalgae, no important food-chain effects of disturbance on these communities are likely, and effects would be negligible.

In summary, localized effects on benthos, zooplankton, and primary producers can be expected where oil, drilling muds and cuttings, and increased turbidities occur as a consequence of oil and gas development. But the numbers of organisms killed and consequent reductions in productivity would be very small in comparison to those in the entire Barrow Arch area, and the level of impact would be minor. In the case of macroalgae, there is a potential for somewhat greater levels of effect (minor to major) because the macroalgal communities are so localized in space. The effects of such impacts on consumers of any of these food-chain components would almost certainly be negligible.

7.5 INFORMATION NEEDS

Because the potential for adverse effects on vertebrates as a consequence of oil and gas related impacts on food chains is so remote, research in lower trophics assumes a secondary priority. Should macroalgal beds be deemed an important resource of themselves (i.e., as a unique community), additional surveys to determine their distribution in the Barrow Arch area and their community structure are recommended. Otherwise, the main priorities for research appear to be at the consumer level, where chances for appreciable adverse impact seem considerably greater, and where the public interest is more intently focused.

7.6 SUMMARY

The lower trophic levels of the Barrow Arch have received little study. Existing data suggest that they are strongly influenced in their structure and productivity by oceanographic, meteorological, and topographic characteristics of the region. Major food webs appear to be primarily benthic. *In situ* primary production and organic detritus transported from elsewhere (primarily the Bering Sea) settle and are consumed by benthic invertebrates, which in turn are cropped by benthic-feeding vertebrates. Pelagic food chains are relatively insignificant in terms of biomass and energy flow. Important aspects of the lower trophic components of this ecosystem, and the factors that affect these components, are as follows:

1) Infaunal invertebrate biomasses over most of the shelf of the Barrow Arch are appreciably higher than those of the Beaufort Sea, and probably higher than those in most areas of the Bering Sea. The biomass seems to diminish with distance northward in the Barrow Arch.

2) The benthic infauna appears to be dominated by detritus feeders, with a considerable complement of filter feeders. It is dominated by boreal Pacific forms.

3) The major predators of the infauna are walruses and bearded seals; cropping by these predators may have severely reduced standing stocks of infauna, particularly clams, in some areas.

4) The shelf epifauna in the Barrow Arch is dominated (in biomass) by echinoderms. The community appears to be similar to that of the extreme western Beaufort Sea east of Barrow, but different from that of the central and eastern Beaufort Sea.

5) The epifauna is particularly important in the diets of bearded and ringed seals, gray whales, and Arctic cod. The epifauna itself appears to be dominated by detritus-feeding forms.

6) The nearshore and littoral invertebrate communities (those within the 20-m depth contour) appear to be similar in general composition, biomass, and diversity to those of the American Beaufort Sea, but different from those south of Point Hope in the Chukchi Sea.

7) The nearshore zone provides food to coastal vertebrates mainly as epifauna (mysids, amphipods,

isopods), if data from the Beaufort hold true. Data from the Chukchi to support this presumption are not yet as conclusive as are those from the Beaufort.

8) Zooplankton communities in the Barrow Arch, similar to those in the Bering Sea, are dominated by copepod species that are small individuals and poor phytoplankton grazers. In consequence, much of the phytoplankton settles to be consumed by benthic organisms, and vertebrates eat mostly benthic invertebrates instead of zooplankton. This contrasts to the situation in the Beaufort Sea (and perhaps the extreme northern part of the Barrow Arch) where zooplankters are large individuals, efficient grazers, and important foods for vertebrates.

9) Macroalgal communities in the Barrow Arch area are more common than they are in the Beaufort Sea; however, the major contributor to carbon fixation is still the pelagic and epontic (under-ice) phytoplankton.

10) Annual levels of phytoplankton production generally diminish from south to north. Most phytoplankton production probably sinks to the bottom before it is consumed, because the water-column grazers (zooplankton) are inefficient.

11) The Barrow Arch benthic environment is rich in organic carbon, presumably contributed mainly by water-column primary production and by detritus transported from elsewhere.

12) The major source of nutrients for the Barrow Arch, and of carbon from outside the system, is the Bering Sea, with large inputs from the Yukon and Kuskokwim rivers.

13) Potential adverse effects of oil and gas development on all lower trophic levels, except perhaps on macrophyte communities, are seen to be inconsequential. Impacts on vertebrate consumers caused by impacts on lower trophic levels will almost certainly be negligible; direct impacts on vertebrates are much more likely. In consequence, research aimed at lower trophic levels is deemed low priority.

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8

Coastal Ecosystems and Sensitivities

by Joe C. Truett

With contributions from T. Albert, A.C. Broad, P.G. Connors, M.A. Fraker, K.J. Frost, J. Geiselman, C. George, B. Gill, D. Herter, J. P. Houghton, J. Imm, B. F. Morris, T.K. Newbury, S. Pace, D. M. Schell, D. Schmidt, A.M. Springer, and S.T. Zimmerman. Meeting Chairman: J. C. Truett.

During the course of the Barrow Arch Synthesis Meeting, a brief session was convened to discuss coastal ecosystems, their important components and processes, and the sensitivities of these components and processes to adverse impact from OCS development. This chapter is largely a presentation of those discussions; additionally, it relies on information presented in Chapters 2–7 of this report.

The coastal zone was arbitrarily defined to include those coastal areas in which the biota is under marine influence, out to approximately the 20-m depth contour. The important aspects of coastal ecosystems were seen to be species of immediate interest to society, the food webs and habitat factors important to those species, and the ways in which the species and their food webs and habitats are vulnerable to the effects of oil and gas development. The discussions of coastal ecosystems that follow address in sequence (1) the major species or species groups important to people, (2) the nature of their supporting food webs, (3) their important habitats, and (4) the places of greatest sensitivity of the species, the food webs, and the habitats.

8.1 IMPORTANT SPECIES

At the outset of workshop discussions, a list of species commonly using the coastal zone and generally recognized to be important to the public and to decision-makers was developed through group consensus. This list included (1) marine mammals (bearded seal, walrus, spotted seal, beluga whale, gray whale, ringed seal, and bowhead whale), (2) birds (alcids, kittiwakes, gulls, terns, eiders, oldsquaws, shorebirds), (3) anadromous fishes (salmon, char, ciscoes, whitefishes, boreal smelt), and (4) marine fishes (Arctic and saffron cod, capelin, sand lance, herring, sculpins, and flounders). For each species (or species group if use of the coastal zone was similar among several species), discussions addressed distribution in time and space, functional use of the coastal zone (e.g., feeding, migration), important food webs, and physical factors influencing distribution and use. Factors limiting or regulating abundance and distribution of the species were identified if possible. These aspects of coastal zone use are presented in the following accounts.

8.1.1 Mammals

Bearded Seal and Walrus

Bearded seals and walruses are the primary vertebrate consumers of benthic invertebrate infauna in the Barrow Arch. They exist in relatively large numbers in the planning area in late summer and fall, and are important to subsistence economies. Though most of their populations at any one time may be seaward of the 20-m isobath, the nearshore populations are particularly important to subsistence hunters. Additionally, the nearshore zone offers a few special habitats not found elsewhere.

These species are adapted to shallow shelf waters (< 100 m deep) that have a partial, but not complete, ice cover. The Barrow Arch is prime habitat from July through September or October, during which time ice is commonly present but does not offer a continuous cover. Both species generally move southward to the Bering Sea in fall, returning to the Chukchi in early summer at the onset of ice breakup. A few bearded seals and walruses overwinter in the

Barrow Arch at sites that offer open-water leads throughout winter.

The Barrow Arch is used by these species primarily as feeding habitat. Further, they appear to require haulout areas in order to successfully occupy and forage in the area. All of the bearded seals and most of the walruses haul out on floating ice, but a few hundred walruses annually use the coast near Cape Lisburne as a haulout site in summer.

Both species are benthic feeders. In the coastal zone, as elsewhere, bivalve molluscs form the preponderance of the walrus diet. Bearded seals as well feed heavily on molluscs, but they also consume large amounts of crangonid shrimps, brachyuran crabs, and sculpins. Both species are largely restricted in their feeding to the relatively deep portions of the nearshore waters; molluscs, and to some extent the epifaunal prey of the seals, are relatively scarce in the shallows where ice action and great variations in water quality make the habitat less suitable.

Ice conditions, abundance of suitable prey, and suitable water depths are important habitat requirements of both these species. The Barrow Arch nearshore zone has favorable ice conditions (broken ice with open water) between early summer and mid-fall. Its water depths are suitable throughout, but prey, especially molluscs, are probably not particularly abundant in the shallower areas.

Potential population regulating factors for these species in the Chukchi Sea include hunting and food scarcity. In the coastal zone in particular, bearded seals are a major subsistence species for local residents; human use of the walrus resource appears to be presently on the decline. Bearded seals do not appear to be currently affected by food shortages, but walruses do. It is speculated that in recent years large populations of both species may be drastically reducing the supply of bivalve molluscs.

Ringed Seal

Ringed seals are abundant year-round in the Barrow Arch. The Chukchi Sea shelf offers some of the best ringed seal habitat in Alaska. Because they normally occupy areas where ice is present, they are least common in the nearshore zone between July and October, when ice-free conditions are most persistent.

Ringed seals use the coastal zone most intensively in winter and spring, when shorefast ice covers most of the nearshore environment. Shorefast ice is their preferred breeding and birthing habitat. Large numbers of the summer population of the Chukchi Sea, and probably of the Beaufort Sea as well, use this habitat between November-December and April-May.

In the nearshore zone as elsewhere, ringed seals are primarily pelagic feeders. They probably eat mainly Arctic cod and secondarily gammarid amphipods, and shrimps, if their diets in the nearshore zone of the Beaufort Sea are indicative. They in turn are consumed by polar bears and subsistence hunters.

Presence of shorefast ice in winter is of primary importance to ringed seals in the nearshore zone. Whether their abundance or productivity in the shorefast ice zone is further affected by food supply is not known. Predation by polar bears and subsistence hunters may help regulate their population levels in coastal areas.

Spotted Seal

Spotted seals are nearing their northerly distributional limits in the Barrow Arch, though a few are found farther northeastward in the Beaufort Sea. They are relatively abundant in the northern Chukchi Sea from breakup to freeze-up (approximately July through October), when they congregate in the coastal waters.

Spotted seals move northward from the Bering Sea in early summer to assemble and haul out along the Chukchi coast in lagoons and bays and near river mouths. In the Barrow Arch, major concentrations recur at Kasegaluk Lagoon (2,000–3,000 seals), at the mouth of the Kuk River near Wainwright, and at the mouth of the Kugrua River in Peard Bay. Kasegaluk Lagoon has the largest number; major haulouts here are Utokok and Akoliakatat passes. Their main uses of these coastal localities are hauling out on sand beaches and feeding.

In these coastal localities, spotted seals presumably eat Arctic and saffron cods, capelin, smelt, and anadromous fishes, if one may judge from their diets elsewhere. No food habits data on spotted seals are available from the Barrow Arch.

As with bearded and ringed seals, ice strongly influences spotted seal use of Barrow Arch habitats. They are excluded from the area in winter by the presence of heavy ice. They move into the coastal areas as ice moves out, and vice versa.

Factors that may limit their abundance and distribution along the coast in summer include food availability and subsistence hunting. That spotted seals assemble near river mouths and in lagoons and bays suggests that they may be congregating where fish are locally abundant (*see* Chapter 6). Though their importance to subsistence hunters is low relative to that of bearded and ringed seals (*see* Chapter 9), they are relatively accessible in summer and hunting could potentially have a strong effect on them.

Beluga Whale

Components of two populations of beluga whales use the nearshore zone of the Barrow Arch. A "spring" population migrates through the area in spring on their way to spend the summer in the Canadian Beaufort Sea. A "summer" population occupies coastal waters in midsummer (*see* Chapter 4).

The spring population of belugas moves northward from the Bering Sea and passes through the nearshore Barrow Arch in April and May. The whales' transit through the area follows the open water of the Chukchi Polynya and is rapid; whether they linger to feed is not known. This same population passes back through the northern Chukchi Sea in fall (September–October) on its way south, but may remain much farther offshore at this time because open water is much more extensive.

The summer belugas (2,000–3,000 individuals) congregate in coastal waters of the Barrow Arch, arriving from the south in mid- to late June and remaining until late July to mid-August. They seem to remain most of the time in shallow waters just outside lagoons and bays; occasionally they are encountered inside lagoons. They are observed most frequently in the vicinity of major passes in Kasegaluk Lagoon—Kukpowruk, Utokok, Akoliakakat—within 0.5–1.8 km of shore. They are also frequently seen near Icy Cape and occasionally at Wainwright and Peard Bay.

The summer belugas appear to use the coastal zone for calving, feeding, and perhaps for molting. Young are frequently seen with adults. The sites where they congregate are good locations for belugas to find anadromous fishes in relative abundance (*see* Chapter 6). It is thought by some that the relatively warm waters of the lagoons and bays may offer a benign calving and molting environment.

It is not known what limits the abundance of belugas. They appear to congregate in relatively warm coastal waters to calve and feed in summer, usually near river mouths or lagoons where fishes are relatively abundant. Perhaps the limits on availability of such sites, plus the effects of harrassment and hunting by subsistence users at these summering locations, tend to regulate their distributional abundance. It has been reported that fewer belugas use the Barrow Arch area now than did historically (K. Frost, pers. comm.).

Gray Whale

Gray whales are relatively widely distributed in summer in shelf waters of the northern Bering Sea and the Chukchi Sea. Though they are seen relatively frequently in the deeper coastal water, no pattern to their use of the Barrow Arch has been observed.

Gray whales occur throughout the Barrow Arch from early July through August. Several hundred to a few thousand are thought to use the northern Chukchi Sea. Though distributed in both nearshore and offshore areas of the shelf, they seem to be more commonly observed within several tens of kilometers of shore.

Calving to the south in Mexican lagoons, they use the Barrow Arch primarily for feeding. Because their primary food, ampeliscid amphipods, are benthic and may prefer small sediment sizes (fine sands, muds), the whales likewise may regulate their feeding distribution according to substrate characteristics. Factors that may limit their currently growing population in the area are speculative.

Bowhead Whale

Approximately 3,500–4,000 bowhead whales, essentially the entire known population, pass through the deep nearshore waters of the Barrow Arch in spring on their way to the Canadian Beaufort Sea. They pass through again in fall, but seldom if ever occupy the nearshore zone at that time.

In April and May, bowheads follow the Chukchi Polynya, just seaward of the shorefast ice, from Point Hope to Barrow. It is suspected that they do not feed in transit. The habitat factor that is vitally important to their use of the area is the open water provided by the annual recurrence of the polynya in spring. It is doubtful that they could move through the region at all in spring should the polynya not be available.

A few bowheads have been reported near Wainwright in summer. Whether they remained throughout the summer, and whether a few are consistently found in the Barrow Arch in summer are not known.

Factors currently limiting bowhead populations are not known. Spring subsistence hunting at Wainwright, Point Hope, and Barrow is the cause for some mortality, but its effect on bowhead population levels is uncertain.

Polar Bear

Polar bears occupy the nearshore zone of the Barrow Arch mainly in winter. In summer, when ice moves offshore, they are usually found only in the northerly and seaward portions of the area.

In winter polar bears are reported most often in the pack ice zone off Icy Cape and Point Franklin. They presumably also use the shorefast ice of the nearshore zone, since ringed seals, their primary prey, are relatively abundant there. Polar bears also prey upon bearded seals and walruses, but these species tend not to use the coastal zone in winter when the bears are most common there.

Polar bears also occasionally den in the coastal zone. The annual consistency and density of denning efforts are poorly known.

Ice conditions and prey density determine to a great extent the seasonal and areal use of the Barrow Arch by polar bears. They hunt for seals mainly on ice where leads are frequent and seals relatively abundant. Ringed seal density has been thought to regulate bear abundance in some areas of the Arctic.

8.1.2 Birds

Seabirds: Alcids

In summer approximately 250,000 cliff-nesting alcids use nearshore waters of the Barrow Arch. Of these, approximately 79% are thick-billed murres, 29% are common murres, 1% are tufted and horned puffins, and less than 1% are other species.

These seabirds arrive in the Barrow Arch about mid-May and stay until approximately mid-September. Their distribution is regulated by how far they forage from nesting cliffs in the Cape Lisburne area; they range from Cape Lisburne northeast to about Point Lay. In general they do not use lagoons and enclosed bays, but feed in deeper parts of the nearshore zone and in shelf areas beyond the nearshore.

Alcids use the nearshore (and offshore) waters for collecting prey for themselves and their young. Their main prey is forage fishes; in priority of importance (biomass consumed) the principal prey are Arctic and saffron cod, sculpins, capelin, and sand lance. Alcids are primarily water-column feeders, and concentrations of forage fishes affect the birds' ability to forage effectively.

Two habitat features (in addition to the availability of coastal nesting cliffs) are important to these birds. One is the availability of open water in leads in spring when they first arrive. Years with little open water in late spring prevent the birds from readily gaining access to prey. Second, the availability of high-density concentrations of prey affects foraging efficiency.

Food availability (controlled by late spring ice conditions and prey density) appears to be a major regulating factor in the annual productivity of these birds. A series of poor food years results in low reproductive success and, subsequently, lower population levels. Egg harvest by subsistence users also affects reproductive success and population levels, but to a lesser extent.

Seabirds: Kittiwakes and Gulls

Kittiwakes and large gulls are the most abundant surface-feeding seabirds of the northeastern Chukchi Sea. This group is dominated in number by kittiwakes (~30,000), followed by glaucous and Ross' gulls (a few thousand each) and ivory gulls (<1,000).

In general, these species inhabit the Barrow Arch from May through October. Ivory and glaucous gulls may persist for a month or two later in fall; Ross' gulls are present only in fall. The distributional uses differ among species. Kittiwakes, like alcids, nest on cliffs at Cape Lisburne and Cape Lewis, foraging northeastward to Point Lay and up to 60 km offshore. They also congregate all summer on the deltas of the Pitmegea River and Thetis Creek to bathe and rest. Glaucous gulls nest in small coastal colonies on islands and spits, foraging coastwide throughout summer. In late summer many congregate in the Pitmegea River and Thetis Creek deltas to stage. Ross's gulls and ivory gulls feed during migration along the ice edge from Icy Cape north to Barrow in fall.

These birds use the Barrow Arch mainly for nesting and feeding. Kittiwakes and glaucous gulls nest at coastal sites and forage in coastal waters (and offshore to some extent). Ross' and ivory gulls forage along the ice edge.

In general, Arctic cod, capelin, and sand lance are the primary foods for these surface-feeders. Kittiwakes eat mainly Arctic cod at the ice edge early in the season, switching to capelin and sand lance later. Glaucous gulls eat mainly Arctic cod and sand lance but also herring. Ross' and ivory gulls consume Arctic cod at the ice edge; under-ice amphipods are also important to Ross' gulls.

Habitat factors important to these birds in the coastal zone include nesting habitat (for kittiwakes and glaucous gulls), extent of open water in spring, ice conditions, and prey depth in the water column. As noted, kittiwakes use cliffs in the Cape Lisburne area for nesting; glaucous gulls arrive in spring before general breakup, and areas (polynyas, leads) of open water in which to feed are crucial to them at that time. Furthermore, because all these birds feed at the top of the water column, prey must be available at the surface. This last factor, in conjunction with ice conditions, is most crucial, for food may limit reproduction and population levels in these species.

Waterfowl: Eiders and Oldsquaws

Oldsquaws and eiders (mostly common and king eiders) are the waterfowl of greatest concern in coastal habitats. These birds migrate over and feed in coastal waters (over a million eiders pass through annually); some (common eiders) find important nesting habitat in the area.

In general, oldsquaws and eiders use the nearshore zone of the Barrow Arch from early May through October. The earliest use is by migrating eiders (mostly king eiders) that pass along the nearshore lead system on their way to nesting habitats mostly in the Canadian High Arctic. Oldsquaw spring migrants also follow this lead system, but in somewhat fewer numbers. In June a few thousand common eiders nest on small barrier islands bordering Kasegaluk Lagoon. In July and August, post-nesting oldsquaws and eiders (tens of thousands of each) congregate in coastal lagoons and protected bays to molt, stage, and feed. Fall oldsquaw migrants continue to use the lagoons and bays through October.

Uses of nearshore waters by eiders and oldsquaws include resting, nesting, molting, and migration staging. Feeding is an integral part of molting and migration staging activities. Eiders and oldsquaws migrating along the lead system in early spring frequently stop in the open water to rest (and possibly to feed); very large concentrations may assemble in the leads when inclement weather halts migration. Beginning at breakup in July, varying numbers of molting and staging oldsquaws and eiders feed in protected bays and lagoons (mainly oldsquaws) and nearshore marine waters (mainly eiders) through October. The main foods of these staging and molting birds are epibenthic fishes (sculpins) and invertebrates (gammarid amphipods, mysids) and, to some extent, bivalves.

Important habitat factors include the availability of open leads in the ice in spring, favorable winds for spring migrants, the presence of protected bays and lagoons for molting and staging oldsquaws in summer and fall, and the presence of predator-free islands for common eiders to nest on in early summer. Islands secluded from human use may be important to molting oldsquaws. It is probable that the availability of suitable nesting islands (by affording sites secure from fox predation) strongly affects common eider productivity; whether other physical habitat factors or food availability ever limit annual productivity or survival of these species is not known.

Waterfowl: Black Brant

The Barrow Arch coastal zone is especially important to black brant. It provides the only known fall staging area north of the Alaska Peninsula for the largest arctic Alaska nesting population of brant, which nests and molts in the Teshekpuk Lake area near the Beaufort Sea coast. Smaller numbers of locally nesting birds also use the area.

Brant use the coastal salt marshes, particularly those in the vicinity of Icy Cape and Peard Bay, between early June and late September. They are particularly abundant there as spring migrants in June ($\sim$37,000 birds) and again in late August and September as fall migrants (70,000–80,000 birds). In these staging habitats, they feed on salt marsh vegetation (grasses, sedges).

The presence of salt marshes relatively free from human disturbance appears to be the most important habitat factor affecting brant. It is likely that availability of this habitat has a strong influence on continuing productivity of the black brant in arctic Alaska.

Shorebirds of Marshes and Mud Flats

In July and August, post-nesting shorebirds of several species congregate in salt marsh and mud flat habitats in the Barrow Arch area to feed prior to migration farther south. These birds have come from tundra nesting sites nearby and elsewhere.

The distribution of these staging shorebirds is dictated by the presence of the salt marsh and mud flat habitats in which the birds feed. The most extensive of these habitats are in the northern part of Kasegaluk Lagoon, especially near Icy Cape. Less extensive habitats occur on the spits and mainland shores of Peard Bay. Small areas occur near Point Hope, but the importance of these to shorebirds is not known.

The important habitat factors are associated with the salt marshes and mud flats and the invertebrate prey (mainly adult and immature chironomids) they provide to the staging shorebirds. It is not known whether these factors act to limit shorebird populations that stage here. The primary factors that regulate shorebird numbers are not known.

Beach Birds

Representatives of three groups of birds in the Barrow Arch—shorebirds, gulls, and terns—concentrate their activities along or very near beaches. The principal species are red and red-necked phalaropes, Sabine's gull, and arctic tern; other gull and sandpiper species are present in low numbers.

As a group these birds are found along beaches of barrier islands, spits, and the mainland from June to early October. Primary places of concentration are spit and island shorelines and river deltas; important sites in the planning area include Point Franklin, Seahorse Island, Icy Cape, the entire length of Kasegaluk Lagoon, and perhaps Point Hope.

The primary use these birds make of these sites is feeding. (Additionally, arctic terns nest on island beaches.) Most of the food is taken from shallow water near the beaches, and includes amphipods (primarily *Apherusa* and *Onisimus*), copepods, euphausiids, and Arctic cod.

Habitat factors important to these birds are the local complexity of shoreline substrates and habitats, shoreline configuration (e.g., points of land appear to attract feeding birds), the presence of beach-grounded pack ice, and (for arctic terns) the presence of islands on which to nest. Very little is known about how populations of these birds are limited.

8.1.3 Anadromous Fishes

The principal species of anadromous fishes in the Barrow Arch coastal zone are pink and chum salmon, Arctic char, boreal smelt, small numbers of least cisco, and perhaps some whitefishes.

Temporal and spatial distributions are related to general habitat preferences and to timing of spawning runs. Salmon are essentially marine after they leave rivers as juveniles and, except perhaps for a few weeks or months in river estuaries as smolts, and a short time in coastal transit as returning adults, remain largely outside the coastal zone. Char are more estuarine during their ocean life than salmon, but less so than ciscoes and whitefishes, which tend to remain in relatively warm, brackish, and semi-protected coastal waters. Boreal smelt are probably widely dispersed on the nearshore shelf, but assemble in estuarine areas prior to spring spawning runs.

Specific distributions in coastal waters vary among species, though little is known about distributions of some. Juvenile salmon are found near river mouths for short periods in summer; returning adults are found coastwide in the nearshore in summer, though numbers are thought to be lower in the northerly areas. Char and especially ciscoes and whitefishes are relatively abundant in lagoons, bays, and estuaries near their natal streams during the open-water season; char are more abundant in southern parts of the planning area. Boreal smelt apparently overwinter in relative abundance in Kuk Inlet prior to spring spawning.

Most of the known prey of these fishes in nearshore environments are epibenthic in habit. Salmon consume mysids, amphipods, harpacticoid copepods, and small fishes. Smelt appear to prefer mysids and small fishes. Char smolts in coastal waters have been found to eat chironomid larvae and copepods; adults consume shrimps, amphipods, and other crustaceans. Cisco and whitefish diets have not been examined, but are presumed to include mainly epibenthic crustaceans such as mysids and amphipods.

Habitat factors that are thought to influence the abundance of anadromous fishes in coastal waters are nearness of natal streams (especially for smelt, ciscoes, and whitefishes), presence of suitable overwintering sites, and water temperature and salinity. The size, type, and availability of overwintering and spawning areas appear to limit their populations.

8.1.4 Marine fishes

Marine fishes that are important components of the coastal ecosystem include Arctic and saffron cod, capelin, herring, fourhorn sculpin, sand lance, and Arctic flounder. Most of these are important forage fishes for other fishes, birds, and mammals.

Herring and cods are widely distributed on the shelf, in both offshore and nearshore waters. The other species are mostly nearshore marine in distribution. Most of these fishes (excluding Arctic cod, fourhorn sculpin, and Arctic flounder) are essentially Bering Sea fishes that range northward into the Chukchi. Thus, though distributions of most species in the Barrow Arch are not well known, it may be suspected that these Bering Sea fishes might diminish in abundance northward.

All of these species occur year-round in the coastal waters. In summer and fall many may be found in bays and lagoons. Most shift seaward in winter as ice thickens. Capelin and herring move to shallow waters in summer to spawn. Most of the other species spawn in deeper water in winter. Most of these species, similar to the anadromous species, feed largely on epibenthos in coastal waters. Diets include mysids, amphipods, copepods, cumaceans, fishes and fish larvae, polychaetes, and shrimps. Flounders consume bivalves to some extent.

Most of these species are influenced in their distribution and abundance by water mass movement and distribution. Specifically, many respond to the intrusions of the Alaskan Coastal Current and other components of Bering Sea water from the south. Others may move to protected coastal sites in summer. Presumably they are responding to temperature. Additionally, Arctic cod are known to congregate near the ice edge. Factors that regulate populations of these fishes are generally not known.

8.2 COASTAL FOOD WEBS

The coastal ecosystem may be arbitrarily divided into two depth zones for a discussion of food webs. The shallow nearshore (defined as areas approximately 5 m deep or less) is somewhat discrete from the deep nearshore (defined as areas about 5–20 m deep) in terms of major consumers and lower trophic levels (Fig. 8.1). The shallow nearshore includes the coastal estuaries, lagoons, and semi-enclosed bays, and is frequently relatively brackish and warm. The deep nearshore is located beyond barrier islands and spits and is essentially marine in water quality.

In the shallow nearshore, the consumers (spotted seal, beluga whale, brant, oldsquaw, eiders, marsh and mud flat birds, beach birds, and anadromous and marine fishes) are with few exceptions summer and early fall inhabitants of the area. Except for terrestrial vegetation and for zooplankton transported largely from offshore, the food base is benthic. Most of the benthos consumed are epifaunal invertebrates; these are largely detrital feeders.

In the deep nearshore, consumers inhabit the Barrow Arch both in summer/early fall and in winter. The birds (kittiwakes, gulls, alcids, eiders) and some mammals (gray whale, bearded seal, walrus) are summer foragers essentially absent in winter. Some mammals (ringed seal, polar bear) are primarily winter inhabitants. Marine fishes (cods, capelin, herring, sand lance) are present both summer and winter, though perhaps in different relative abundances. Although having mainly a detritus-driven food base (via the benthos) like the shallow nearshore, the deep nearshore consumers may depend to a greater extent on a plankton base (through fishes).

Thus both the shallow and the deep nearshore biota

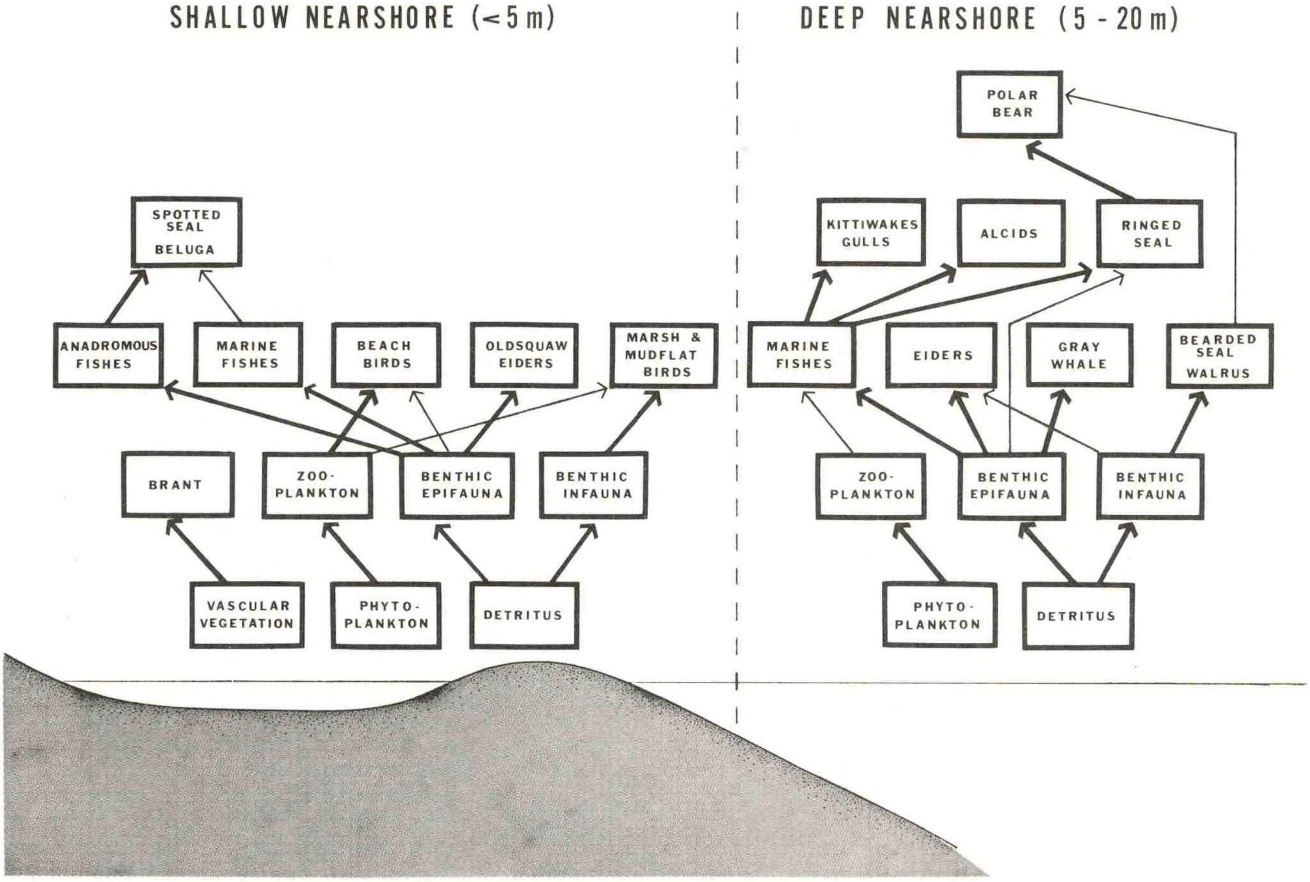

FIGURE 8.1—Simplified food web of the Barrow Arch coastal ecosystem. Arrow width indicates relative importance of food source.

are supported to a large extent by a benthic food base. Further, except for the bearded seal and walrus, the base is mainly epibenthic. Both epifauna and infauna appear to be mainly detritus feeders. Whether this detritus is mainly from *in situ* primary production in the water column, or detritus transported from the south by north-moving water masses is unclear at present.

8.3 PHYSICAL HABITAT FACTORS

We have seen that, in addition to food webs, physical attributes of the coastal ecosystem influence the distribution and abundance of many of the species that use the Barrow Arch. Distributional characteristics of selected physical phenomena appear particularly important. These phenomena include seasonal ice conditions; water temperature, salinity and depth; bottom sediment type; coastal cliffs, islands, and spits; river deltas, protected lagoons, and bays; and salt marshes and mud flats (Table 8.1).

In winter and spring, the important phenomena appear to be ice conditions. The most important is the presence and characteristics of the ice lead system (Chukchi Polynya) that extends from Point Hope to Barrow just beyond the shorefast ice edge. The lead system is of critical importance to migrating and feeding mammals and birds. Second in importance is the actual presence of shorefast ice, in which ringed seals bear young.

In summer and fall, the physical habitat factors to which biota respond are more variable. They include (1) the required presence of coastal cliffs and barrier islands for certain nesting and feeding birds, (2) the presence of salt marshes and mud flats for feeding brant and some shorebirds, (3) the presence of warm, semi-enclosed lagoon and bay waters for anadromous fishes, (4) the complexity of mainland and island shorelines in relation to foraging beach birds, (5) the proximity to coastal sites of natal streams of anadromous fishes, (6) the presence of deep areas in the shallow nearshore for some overwintering fishes, (7) the distribution of bottom sediment-types that possibly influence feeding gray whales by influencing the distribution of their prey, (8) the location of the pack ice edge in fall in relation for foraging of Ross' and ivory gulls, and (9) the water mass characteristics and movements in the deeper nearshore waters, which influence the distribution of forage fishes and their consumers.

Where and when the biota respond to these physical habitat factors have strong implications regarding the potential sensitivity of the biota to oil and gas development activities.

8.4 COMPARISONS WITH BEAUFORT SEA

During the workshop a summary of comparisons was made between coastal ecosystems of the Chukchi Sea and the adjacent Beaufort Sea. The purpose of making these comparisons was to gain insight into

TABLE 8.1—Physical habitat factors important to biota in the coastal zone of the Barrow Arch. Times and places of major importance are shown.

Species	Habitat Factors	Time	Place
Marine mammals			
Bearded seal	Water depth >5 m	Summer, fall	Deep nearshore
Walrus	Broken ice conditions	Summer, fall	Deep nearshore
Ringed seal	Shorefast ice	Spring	Deep nearshore
Spotted seal	Secluded ice-free near-shore waters	Summer	River mouths, lagoons
Beluga whale	Ice-free (warm?) near-shore waters	Summer	River mouths, lagoons
Gray whale	Bottom sediment type (?)	Summer	Deep nearshore
Bowhead whale	Open leads in ice	Spring	Deep nearshore
Polar bear	Open leads and cracks in ice	Winter, spring	Deep nearshore
Seabirds			
Alcids	Coastal cliffs	Summer	Cape Lisburn area
Kittiwakes	Open leads in ice	Spring	Cape Lisburne area
Glaucous gull	Barrier islands	Summer	Kasegaluk Lagoon, Icy Cape, Peard Bay
Ross' and ivory gulls	Pack ice edge	Fall	Deep nearshore (northern parts)
Waterfowl			
Eiders	Open leads in ice	Spring	Deep nearshore
	Open water	Summer	Deep nearshore
	Barrier islands	Summer	Kasegaluk Lagoon, Icy Cape, Peard Bay
Oldsquaw	Open leads in ice	Spring	Deep nearshore
	Protected bays, lagoons	Summer	Kasegaluk Lagoon, Icy Cape, peard Bay
Black brant	Salt marshes	Summer, fall	Icy Cape, Peard Bay
Shorebirds of marshes and mud flats	Tidal flats, salt marshes	Summer	Vicinity of Icy Cape, Peard Bay
Beach birds	Shoreline complexity	Summer, fall	Shorelines throughout
Phalaropes, Sabine's gull, and arctic tern	Presence of spits and islands	Summer	Kasegaluk Lagoon, Icy Cape, Peard Bay
Anadromous fishes	Warm, brackish water	Summer	Protected lagoons and bays
	Proximity of natal streams	Summer, fall	Vicinity of mouths of large streams
	Deep areas under ice	Winter	Kuk River inlet
Marine fishes	Water mass distribution and movement Water temperature (?)	Summer, fall	Deep nearshore

the function and structure of the Chukchi Sea coastal zone by viewing what was known about the somewhat similar but much better known Beaufort Sea coastal ecosystem. Comparisons between the two included their important faunal inhabitants, the food webs supporting these inhabitants, and the physical habitat factors important to the biota.

Comparisons of the vertebrate fauna of the two coastal ecosystems indicated that the Chukchi Sea in general, and the Barrow Arch area in particular, have (relative to the Beaufort)

1) more species and a greater biomass per unit area of marine mammals;
2) more species and a greater unit area biomass of marine fishes;
3) fewer species of non-salmonid anadromous fishes and smaller biomass per unit area;
4) a lower density of feeding and molting oldsquaws in summer;
5) a greater density of feeding and molting eiders in summer;
6) a much greater abundance of cliff-nesting seabirds (the American Beaufort Sea has essentially none); and
7) no obvious general differences in densities and habitat use patterns of shorebirds (but a few differences in species compositions).

With respect to food webs, the Chukchi Sea coastal ecosystem in comparison with that of the Beaufort Sea appears to have

1) greater annual primary productivity (in biomass carbon fixed per unit area), but a smaller percentage of primary production cropped by water-column grazers (zooplankton) and a greater proportion settling to benthic environments;
2) greater diversity and higher biomass per unit area of benthic feeders;
3) a smaller percentage (biomass) of epibenthic mysids in diets of nearshore consumers (fishes and birds); and
4) a greater variety of marine forage fish species and a greater diversity and biomass of forage fish predators.

Comparisons of physical phenomena that exert a strong influence on the biota indicate that the Chukchi Sea coastal zone has

1) generally more open water in time and space (open water persists longer in winter and, on average, larger percentages of the nearshore environment are open at any one time);
2) a greater influence from inputs of Bering Sea water as opposed to Arctic Ocean water;
3) marine-like water (cold, salty) that pervades nearshore environments to a much greater extent in space and time;
4) a large polynya, or lead system, that persists throughout spring each year in or just offshore from the deep nearshore environment (the Beaufort Sea has no such feature in the nearshore);
5) relatively few natal streams as sources of anadromous fish populations; and
6) large cliffs suitable for seabird nesting (the Beaufort Sea has no such cliffs).

8.5 ENVIRONMENTALLY SENSITIVE AREAS

Places in the coastal environment of the Barrow Arch in which the fauna appears particularly susceptible to adverse impacts caused by oil and gas development have been identified in Chapters 4–7. These areas include places where large proportions of regional populations congregate for a function judged to be important to survival of the population. Maps of these areas are depicted in these chapters, and details of their importance to biota are discussed. Figures 8.2 and 8.3 are a synthesis of maps in these chapters. A summary identifying the areas that appear particularly sensitive and the time and nature of their importance to biota follows. These are not discussed necessarily in order of priority, but generally in progression from sea to land.

Chukchi Polynya

Extending the entire length of the Barrow Arch just outside the fast-ice zone, the Chukchi Polynya is a major open-water lead system that recurs annually in spring. It is the only dependable spring migrating pathway for bowhead and beluga whales, and is important as well for spring-migrating eiders (>1 million) and for hundreds of thousands of early-arriving alcids, kittiwakes, and gulls that breed in the Barrow Arch. Because all these animals at times require open water, and this lead system is the only dependable open water available in spring, use of it is vital to their survival. Spilled oil, intensive boat traffic, or other development-related activity that coincides in time and space with the use of the lead system by these animals could have detrimental effects.

Waters Off Cape Lisburne

Marine nearshore areas extending west to northeast and within about 60 km of Cape Lisburne are the primary late summer and fall feeding habitat for most of the seabirds nesting at Capes Lisburne and Lewis, and sometimes for most of the seabirds from Cape Thompson as well. These birds feed to a lesser extent out to 120 km. Because these birds feed at the surface or in the water column and are very sensitive to being oiled, spilled oil that coincides in time and

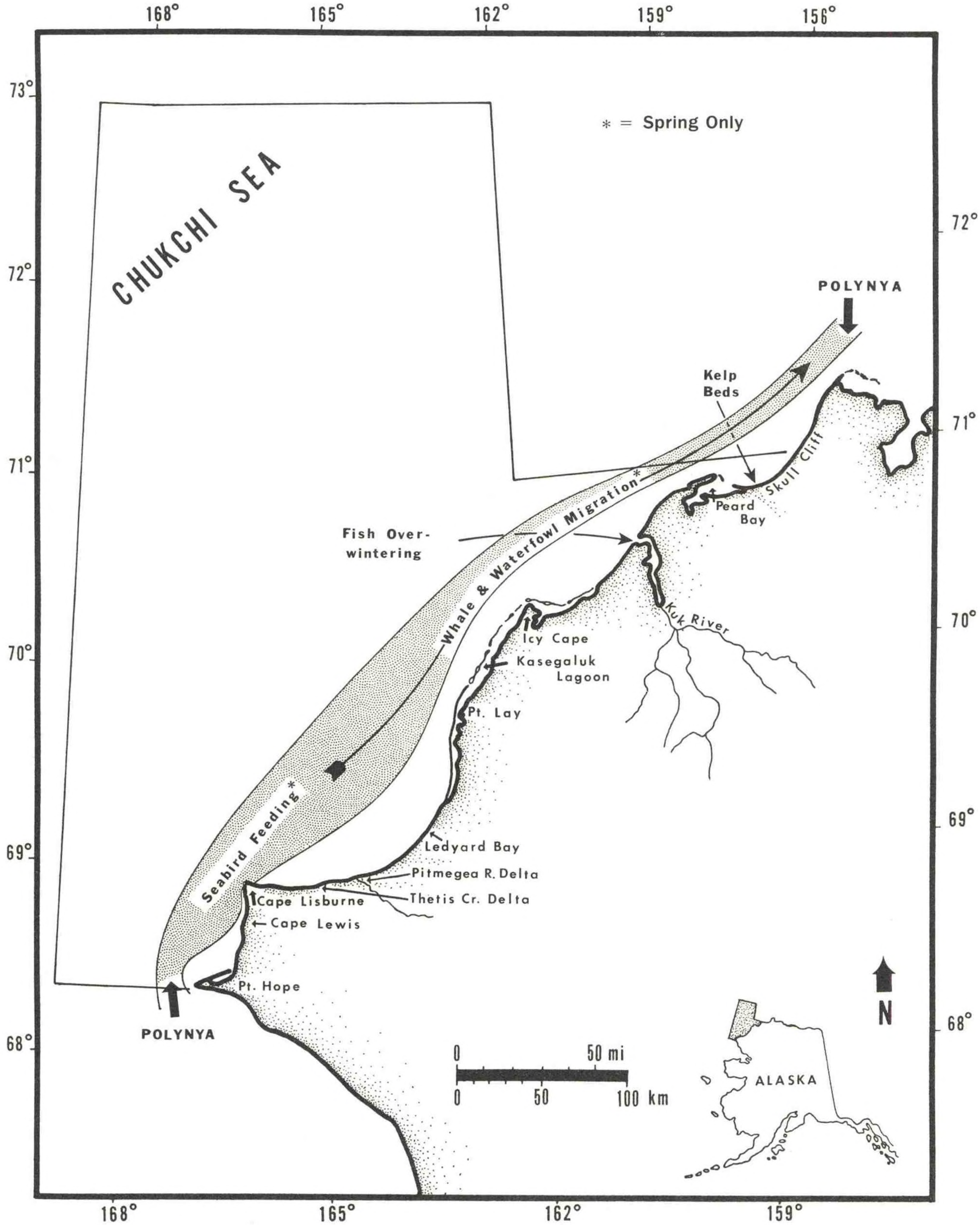

FIGURE 8.2—Areas of biological use in winter and spring (December–June) in the Barrow Arch where biota are thought to be sensitive to activities associated with oil and gas development.

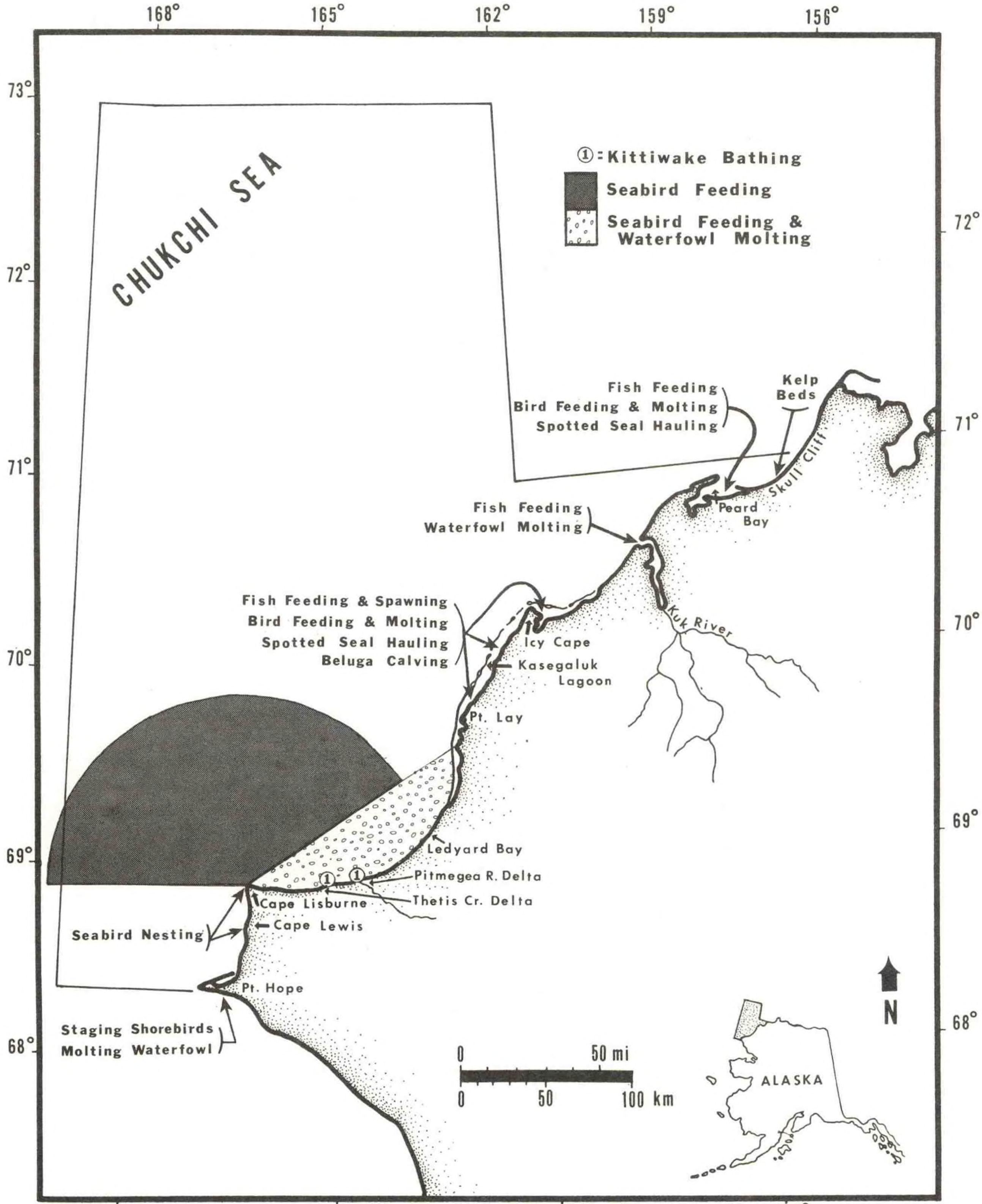

FIGURE 8.3—Areas of biological use in summer and fall (July–November) in the Barrow Arch where biota are thought to be sensitive to activities associated with oil and gas development.

space with their use of the area would undoubtedly threaten the survival of many.

Ledyard Bay

A wide, open, and relatively shallow embayment between Cape Lisburne and Point Lay, Ledyard Bay provides rich feeding grounds for seabirds from early summer through early fall and is a primary molting area for eiders in summer. Almost all alcids and larids nesting at Capes Lisburne and Lewis feed there from early June to early August; tens (perhaps hundreds) of thousands of common and king eiders stage and molt there in July and August. Oil in Ledyard Bay in summer could be disastrous to many of these birds.

Skull Cliff Kelp Beds

Substrates in shallow waters (<18 m) off Skull Cliff extending to about 20 km northeast of the eastern end of Peard Bay locally support beds of kelp, primarily *Laminaria saccharina* and *L. solidungula*. It is not known that these kelp beds provide important habitats or sources of carbon for fauna of major concern, but they are relatively unusual in Alaskan arctic seas. Macrophytes also are reported to occur in several other localities along the Barrow Arch coast (*see* Chapter 7) but less is known about their extent and composition. A variety of nearby activities could conceivably affect this community.

Kasegaluk Lagoon

Kasegaluk Lagoon, defined here to include the semi-enclosed coastal waters from Icy Cape south to the southern terminus of these waters in Ledyard Bay as well as those immediately north of Icy Cape, is important to several groups of biota. Non-salmonid anadromous fishes forage here in summer (as they do in other lagoons and enclosed bays) in preference to the adjacent marine waters outside the barrier islands. Small numbers of herring, and perhaps capelin, spawn there in spring and late summer, respectively. This lagoon, including its closely adjacent wetlands and nearshore marine waters, is the most important staging, molting, and feeding habitat for non-cliff-nesting birds in the Barrow Arch. From early summer to mid-fall it hosts various combinations of hundreds of thousands of oldsquaws, brant, shorebirds, gulls, and terns. Its islands provide unique coastal nesting habitat for a few thousand common eiders and hundreds of arctic terns. It is the major summer concentration area for beluga whales and spotted seals in the Barrow Arch. Belugas bear their young and presumably feed in the area in July and August; most are seen in the vicinity of lagoon passes north and south of Icy Cape. Protected spits and river mouths provide the most important summer haulout sites for spotted seals in the Barrow Arch. Oil or development actions in or near Kasegaluk Lagoon could have a variety of adverse effects.

Peard Bay

Peard Bay, though generally less important than Kasegaluk Lagoon, provides important summer habitat for birds, anadromous fishes, and spotted seals. Throughout the open-water season, non-salmonid anadromous fishes probably prefer the relatively warm, brackish waters to the marine waters nearby. Peard Bay is an important molting and staging habitat for oldsquaws, and feeding and staging habitat for a large number of red phalaropes. The associated spits and islands host small but locally important summer populations of nesting arctic terns, black guillemots, and sometimes common eiders. A small number of spotted seals haul out here in mid- to late summer. Oil spills or other development activities here could have the same general kinds of adverse effect that they would in Kasegaluk Lagoon, but would probably affect fewer animals.

Kuk River Inlet

The main importance of the inlet at the mouth of the Kuk River is for anadromous fishes. Relatively small numbers of several anadromous species probably forage there in summer. Because it is deeper than most enclosed coastal waters, it may provide a unique overwintering habitat for some species; rainbow smelt (and possibly populations of other species) overwinter there. Localized activities or oil spills might have adverse effects in Kuk Inlet on anadromous fishes, especially in winter.

Pitmegea River and Thetis Creek Deltas

The deltas of Pitmegea River and Thetis Creek are summer-long, daily resting and bathing sites for thousands of kittiwakes, and may host several thousand staging glaucous gulls in late summer. Oil or localized activities in summer could be detrimental to birds at these sites.

Capes Lisburne and Lewis

Coastal cliffs at Cape Lisburne and Cape Lewis support large nesting colonies of seabirds from late spring to early fall each year. Major percentages of alcids and larids that breed in the eastern Chukchi Sea nest here. Additionally, since 1975 up to several hundred walruses have used beaches near Cape Lisburne in summer as haulout sites. This is currently the only major terrestrial haulout site for walruses on the eastern Chukchi coast. Aircraft traffic or human activity very near the nesting cliffs stand to adversely affect the reproductive success of the bird colonies. Increased human activity near the walrus haulout area may have adverse effects, but how the walruses will respond is not currently predictable.

Point Hope Spit

The spit and associated wetlands at Point Hope undoubtedly serve as a natural concentration point for nesting, molting, and migrating birds, especially staging shorebirds in late summer. Few data are available concerning its use by these birds, so estimates of its importance are tenuous. Potential effects of oil development include those normally associated with oil spills or human activities on birds in coastal lowland habitats.

8.6 SUMMARY

In the coastal ecosystem of the Barrow Arch, the principal biotic components of direct concern to humans include bowhead, beluga, and gray whales; bearded, ringed, and spotted seals; walrus; several species each of seabirds, waterfowl, and shorebirds; and several species each of anadromous and marine fishes. The area hosts few winter or year-round residents; ringed seals, polar bears, boreal smelt, and marine fishes are the only ones that might commonly be encountered throughout the year. Another few populations use the nearshore (its lead system) only as a migration route in spring—its entire complement of bowheads and major portions of its beluga, eider, and oldsquaw populations. It is a summer (July–October) habitat for many, including gray whales, bearded seals, spotted seals, walruses, and part or all of the populations of its bird and anadromous fish species.

The major food web base in the nearshore environment is benthic. Most of the mammals, birds, and fishes feed on epibenthic invertebrates or on vertebrates that eat epibenthos. Two marine mammals (walrus, bearded seal) feed heavily on the benthic infauna in the deep nearshore; as do some shorebirds (in the coastal marshes and mud flats). Diets of a few (e.g., shorebirds, forage fishes, and forage fish consumers) derive from water-column food webs. This pattern contrasts to some extent with that found in the nearshore Beaufort Sea, where there are no major predators on infauna and where more of the food chain of the deep nearshore waters is located in the water column. Brant, essentially a terrestrial species, eats vascular plants.

Physical habitat factors strongly influence the distributional abundance of many species in the nearshore zone. Ice distribution and quality dictate the distributional patterns of nearly all mammals, birds, and anadromous fishes at some time of year. The morphological configuration of coastal water bodies and substrates (e.g., existence of bays, barrier islands, lagoons, and inlets) and the associated water quality affect the habitat use patterns of some mammals and most birds and anadromous fishes. Large-scale water mass movements and points of river entry affect distributions of fishes and perhaps some of their consumers (e.g., seabirds, belugas, spotted seals).

Approximately 10 coastal sites have been identified as areas where biota concentrate for specific activities and are likely to be particularly sensitive to impacts of oil and gas development. These include the annually recurring Chukchi Polynya; coastal lagoons and bays and the associated barrier islands and spits; coastal cliffs and the adjacent waters; river deltas and inlets; and an area that supports kelp beds.

9

Subsistence Economics and Marine Resource Use Patterns

by Stephen R. Braund and David C. Burnham

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The purpose of this chapter is to provide information on the current patterns of subsistence use of marine resources by the Chukchi Sea communities of Point Hope, Point Lay, Wainwright, Atqasuk, and Barrow. The first section documents how the rapid increase in local employment in the past decade has affected subsistence activities, and how cash intensive, technologically advanced harvest equipment has altered the seasonal subsistence cycle of North Slope residents. The second section presents maps and descriptions of major marine subsistence use areas for the five communities. In the final section, potential impacts of offshore oil and gas development on current marine subsistence use patterns are discussed. Main sources of information are two: (1) the subsistence portion of Minerals Management Service's SESP Technical Report No. 101 (Alaska Consultants *et al.* 1984); and (2) the proceedings of the Barrow Arch Synthesis Meeting human resource use workshop, the goals of which were to describe baseline subsistence information for Chukchi Sea marine resources and identify potential impacts related to oil and gas development.

9.1 REGIONAL SUBSISTENCE ECONOMY

Economic opportunity in the form of wage and salary employment has greatly increased in North Slope communities in the past 10 years, primarily related to the discovery and development of oil and gas reserves and the subsequent incorporation of the North Slope Borough (Kruse *et al.* 1981). This section considers changes in the interrelationship between the subsistence and more modern wage economies during the past 15 years. Of special interest are the impacts which increased wage and salary employment has had on subsistence activities, including the amount of time available for subsistence, scheduling, harvest ranges, and equipment. The quantity of wildlife resources harvested is beyond the scope of this analysis.

Increased employment opportunities have affected the subsistence activities of North Slope Borough residents in two ways. First, high employment levels have increased the amount of money readily available for investment in technologically advanced subsistence equipment. Second, employment has reduced the time available for subsistence pursuits. These two impacts have changed harvest techniques, the timing or scheduling of specific harvests, the amount of time necessary for the successful harvest of specific resources, hunting ranges, and in some cases, target species. On the other hand, for some species the techniques used, the range and the timing of the harvest have remained the same.

The impacts of modern wage economy and the resultant changes in subsistence economy have occurred since the introduction of the rifle and other western equipment in the nineteenth century. However, the rate of change has greatly accelerated during the past two decades. Although the rifle required some access to money or trade goods, it did not necessitate the high levels of cash needed to purchase, maintain, and operate modern equipment. The major technological innovations of the past 20 years that have become commonly available and widely used as a result of the increased buying power of local residents include the replacement of dog teams by snowmachines, the use of wood and aluminum boats with increasingly powerful outboard motors, and the addition of the three-wheeler and, in some communities, the airplane to the repertoire of subsistence harvest tools. Using examples from the study communities, the interactions between the wage and subsistence economies and the impact of these new subsistence harvest tools are discussed.

9.1.1 Snowmachine

The replacement of the dog team by the snowmachine began on the North Slope in the mid-1960's and, while there are still a few active dog teams, most families presently use snowmachines for travel and hunting during the winter. Local residents indicated that the snowmachine has numerous advantages over the dog team including speed, mobility, and a reduced demand for dog food. Perhaps most important is the increased travel speed which snowmachines provide. Trips which used to take villagers 4 days with a dog team are now accomplished in a single day (fieldwork for this study). Snowmachines also allow villagers to travel further from the village and cover a greater area while hunting, thus bettering their chances of a successful hunt. Another advantage of snowmachines is that they do not have to be fed except when they are being used. Dog teams must be fed year-round, including the summer when they are rarely used and during the week while the hunter is employed. In the latter case, the snowmachine is much easier to own. It can sit idle with no effort expended by the hunter during the week and only requires fuel while in use.

The speed, hauling power, and mobility of the snowmachine have enabled villagers to balance local employment and subsistence pursuits. For example, snowmachines have facilitated weekend hunting by allowing hunters to travel faster and harvest a week's worth of game in a single day. As one resident stated, "Because less time is spent traveling, the snowmachine gives you more time to hunt and more time to work." Thus the single most important advantage which snowmachines provide is to reduce travel time to and from harvest areas.

Conversely, there are also disadvantages to snowmachines. These include dependability, price, and operating costs. One resident summed up the dependability of dog traction when he said, "Dogs will always bring you back home." Also, residents noted that dog teams are much better on sea ice where they are better suited to negotiate pressure ridges and, because of the distribution of weight over a large area, safer than the heavy snowmachines. Snowmachines are also costly to repair. Their continual use in harsh conditions (especially rough ice), and the high cost of replacement parts makes them one of the most expensive harvest tools to maintain and repair. Some families average $1,000 each winter on repairs. New machines average $3,500 and generally only last 2 or 3 years. Families with several adult sons who continually use the household snowmachine reported that they only got one winter out of a new machine. Thus, as with all hunting equipment, the useful life depends on the use and care given to the tools.

9.1.2 Three-wheelers

In recent years, three-wheelers have come into use in the study communities. These all-terrain vehicles travel on gravel beaches, hard packed snow, mud, shallow water, ice, and land. They are fast, economical to operate, and according to the 1983 interviews, well built. Less expensive than snowmachines ($1,600 to $2,400), they require fewer repairs and reportedly travel in excess of 60 miles on one tank of gas. Villagers indicated that three-wheelers lasted approximately 2 to 3 years.

The effectiveness of three-wheelers is variable among the study communities. For example, in inland Atqasuk the use of three-wheelers is limited to travel within the village because the tussock tundra which dominates the area results in difficult traveling conditions. On the other hand, three-wheelers are more pervasive in Point Hope than any other community in the study area. The barrier beaches in the Point Hope area are natural roadways. Villagers noted that one can travel from Cape Thompson in the south to Sinuk in the north without interruption. Also, three-wheelers provide summer and fall access to caribou hunting areas in the Kemegrak Hills. In Point Lay hunters stated that the windswept northern foothills of the Brooks Range were clear of snow all winter and that three-wheelers were used for caribou hunting throughout the winter. In summary, three-wheelers provide quick access to previously inaccessible areas in certain seasons, reduce travel time to harvest areas, expand the seasonal hunting range, and allow hunters time to devote to wage employment.

9.1.3 Boats and Outboard Motors

In the past 10 years, increasingly more powerful outboard motors and lighter aluminum and fiberglass boats have become more available to North Slope residents. This equipment has reduced the number of sea mammals harvested to maintain skin boats (now primarily used for whaling) and increased hunter speed, mobility, and marine harvest ranges. The increased mobility provided by these larger motors allows the hunters to travel to hunting areas faster, and cover large areas which would have been considered too far and too dangerous in the slower man-powered skin boats.

Boats with outboards are now also the common means of river transport, although both the boats and motors are generally smaller than their oceangoing counterparts. Prior to the adoption of outboard motors, dog teams were often used to pull boats upriver to inland fishing and hunting areas. Outboard motors have the same advantage over dogs as do snowmachines in that they do not have to be fed when they are not in use.

Some marine hunting activities have not been directly altered by this new equipment. For example, in Point Hope and Barrow, the skin-covered umiak is still used for spring bowhead whaling. However, because the umiaks are now no longer used in these communities for other subsistence activities, their skins now last longer before they need to be replaced. In Wainwright, on the other hand, the lead conditions are different and the majority of whaling captains presently use aluminum boats with powerful outboards to pursue and harvest bowhead whales. This practice is especially effective late in the whaling season when the leads are wide and bowheads travel further from shore. In 1983, there were no skin boats in Atqasuk or Point Lay.

While the general tendency has been to use more powerful motors and primarily aluminum boats, each study community has adopted equipment suitable to the particulars of their local environment. For example, Point Lay hunters presently use aluminum boats between 16 to 18 feet in length and virtually all the outboard motors are 35 horsepower. This homogeneity results from the importance of the shallow Kasegaluk Lagoon in the subsistence activities of local residents (*see* Point Lay subsistence land use patterns). More powerful outboards tend to draw too much water whereas smaller motors would limit the effectiveness of local beluga herding techniques. In inland Atqasuk the boats are also specialized. Primarily used for river fishing and traveling, these boats are both smaller and last longer than those used in the marine environment. In addition, the outboards used in Atqasuk are substantially smaller (4.5–15 horsepower) than those used in any of the coastal villages. Finally, Barrow's large population as well as the availability of local employment over a longer period of time has resulted in some families accumulating a variety of marine harvest equipment adopted for specific harvest activities (i.e., a different boat for marine mammals, upriver fishing, and whaling).

As with the snowmachine and three-wheeler, the most important change which has occurred since the adoption of boats and outboard motors is the reduction in traveling time to and from harvest areas. Hunters now travel to hunting areas for particular species and return in a fraction of the time formerly necessary, allowing them to maintain steady employment and still hunt and fish the desired quantity of food.

9.1.4 Airplanes

Barrow and Atqasuk are the only communities in the study area which have residents who rely on airplanes for subsistence activities. Atqasuk residents use the daily air service to travel to and from Barrow. Because some of these trips to Barrow are for sea mammal hunting, airplanes could be considered a subsistence tool for Atqasuk hunters. Barrow residents' most common use of airplanes is for travel to and from inland fish camps. These camps play an important role in the subsistence activities of Barrow residents and are commonly used throughout the summer and early fall for fishing and caribou hunting.

Traditionally, there were two ways to get to fish camp. Barrow residents either traveled overland early in the summer when there was still sufficient snow cover, or, if their camp was in the lower portion of one of the larger rivers, they waited until later in the summer when the ocean was free of ice and then traveled by boat. While these methods are still practiced by some Barrow residents, the time constraints resulting from conflicts with employment necessitate some families using airplanes. These families are unable to spend the amount of time required by the vagaries of the weather in traveling to and from fish camp.

The airplane is a convenient method for solving time conflicts between employment and subsistence activities in Barrow. Knowing that the best fishing occurs in the fall, an employed hunter may decide to take 2 weeks of subsistence leave from his borough job in the month of September but, because onshore winds hold the ice near the shore, he is unable to leave Barrow by boat. Rather than miss this important subsistence harvest, he will fly his family to camp. Unlike the other villages of the study area where there is relatively easy access to fishing areas, Barrow fishermen's access to their camps can be restricted by the proximity of ocean ice. While traveling to fish camp by airplane is expensive (the average one-way charter is $300), the high value which residents place on this activity justifies the cost.

9.1.5 Costs Associated with Subsistence Activities

Because the equipment now used in the seasonal round of subsistence harvests is expensive to acquire, maintain, and operate, it is necessary for a hunter to have access to cash. The harsh arctic conditions and the intensity of seasonal use result in very short life spans for the equipment, especially snowmachines. Equipment needed and other annual costs include boats, outboards, snowmachines, three-wheelers, repairs, ammunition, rifles, tents, sleeping bags, cook stoves, fuel, binoculars, sleds, and nets.

Table 9.1 is a partial list of subsistence expenses in the study area. It indicates that a hunter who is not a whaling captain spends an an estimated $3,800 annually for fuel, ammunition, and repairs. Combining the estimated life of the four major equipment expenditures with their average purchase prices results in an annual average cost of $3,927 for the purchase of an aluminum skiff, outboard motor, snowmachine, and three-wheeler. Although a hunter does not purchase each of these items every year, the relatively short life span of this equipment in the study villages requires that he often purchases at least one of them annually. Thus, in order to replace this equipment as it wears out, the hunter currently spends approximately $4,000 per year. Combining this with the annual costs for fuel, ammunition, and repairs results in an estimated annual cost of $7,727. That figure represents the capital outlay for an individual hunter and is not necessarily representative of the collective subsistence costs for a household or family unit. If there are two hunters in a household, the costs would increase but not necessarily double because not all equipment is duplicated. In addition, some related families living in separate households hunt together and purchase some equipment collectively. Although each hunter may have a snowmachine, the group may only purchase one seagoing boat and outboard motor. If the hunter is a whaling captain who only whales in the spring (Point Hope, Wainwright, and some Barrow captains), his annual subsistence costs are approximately $12,227. If he also whales in the fall (Barrow captains only), his annual subsistence expenditures rise to approximately $15,227.

The relatively high costs associated with the purchase, maintenance, and operation of boats, outboard motors, snowmachines, and three-wheelers has probably resulted in a higher financial cost of harvesting a given amount of meat than 20 years ago. Thus, although hunting is more efficient in terms of the effort necessary to harvest meat it is less efficient in terms of the amount of money it costs. Under present circumstances of high local employment opportunities, the cost of subsistence harvesting is not a disadvantage. Hunters in the study communities are presently able to earn the necessary money but this will not necessarily continue to be the case.

9.1.6 Employment and Subsistence Leave

The recent availability of local temporary and permanent jobs associated with or resulting from the North Slope Borough's capital improvements program has greatly contributed to villagers' ability to obtain, maintain, and operate their hunting equipment. For example, in the villages of Point Lay and Atqasuk, local employment opportunities were so

TABLE 9.1—Partial list of subsistence expenses, Chukchi Sea villages, 1983.

Equipment	Cost Range (dollars)	Average Cost (dollars)	Estimated Life (years)	Estimated Average Annual Cost
Aluminum skiffs	1,800– 3,000	2,400	5–6*	436
Outboard motors	1,500– 4,000	2,750	2–5	786
Snowmachines	2,800– 4,500	3,650	1–3	1,825
Three-wheelers	1,800– 2,600	2,200	2–3	880
	7,900–14,100	11,000		3,927
Estimated annual costs:				
Fuel	1,600– 2,000	1,800		
Ammunition	200– 600	400		
Repairs	1,200– 2,000	1,600		
	3,000– 4,600	3,800		3,800
Spring whaling	3,000– 6,000	4,500		4,500
Fall whaling	2,000– 4,000	3,000		3,000

SOURCE: Based on interviews by Stephen R. Braund & Associates of 34 subsistence harvesters in Point Hope, Point Lay, Atqasuk, and Barrow. Generally, all persons interviewed were employed during the past year (seasonal construction, full-time permanent, or part-time permanent). Four were unemployed at the time of the interviews.

NOTE: Does not include the cost of rifles, sleeping bags, cook stoves, tents, or binoculars.

* The estimated life of aluminum skiffs is the number of years they can be used safely in the ocean. Often, after they are considered unsafe for ocean use, villagers (especially from Barrow) take them upriver to fish camps.

high in June 1983 (fieldwork for this study) that there were no local residents working outside the village. Similarly, in September 1982, only 3 of the 112 employed residents of Point Hope worked outside the village (Alaska Consultants *et al.* 1984). This is substantially different than previous Point Hope employment patterns where residents seasonally (i.e., summer) left the village to work (Foote and Williamson 1966). Wainwright residents have enjoyed a similar increase in the amount of local employment, demonstrated by a 141% jump in local employment between 1977 and 1982. The relatively large number of locally available jobs is of preeminent importance to the present interrelationship between the cash and subsistence economies, as these local jobs enable individuals to both work and participate in local subsistence activities.

Most jobs in each village are either related to construction or are permanent North Slope Borough positions. The borough has a generous leave policy for permanent employees which allows them time to pursue subsistence interests. Construction jobs are generally high paying, seasonal, and temporary. Many local males prefer to participate in temporary construction work rather than full-time, year-round employment because it allows them more time to pursue subsistence activities. They can hunt during periods of unemployment, and the new equipment, which greatly increases hunters' mobility and travel speed (previously discussed), allows these workers to harvest wildlife in the evenings and on weekends while still employed.

From the villager's perspective, local employers generally allow adequate leave time for employees to pursue subsistence activities. For example, the North Slope Borough provides two types of leave which employees may use for this purpose: subsistence leave and personal leave. Under the borough's subsistence leave policy, any full-time permanent employee is entitled to 10 working days of unpaid leave per fiscal year to pursue subsistence activities. In addition, North Slope Borough employees who work the entire year accrue between 30 and 45 days of paid annual leave per year, depending on the length of their employment.

Workers often take this leave in smaller chunks of time to coincide with various subsistence pursuits. For example, if a hunter had 36 days of personal leave and 10 days of subsistence leave, he might take 2 or 3 weeks for spring whaling, 2 weeks for spring sea mammal hunting, 2 weeks for fall fishing and caribou hunting, and occasional days throughout the winter for caribou hunting. In addition, he would probably hunt on weekends and evenings when the weather permitted. Thus, by manipulating employment, leave time, and free time (i.e., evenings and weekends), allowing for seasonal wildlife availability, as well as taking advantage of improved technology, local hunters participate in the major harvests of the year and generally harvest as much meat as they desire (except when regulations or quotas limit hunting).

Generally, construction contractors in the villages do not have any formal subsistence leave policy for local workers, but they indicated that they let villagers go hunting and fishing when they so desired. This absence from the job, however, was without pay. When the hunters return to the village, they have a job if one is available. Most village corporations and their subsidiaries do not have formal subsistence leave policies, but leaders said they were very flexible, especially during whaling season.

In conclusion, considering the cash requirements for contemporary subsistence activities, the availability of local jobs, the seasonal or temporary nature of much of the employment, and the generous policies related to annual and subsistence leave for permanent workers, the recent employment opportunities in the North Slope are compatible with current subsistence activities.

9.1.7 Changes in Target Species

Because of changes in resource population abundance and migration patterns, as well as fluctuating and unpredictable weather and ice conditions, a viable subsistence economy must be flexible and capable of adjusting to seasonal and yearly variations. A change in one or two of a number of variables can result in a change in target species hunted in a particular area. Consequently, a healthy subsistence economy in the Arctic relies not on just a few species, but rather is based on a broad range of available resources to allow hunters to select species as availability and other conditions change. An example of how new hunting technology interacts with employment and other variables to change the hunting emphasis on specific resources is the decline of winter seal hunting in the study area.

With the replacement of sleds by snowmachines, it was no longer necessary for villagers to harvest vast quantities of wildlife for dog food. Prior to the use of snowmachines, sled dogs, which consumed an average of 2 to 3 pounds of meat per day per dog, often outnumbered people in the village and hence doubled the harvest requirements of the local hunters. Although the disappearance of dog traction has greatly reduced the amount of meat needed by subsistence hunters, it has not affected the hunting of all species equally. In many coastal villages (including the study communities), seal and walrus meat and, to a lesser extent, fish provided the bulk of food for the sled dogs. Walruses were large and therefore efficient to hunt, and seals and fish were generally available in the winter.

Besides eliminating the needs for a large winter seal harvest, the snowmachine's physical characteristics contributed to the decline in winter sealing. Snowmachines are not very compatible with sea ice hunting as they are heavy and their centralized weight does not offer the weight distribution advantages of the dog team. This increases the danger of falling through the ice. Furthermore, dogs are able to individually climb over ice ridges and the hunter can then lift and push the sled over while the dogs pull. The heavy snowmachine does not offer this advantage and rough sea ice often forms an impassable barrier. Consequently, most winter sealing now occurs along the landfast ice margin, with hunters traveling farther from the village but staying closer to shore.

On the other hand, the speed of the snowmachine proved very useful hunting caribou inland. Thus, when snowmachines replaced dogs, hunters tended to spend more time inland hunting. The recent (i.e., past 5 years) abundance and availability of caribou has also encouraged hunters to concentrate on this species during the winter when snowmachines can be used. In addition, caribou is a more preferred meat for human consumption than seal (Alaska Consultants, Inc. and Stephen R. Braund & Associates, 1984). To summarize, the reduced demand for dog food, new technology which favored inland travel, presently abundant terrestrial alternatives, and the availability of local employment, money, and store-bought meat have combined to change the winter target species from seal to caribou. However, if local wage employment opportunities fall off or the caribou population decreases, local hunters may resume more active winter seal hunting efforts, as flexibility is a necessary component of any subsistence economy.

It should be noted that the change in winter harvest activities did not necessarily decrease the desire for seal oil and sea mammal meat for human consumption. While a few hunters continue to hunt seals during the winter months, many have altered their seasonal round to obtain sea oil and meat later in the year. The availability of more powerful outboard motors and sturdy aluminum boats enhanced this process. At present in all study communities, the major sea mammal harvests occur during the open-water season as the hunters travel in and among the numerous ice pans and floes looking for sea mammals asleep on the ice. The increased mobility and safety of this new oceangoing equipment has allowed hunters to concentrate on the larger and preferred ugruk (bearded seal) during the open-water months of June, July, and August.

9.1.8 Barrow Case Study

To this point, the discussion of the regional subsistence economy has been fairly general with specific examples from the study area villages. However, since the 1930's Barrow subsistence economy has evolved differently than that of the smaller villages of the North Slope region. The differences, largely a result of Barrow's more rapid rate of population growth and concurrent growth in local employment opportunities, are presented here to demonstrate the flexibility necessary for a successful subsistence harvest strategy.

Likely the single most important difference in Barrow's subsistence economy and that of the other villages of the study area results from Barrow's large Inupiat population (the 1980 Census counted 1,720 Alaska Natives in Barrow). This large population affects Barrow's subsistence economy in several ways. First, there is diversity among families as to species they prefer to hunt which, in turn, affects timing and equipment costs. Second, the areal extent of subsistence use areas is greater for Barrow than any other study village, increasing operating costs and reducing equipment life. Finally, the large population of Barrow results in a wide range of economic and subsistence strategies among families and individuals.

The number of wildlife resources available to Barrow residents is not necessarily greater than those of the other study villages. However, Barrow's unique physical setting and large population affects familial and individual harvest patterns. One important factor in determining the target species for an individual or family is taste preference, which varies considerably in such a large community. Other equally important factors include cultural significance, species availability and abundance, weather, ice conditions, and the availability of employment. The variable nature of most of these factors demonstrates how the target species for a family or an individual may differ from year to year. The importance of Barrow's unique physical setting is demonstrated by the two-season bowhead whale harvest. Barrow is the only village on the North Slope which can hunt the bowhead in both the fall and spring.

Barrow's large population necessitates a larger harvest area than is required in the smaller study villages so that hunters do not exceed the carrying capacity of the local environment (*see* Barrow's subsistence land use patterns). For example, a local area can be fished out if there is too high a density of fishermen. One resident stated that he had to go far afield from Barrow in order to find a suitable fishing location which was not already occupied by a Barrow or an Atqasuk family. While the highly migratory nature of caribou and most sea mammals minimizes this problem, variations in weather and ice conditions require a large area for these species as well. This large area results in more wear and tear on subsistence harvesting equipment, particularly boats, outboard motors, and snowmachines, which increases subsistence costs.

Barrow's large population supports considerable variety in terms of economic and subsistence strategies within the community. Not all working age residents of Barrow are employed. Some prefer to spend all of their time engaged in subsistence activities. Other family members who are employed may supply these hunters with the necessary equipment and cash in trade for a share of the harvest product. As discussed below, hunters who do not work are able to keep their expenses down by maintaining traditional harvest patterns. All 18 of the Barrow subsistence harvesters who were interviewed as part of the 1983 fieldwork were involved in the wage economy at least on a part-time basis. The following three examples from Barrow demonstrate different solutions to the high costs of subsistence activities:

1) Two brothers alternate years as whaling captain to compensate for the high cost of operating a whaling crew. While many Barrow residents are able to earn the necessary cash to place a crew on the ice each spring, others find the costs prohibitive. By alternating years as captain, these brothers are able to save money for other household and subsistence needs.

2) One young hunter who was interviewed did not own a boat, three-wheeler, or snowmachine. Instead he used his father's equipment. If both he and his father went hunting, they divided the operating costs for the trip. If the son went out by himself, he paid for the fuel and other expenses. In return for the use of his father's equipment, this young man supplied all of the meat for his parents' household, resulting in a mutually agreeable division of subsistence costs. This agreement allows the young hunter to spend his money on house and land payments and other costs related to his own nuclear family. In addition, his parents store food for his family in their ice cellar.

3) A final example demonstrates how costs of expensive items are distributed among family members. In this instance, a father and his sons have formed a collective subsistence hunting team and distribute the costs equally among themselves. All of the equipment is stored in a shed at the father's home, and each son has particular responsibilities. One takes care of the snowmachines and their repairs, another tends to the sleds and camping gear, and so forth. In this situation, not all members of the group own all of the necessary subsistence harvest equipment, and each has reduced his own costs while, at the same time, maintaining access to the equipment.

9.1.9 Conclusion

In summary, increased supplies of cash provided by local economic opportunities have changed the harvest techniques and the timing of the harvest of many marine mammals. Because of wage employment, free time is an increasingly scarce commodity which local residents use to the fullest. High levels of local employment have resulted in greater use, if not dependence, on three-wheelers, snowmachines, and wooden or aluminum boats with outboard motors. These modern subsistence tools have minimized the "down time" normally spent in preparation for and traveling to and from harvest areas. The increase in mobility has made weekend and evening hunting feasible and productive. North Slope residents stated employment has little effect on hunting participation because weekends and evenings, in combination with a few longer seasonal trips (i.e., bowhead whaling, fall fishing), provide sufficient time to harvest the desired amount of wildlife resources. Thus, increased cash provided by employment is seen as a complement to subsistence pursuits. As one hunter stated:

> The best mix is half and half. If it was all subsistence, then we would have no money for snowmachines and ammunition. If it was all work, we would have no Native foods. Both work well together.

The successful mix of cash and subsistence presently visible in the study communities is dependent on a few variables which could change in the future. First, the most important aspect of current village employment opportunities is that the jobs are local. Working at Prudhoe Bay or some other site outside a community would not provide village hunters with as much flexibility as local employment and leave time would not necessarily coincide with the availability of the specific resource which the hunter would like to harvest. Furthermore, hunting on weekends and in the evenings would be impossible and the flexibility to hunt when the weather, ice conditions, and local availability or resources were favorable would be lost. Villagers prefer to work in their own communities. Second, the recent abundance of caribou in the study communities enables local hunters to have successful hunting trips in a relatively short time. Caribou populations and migration routes fluctuate greatly over time. During periods of lower local abundance, villagers would probably have less hunting success during short trips (i.e., evenings and weekends), which could increase dependence on marine mammals.

9.2 SUBSISTENCE LAND USE PATTERNS

For purposes of this study, subsistence land use patterns involved a review of local (Chukchi Sea village Inupiat) use of coastal lands and offshore areas for subsistence activities. Furthermore, because this study is related to offshore oil and gas development, this discussion and associated subsistence maps are marine oriented with little attention to terrestrial resource use. The subsistence maps accompanying descriptions of individual communities identify marine and coastal harvest ranges by species for key marine resources (bowhead whales, beluga whales, seals, walruses, fishes, and birds) in each of the various Chukchi Sea villages. Available subsistence information for these villages was uneven. For example, considerable data were available for Wainwright (Milan 1964; Nelson 1969, 1981; Ivie and Schneider 1979; John Muir Institute 1983) and therefore no additional subsistence fieldwork was done for this village. Some data were available on Point Hope (Pedersen 1979b; Lowenstein 1981), but relatively little subsistence range information existed for Point Lay (Schneider and Bennett 1979), Atqasuk, or Barrow (Schneider *et al.* 1980). Consequently, the field effort related to mapping coastal subsistence harvest ranges concentrated on Point Hope, Point Lay, Atqasuk, and Barrow. As part of the subsistence mapping, coastal areas of critical subsistence importance (i.e., intensive use areas) were identified. In the discussion of marine resource use, the harvest seasons for each species are also identified. (See Chance [1966] and Spencer [1959] for a general discussion of Inupiat, Pedersen [1979a] for a description of regional subsistence land use on the North Slope, and Worl [1980] for a discussion of Inupiat whaling.)

An assessment of recent changes in the coastal harvest ranges of the Chukchi sea villages indicated that recent technological improvements (snowmachines, powerful outboard motors, and three-wheelers) have allowed subsistence hunters to travel to harvest areas much faster and cover more area while hunting. Hunters can now travel in a few hours what used to take a day or longer. Thus, although they may spend less time hunting than 20 years ago, they are much more efficient (i.e., it takes less time to harvest the same amount of meat) and the harvest ranges have not diminished. Discussions with elders indicated that present ranges are similar to traditional use areas. In some cases, the range has expanded (e.g., fall whaling in Barrow).

Although the fieldwork indicated recent technological improvements have not altered the range of species harvested, in some cases there was a shift in the intensity of utilization among species. For example, as discussed in the regional subsistence economy section, a combination of variables, including the replacement of dog traction by the snowmachine and the present abundance of caribou led to an increased emphasis on caribou hunting in the winter and a reduction in overall winter hunting effort for seal. In addition, more powerful outboard motors have facilitated an increased hunting emphasis on large sea mammals, especially during the spring and summer sea mammal season. Thus, snowmachines and powerful outboard motors have changed the emphasis on particular species during certain seasons.

Limited field time necessitated the collection of subsistence resource data by interviews with knowledgeable subsistence harvesters in each community. Active harvesters between the ages of 20 and 60 were interviewed. Harvest areas of inactive or retired hunters were not mapped. The number of interviews is identified under each community discussion. Each interview consisted of a checklist of marine and coastal species, the timing or seasonality of harvest activities, the level of effort and mapping of the area used to harvest each species. Because the focus was on present land use patterns, local harvesters were asked to concentrate their responses on the activities of the past 5 years. Hence, the intensive use areas identified on each map depict this focus and do not represent a historical land use inventory. The maximum areal extent used for harvesting each species is a dynamic factor which is affected by species abundance and range, changes in harvest technologies, and physical parameters such as weather and ice conditions. As a result, the maximum use boundary does not correspond with the intensive use areas, but represents the farthest limits respondents remembered going for the harvest of a particular species. In addition to the field interviews, materials from the scientific literature and agency documents were reviewed. Subsistence land use patterns were delineated on 1:500,000 and 1:1,000,000 scale maps and then reduced for this report.

9.2.1 Point Hope

While residents of Point Hope (population 570) enjoy a diverse resource base, including both terrestrial and marine animals, this discussion concentrates on marine-oriented subsistence activities. The subsistence land use maps are based on interviews with 12 local hunters and fishermen. The physical setting of Point Hope on a cuspate spit has always proved advantageous for harvesting sea mammals, the traditional primary source of food in this village.

Point Hope's location provides three distinct advantages to local residents who harvest marine resources. First, because most of the marine mammals which Point Hope hunters harvest are migratory, the point forms a natural barrier in the animals' annual migration route. The migrating animals are concentrated in the waters off the point, placing local hunters in a strategic location. Second, the dominant surface currents that flow north along the coast are relatively warm and rich with a wide variety of marine life. These warm currents result in only seasonal ice formation in most of the Chukchi Sea which allows marine mammal populations to occur in greater numbers than in the Beaufort Sea where perennial ice limits the number of leads and ice-free areas. Finally, the location of the spit in relation to prevailing winds increases hunters' chances of finding suitable open water in which to hunt sea mammals. Most marine mammal hunting occurs in open leads in the pack ice, and suitable leads open on both sides of the spit depending on the wind direction. Point Hope's physical setting is so advantageous to marine mammal hunting that the spit has been continuously inhabited for at least the last 2,000 years (Larsen and Rainey 1948).

Bowhead Whale

In late March or early April a large lead forms south of Point Hope through which bowhead whales, and other marine animals, migrate north. The establishment of 15 to 18 spring whaling camps along the edge of this lead marks the beginning of Point Hope's annual spring marine mammal hunt. Although the actual harvest area varies from year to year depending on where the open lead forms, the whaling camps in the recent past have all been confined to a relatively small area south and southeast of the point (Fig. 9.1). Historically, whaling camps were also established near Cape Lisburne (Burch 1981) and camps as far south as Cape Thompson were reported during fieldwork for this study.

The intensive use area delineated in Figure 9.1 indicates the location of the leads and the corresponding harvest areas over the past few years. The distance of the lead from shore varies from less than 1 mile to 10 miles in extreme cases. Although Point Hope has open water for a long time during the whaling season, the lead is generally narrow. Sometimes two narrow leads develop, the furthest lead being inaccessible to Point Hope hunters. These ice conditions can result in poor harvest success for Point Hope as the whales may travel in the inaccessible lead or after being struck, sound and resurface in this second lead.

Traditionally, whaling in Point Hope began in late March, the earliest a suitable lead formed, and lasted until the first part of May. By that time, the majority of bowheads have passed and the landfast ice margin deteriorates so rapidly that landing a bowhead becomes difficult. Since the implementation of the International Whaling Commission's bowhead quota system in 1978, the spring whaling season has often been curtailed to less than 3 weeks. Once Point Hope hunters have exhausted what they consider to be an inadequate opportunity (four strikes per season for 1982 and 1983), many whaling captains leave the ice due to the high cost of maintaining a whaling crew. The bowhead harvest is now concentrated in April when ice conditions are most favorable.

Of all the marine resources harvested by Point Hope hunters, the bowhead whale is the most important in the subsistence economy, accounting for 22.3% of the subsistence harvest over the past 20 years (Stoker 1984). Harvest success varied from 0 to 14 animals over the same period. In 1982 and 1983, Point Hope whalers landed one bowhead each year. For a more complete discussion of Point Hope whale hunting see Lowenstein (1981), VanStone (1962), and Rainey (1947).

Seals

Point Hope residents' subsistence use patterns for hair seals and bearded seals (ugruk) are concentrated south and southeast of the point, an area Point Hope hunters indicated is both safer and more productive than the north shore (Fig. 9.2). Winds from the north open leads suitable for hunting, while the prevailing onshore currents prevent hunters from drifting off or being separated from land by water. According to Lowenstein (1981), when onshore currents prevent the ice from drifting away, hunters can go out 10 to 15 miles or more on the south side. While the areas used to hunt bearded, ringed, and spotted seals are similar, periods of concentrated hunting are different for each species.

Ringed seals are generally available from October through June but primarily harvested during the winter months from November through March. The availability of preferred species or resources with greater catch per unit effort ratios limit the ringed seal harvest during the rest of the year. Both traditionally and presently, the February harvest of ringed seals is the single most important hair seal harvest. Ringed seals are also an important resource at spring whaling camps where, along with belugas and eiders, they supply food for the crews.

Although Point Hope hunters generally prefer the south shore (from the point to Cape Thompson) for seal hunting, this activity also takes place north of the village. North shore hunting for ringed seals usually occurs close to shore and is most successful at Sinuk (the mouth of the Kukpuk River) and the numerous small points between the village and Cape Lisburne where open water is found (Kilikralik Point and Cape Dyer). Ringed seal hunting off the south shore is generally concentrated within 5 miles from

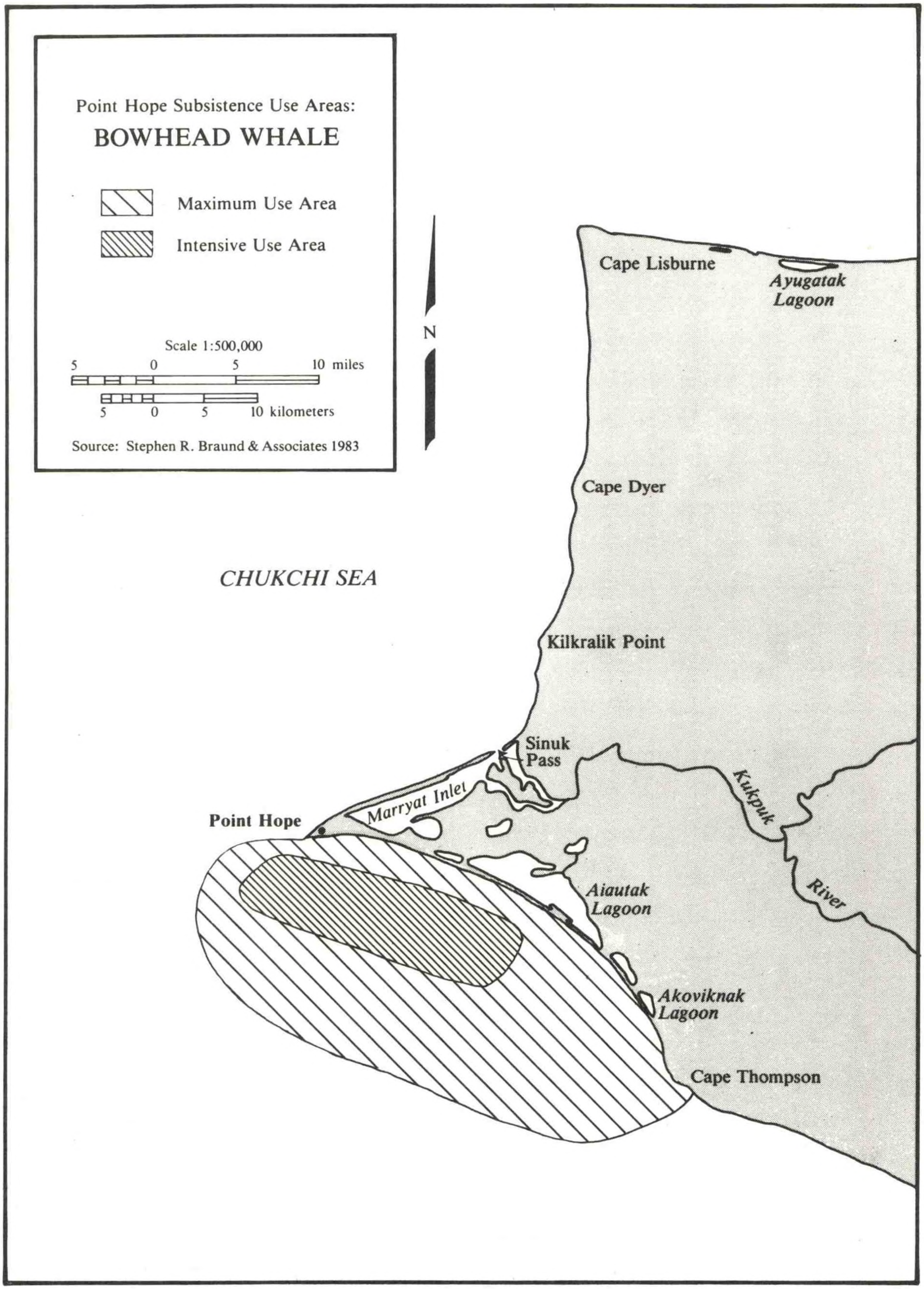

FIGURE 9.1—Point Hope subsistence use areas: bowhead whale.

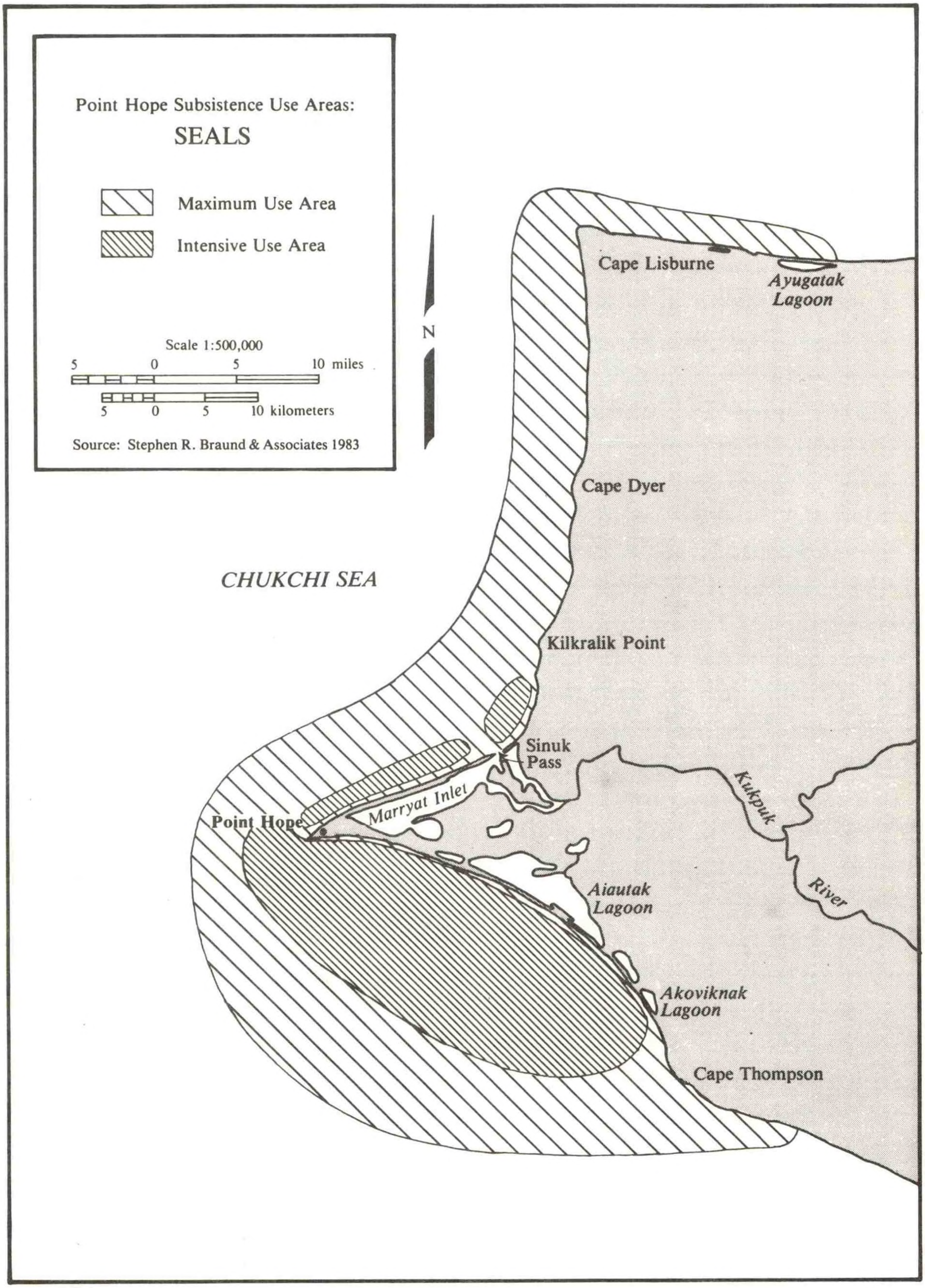

FIGURE 9.2—Point Hope subsistence use areas: seals.

shore on the ice pack between the point and Akoviknak Lagoon.

Spotted seals are more common than ringed seals in the open-water months of summer and early fall. They are occasionally taken along the north shore and at Sinuk as they feed on anadromous fishes. Ribbon seals are rare and are seldom harvested.

The harvest of bearded seal, or ugruk, has always been an important subsistence activity in Point Hope, because it is a preferred food and because of its use as covers for the whaling umiaks. Almost all spring marine mammal hunting is initiated from spring camps established after whaling. These camps begin just in front of the village and extend south along the coast to Akoviknak Lagoon. With quick access to town (it takes only 1 hour to travel to Cape Thompson from the village on a three-wheeler), residents are now going to their camps after work and on weekends rather than for continuous occupation.

The major bearded seal harvest is concentrated during May and June (to as late as mid-July in some years) concurrent with the breaking up of the pack ice into numerous pans and floes. With the first signs of open water and lead formation in the landfast ice and the adjacent pack ice, hunters begin to search the ice for seals. Because of the need for bearded seal skins, as well as the larger size of this species, local hunters concentrate on them over the smaller hair seals. As the ice continues to deteriorate and break up into smaller pans, residents begin to travel in wooden and aluminum boats among the floes looking for seals and walruses. Powered by large motors, these boats allow hunters to cover a larger area in equal or less time than in the past. One resident stated that as long as there is ice there will be ugruk, and whaling captains who need more skins will continue to hunt this species until the last remnants of ice are gone, usually in July.

Walrus

Walrus, traditionally one of the primary sources of dog food, continues to be harvested by the Eskimos of Point Hope as a human food source. The local abundance of walruses has fluctuated with the overall population and distribution of this species in the northern Bering and Chukchi seas. During the past decade the use of the walrus resource has increased in Point Hope as the number of locally available animals increased.

The major walrus hunting effort in Point Hope coincides with the spring ugruk harvest, and the same spring camps are used as bases for both activities (Fig. 9.3). June through early July is the primary season for walrus hunting, and the estimated village harvest ranges from 10 to 30 animals during this period. As in the case of ugruk, the harvest technique involves boat travel among the ice floes, shooting walruses as they bask on the ice.

Point Hope residents also hunt walruses during the rest of the summer along the north slope, especially at the rocky capes where the animals tend to haul out.

Harvesting as far north as Cape Lisburne is done at this time in conjunction with other subsistence activities such as egging, fishing, or traveling the shores in search of caribou. The last walrus hunting occurs during September and October as they pass the point on their southward migration.

Beluga

The Point Hope harvest of beluga whales is concentrated offshore during the whaling season and along the coast during the open-water months, particularly July. The total beluga harvest area extends from Cape Dyer on the north to Cape Thompson on the south (Fig. 9.4). Belugas are available as early as the end of March through the end of August. Point Hope hunters actively pursue and harvest the whales during two distinct seasons: offshore during spring whaling and again along the coast later in the summer, particularly July. The first and larger harvest occurs during the whaling season when no bowheads are present. At least one crew in 1983 harvested four belugas (fieldwork for this study), and Lowenstein (1981) indicated that it was rare that a crew will not take at least one beluga during the whaling season.

Although animals migrate past the point in May and June, villagers do not harvest them at this time because of deteriorating ice conditions along the landfast ice margins as well as the greater availability of ringed seals and walruses.

Belugas are occasionally harvested during the summer open-water season on the south shore as well as coastal areas on the north side of the point as far as Cape Dyer. Hunters are particularly successful near Sinuk, a result of belugas feeding on anadromous fishes of the Kukpuk River.

Fish

Point hope residents harvest a variety of fishes throughout the year. As soon as the landfast ice breaks free from the shoreline (generally in mid- to late June), villagers use set nets and beach seines to catch Arctic char and three species of salmon: pink, coho, and chum. This activity takes place from coastal fish camps located along the shore from Cape Thompson north to Kilikralik Point (Fig. 9.5). While some Point Hope residents fish outside this area, it is generally done in conjunction with other subsistence activities, such as egging or caribou hunting. The summer fishing season extends from mid- to late June when the ice breaks free from shore through the end of August, with July being the most impor-

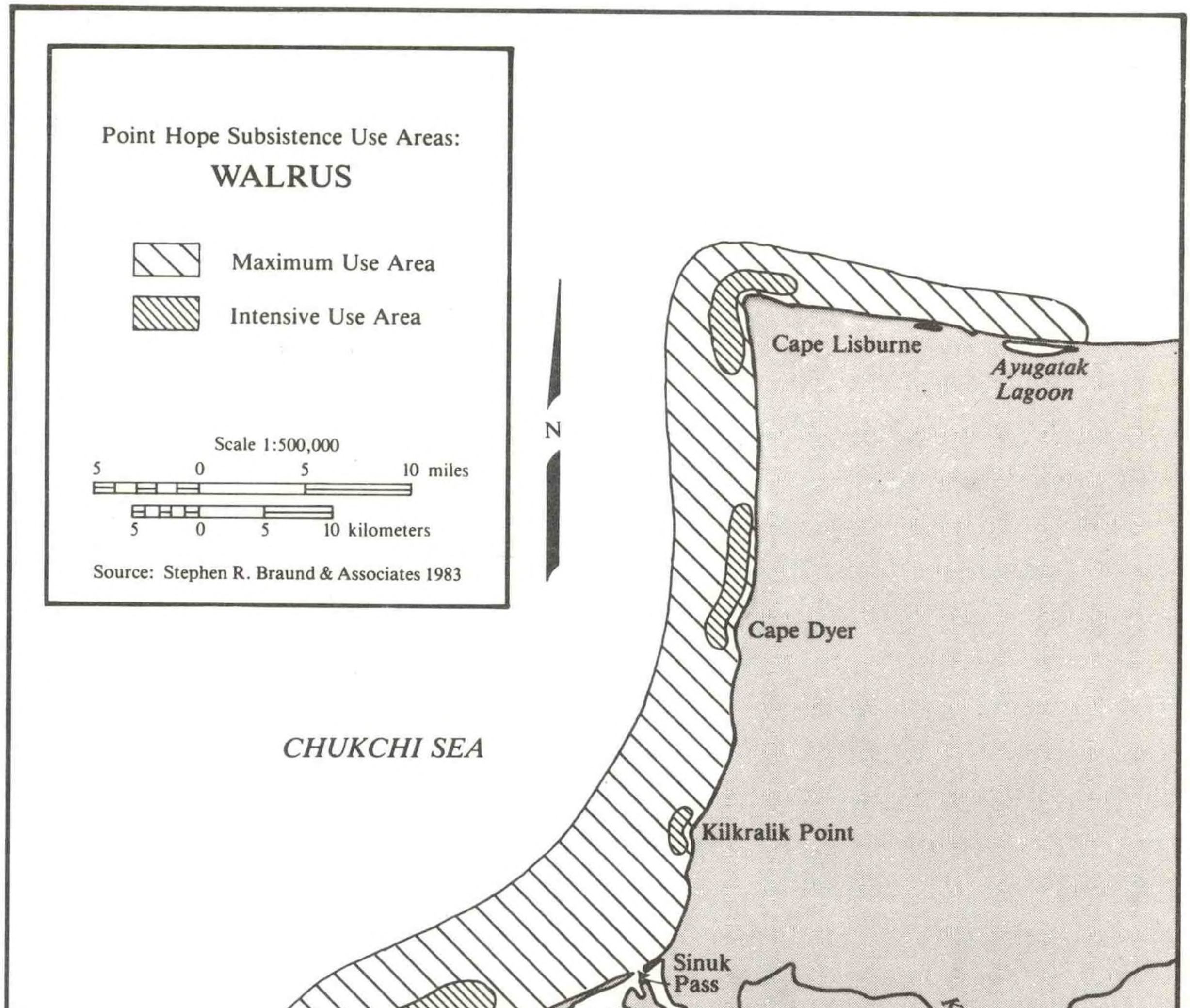

FIGURE 9.3—Point Hope subsistence use areas: walrus.

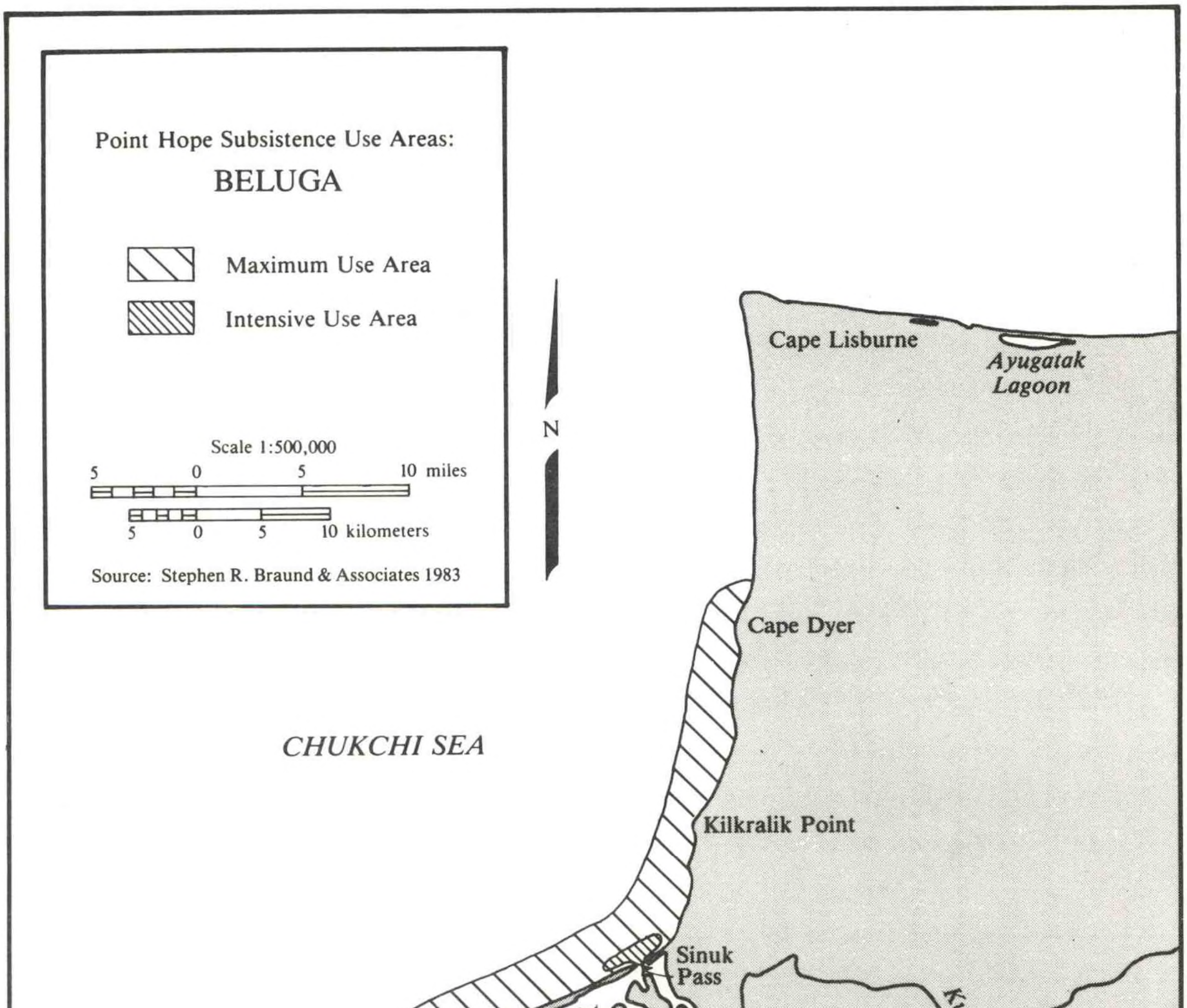

FIGURE 9.4—Point Hope subsistence use areas: beluga.

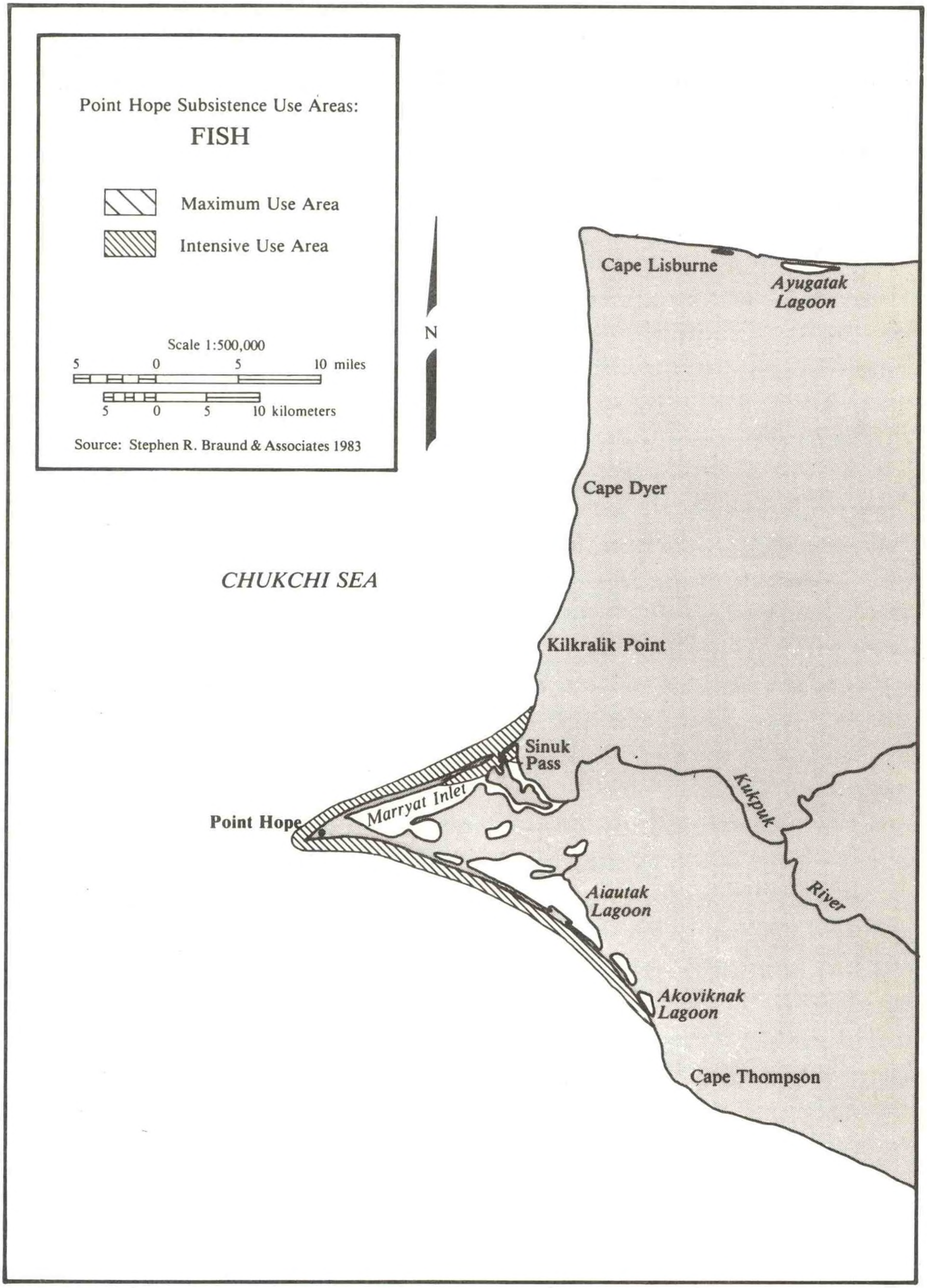

FIGURE 9.5—Point Hope subsistence use areas: fish.

tant month. Summer fishing provides the village with a fresh meat supply at a time of year when other marine resources are scarce.

According to the 1983 field interviews, the first fish to appear in the summer are Arctic char which are traveling north. These fish are followed by pink, coho, and chum salmon. In August, the char again pass the village and are harvested for several days off of the point and along the north beach as they migrate south to overwintering rivers such as the Wulik River near Kivalina. Point Hope residents occasionally travel to Kivalina for the upriver fall char fishery (Braund and Burnham 1983).

Other fish species which Point Hope residents harvest include whitefishes, grayling, saffron cod, and flounders. Occasionally flounders appear as an incidental catch in the beach seine and gill net fisheries during the summer. Villagers harvest grayling and whitefishes on the Kukpuk River during the October upriver fishing period. From December through February, villagers fish for cod through the ice near the point; January is the most important month for this fishing.

Migratory Birds and Eggs

Waterfowl and other migratory birds also provide a source of food for Point Hope residents (Fig. 9.6). Eiders and other ducks, murres, brant, geese, and snowy owls are all harvested at various times of the year. In addition, Point Hope residents still harvest murre eggs from the cliffs at Cape Thompson and Cape Lisburne.

Eiders are fairly common during the whaling season and are harvested as they fly along the open leads. Later in the spring, Point Hope residents harvest a significant number of eiders, geese, brant, and other migratory waterfowl, hunting along both shores of the point as well as the numerous lakes and lagoons. Geese are harvested from the middle of May until the middle of June, while brant are harvested at this time as well as during September as they migrate from their summer breeding grounds. Snowy owls are occasionally trapped later in the fall (October) on their southward migration.

Polar Bear

Point Hope hunters also harvest polar bears, primarily during the winter from January to April. Because seals compose a large part of the bears' diet, the bears are often taken during winter seal hunting. Polar bears are mainly harvested south of the village, generally in the area of intensive seal hunting.

9.2.2 Point Lay

The environmental setting of Point Lay is uniquely different from the other villages of the study area, resulting in different local land use patterns. Point Lay, formed by the delta of the Kokolik River, is a much more subtle physical feature than Cape Lisburne or Icy Cape and is not comparable to the spit formation at Point Hope or Barrow. Fluvial deposits have formed a series of barrier islands and bars along the coast which encloses Kasegaluk Lagoon, the most important environmental feature in the region. The lagoon, which stretches from north of Icy Cape to south of Point Lay, plays an important role in the marine resource harvest patterns of Point Lay residents. The most significant effect Point Lay's unique environmental setting has on local land use patterns is the conspicuous absence of local bowhead whaling in the current seasonal round of Point Lay hunters.

Because of the prevailing coastal current, Point Lay hunters generally begin the spring marine mammal hunt south of the village where the first broken ice appears. This allows successful hunters to dress their kills as they drift north toward the village. If the hunters are unsuccessful near the village or do not get the desired quantity at this time, they can travel north to Icy Cape. In the Icy Cape region shoals ground the ice, concentrating both ice floes and marine mammals in this area after the ice has disappeared farther south.

The general area which Point Lay residents use for marine resource hunting extends from Cape Beaufort in the south to Icy Cape in the north. Point Lay hunters harvest game outside this area, but it is usually done while traveling to or from another village. Point Lay residents indicated that their most important subsistence resource is caribou. However, marine mammals (especially belugas), fishes, and migratory birds play an important role in the local subsistence economy. The following summary of Point Lay marine resource use patterns is based on in-depth interviews with seven local hunters as well as other members of the community.

Beluga

The beluga whale is presently Point Lay's most important marine resource. For the past several years, this species has provided a greater quantity of food to the subsistence economy than any other marine resource. The beluga harvest, and the subsequent dressing and storage, is the only communal subsistence activity currently practiced in this village.

Beluga harvesting is usually concentrated in the first 2 weeks of July. The whales, traveling in pods as they migrate north, stop and feed in the passes of Kasegaluk Lagoon. Point Lay residents concentrate their hunting effort in Naokok and Kukpowruk passes, south of the village (Fig. 9.7). When the belugas are sighted, villagers use as many boats as they have available to drive the animals into the

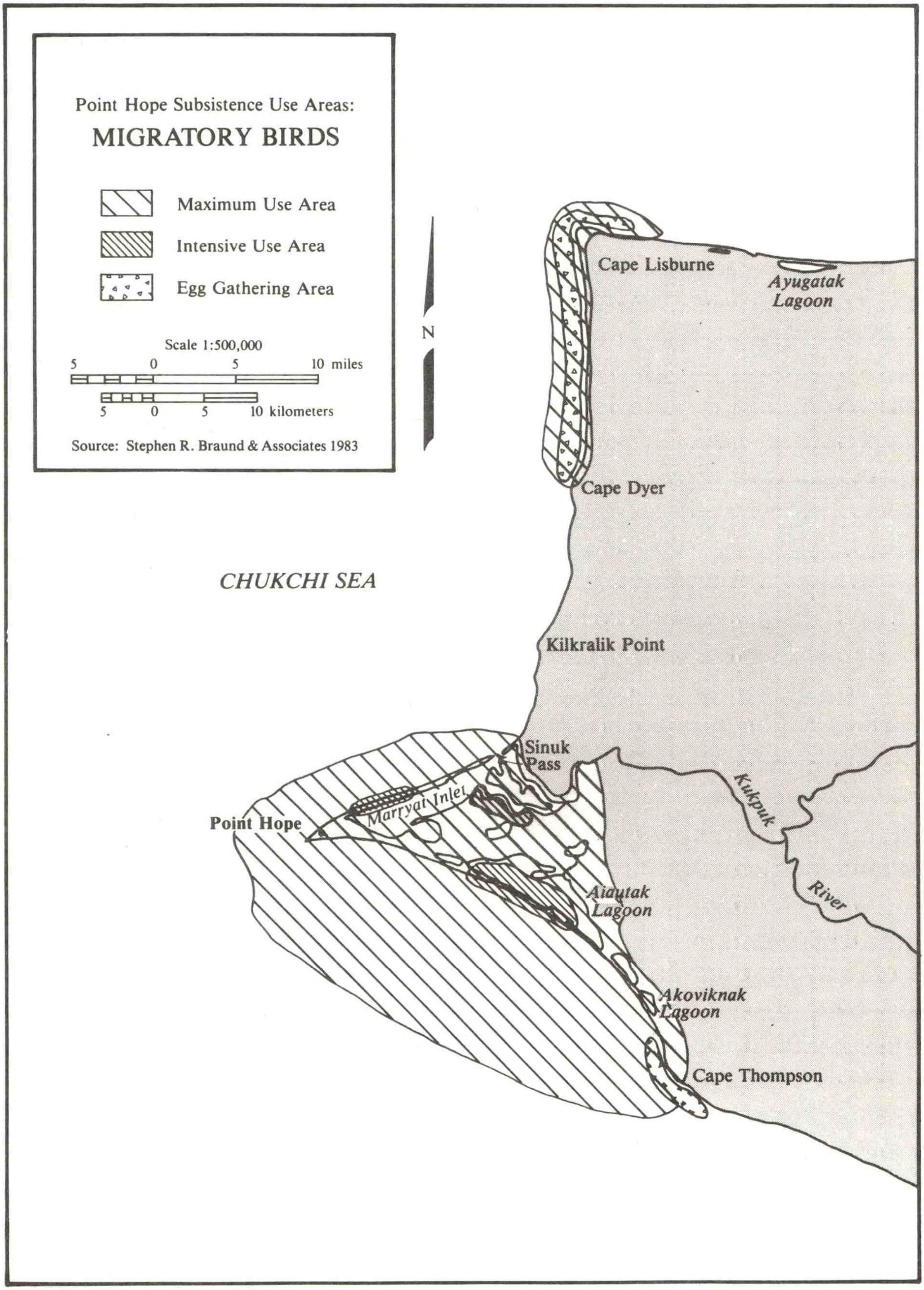

FIGURE 9.6—Point Hope subsistence use areas: migratory birds.

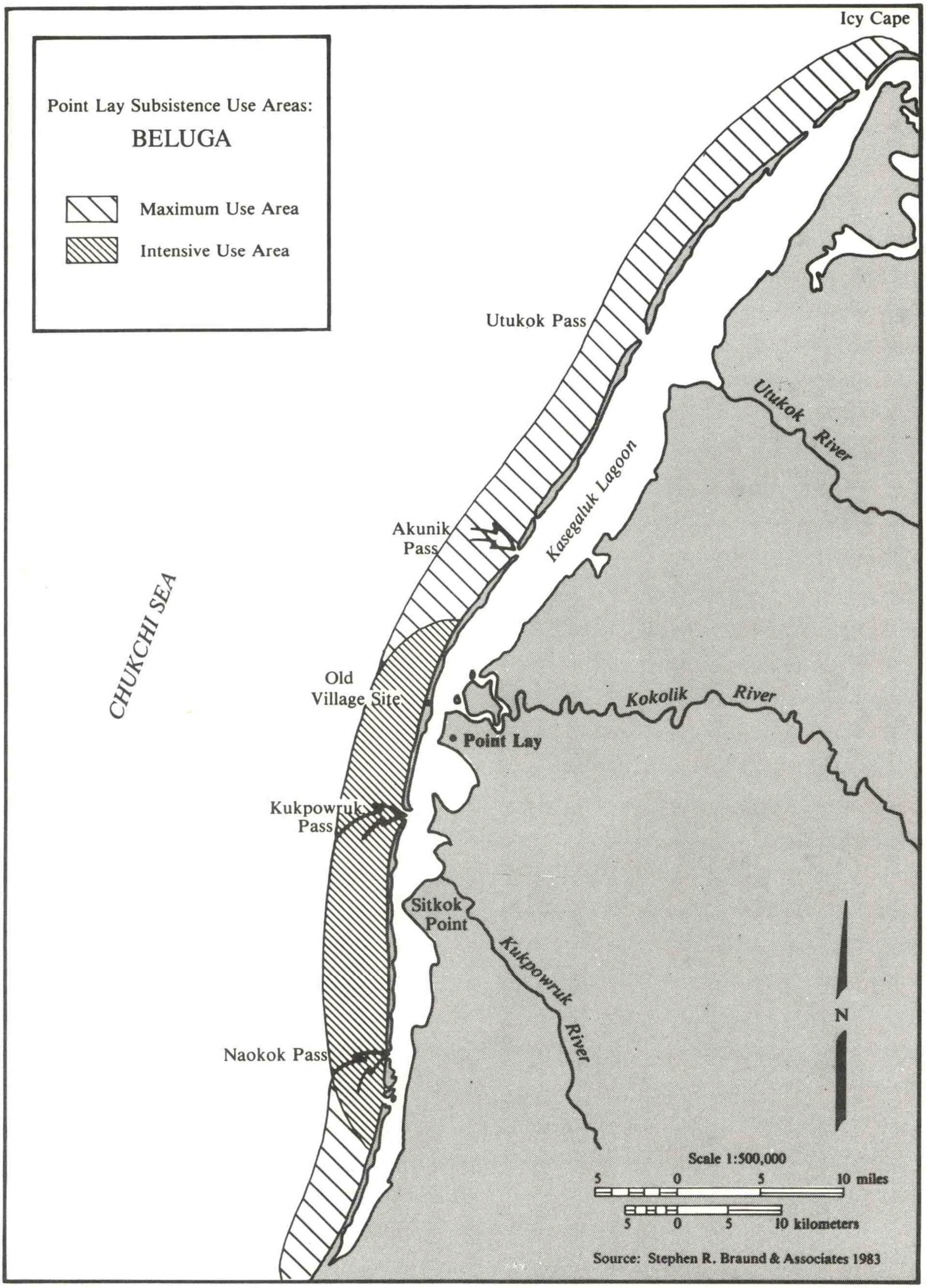

FIGURE 9.7—Point Lay subsistence use areas: beluga.

lagoon. Once inside the lagoon, the belugas are herded into shallow water near the old village site where they are shot with rifles. The belugas sink once shot, but the shallow water prevents the loss of the animals. If the beluga harvest has been unsuccessful in the passes south of the village, Point Lay hunters travel to passes north of the village, ranging in rare cases as far as Icy Cape in search of whales.

In 1982, Point Lay hunters harvested 28 belugas during the July hunt. The hot sun requires that all meat and muktuk be placed in ice cellars or preserved in another manner immediately after the harvest. All able-bodied members of the community participated in this activity.

Fish

Fish are an important resource in the subsistence economy of Point Lay. They are readily available and the activity is not labor intensive. Species harvested include chum, pink, and king salmon, Arctic char, herring, whitefishes, flounders, and grayling. Most of the marine fishing is done with set gill nets during July and August. In addition, Point Lay residents fish upriver, especially the Kukpowruk and Utukok rivers, during the fall months of September and October.

Point Lay's harvest area for marine fishing includes both shores of the barrier island and the mainland coast from Icy Cape to the southern end of Kasegaluk Lagoon (Fig. 9.8). Intensive use areas are Naokok Pass, both sides of the barrier island upon which the old village is located, and the shores of the mainland near the present village site. The area in the immediate vicinity of Icy Cape was repeatedly identified as an excellent fishing area, but Point Lay residents stated that they seldom went this far anymore because local fishing has been successful and there were conflicts with their jobs. August is the best month for marine fishing.

Walrus

The importance of the walrus as a subsistence resource has declined in recent years, but Point lay residents' hunting range for this species is greater than that of any other marine mammal (Fig. 9.9). Traditionally a source of dog food, walruses are now primarily harvested for human consumption. Local hunters reported that during years of favorable ice conditions they may harvest as many as 10 to 15 walruses (1983 was such a year), whereas in a year of difficult harvest conditions (i.e., heavy local ice restricting offshore access), none are taken. Point Lay residents' walrus hunting range extends the entire length of Kasegaluk Lagoon south of Icy Cape and as far offshore as 20 miles.

Weather and ice conditions permitting, walrus hunting occurs at the end of June and throughout the month of July. The animals are generally associated with ice floes and are found as they ride the ice north during their annual migration. Point Lay hunters have observed that approximately 15 miles offshore there is a north-flowing current (Alaskan Coastal Current, *see* Chapter 2) with larger concentrations of marine mammals. Harvesting a walrus this distance from shore can be extremely dangerous and a change in wind direction can trap the hunter among the floes. If unsuccessful nearer the village, hunters occasionally travel to Icy Cape where walrus hunting can continue into August.

Seals

The importance of seals in the subsistence economy of Point Lay has declined in recent years for three reasons. First, there has been a decrease in the need for dog food associated with increased snowmachine use. Second, wooden and aluminum boats have replaced umiaks covered with bearded seal skin. Finally, the present proximity and abundance of the western arctic caribou herd has decreased hunting pressure on seals. The general harvest area for these species is from Cape Beaufort in the south to Icy Cape in the north and a maximum of 15 miles offshore (Fig. 9.10).

Ringed seals, generally available in all but the ice-free months of July and August, are usually harvested during the spring (April–June). Local residents rarely harvest ringed seals prior to this time as they are busy hunting caribou and trapping furbearers. Ringed seals are harvested near Cape Beaufort in April because open water appears there first. Hunting takes place nearer the village as spring progresses, and some ringed seals are taken from boats as Point Lay hunters travel among the floes looking for bearded seals and walruses in June and July. Spotted seals feed in the lagoon during the summer and are occasionally harvested as they rest on the shore adjacent to the numerous passes of Kasegaluk Lagoon. These seals have desirable pelts and can be hunted in the late summer in open water because they are fat and do not sink when shot (North Slope Borough Contract Staff 1979).

Bearded seal hunting begins soon after other seal hunting in the spring in the same harvest areas. Point Lay bearded seal hunting is concentrated in June. By this time ice has begun to break up and hunters look for the seals among the floating ice. Usually the hunting takes place 5 or 6 miles offshore but, later in the month, Point Lay hunters may go out further as they look for walruses and bearded seals. In recent years, Point Lay hunters have taken a total of 2 to 10 bearded seals per year, while the harvest of ringed seals has averaged three or four per family

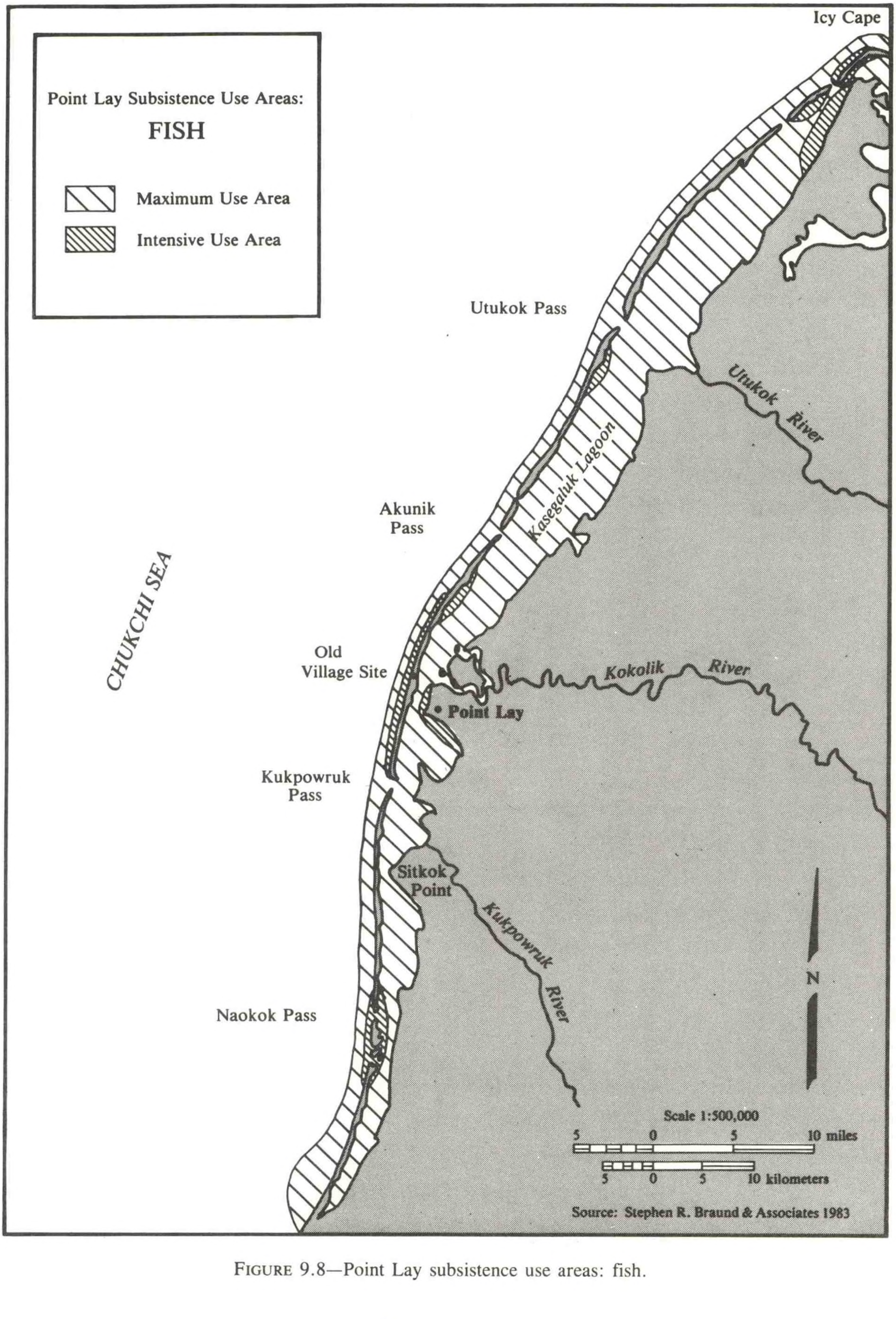

FIGURE 9.8—Point Lay subsistence use areas: fish.

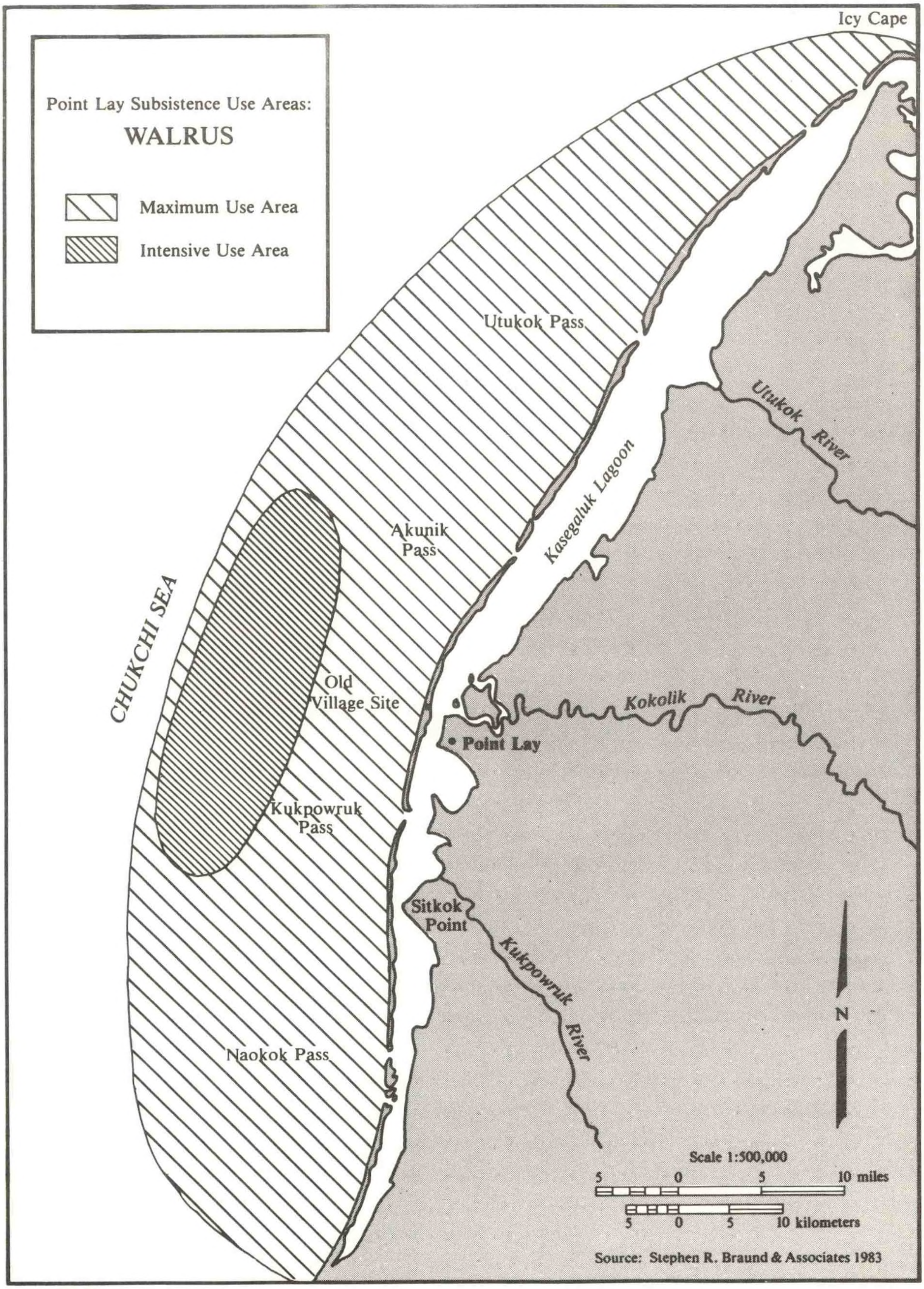

FIGURE 9.9—Point Lay subsistence use areas: walrus.

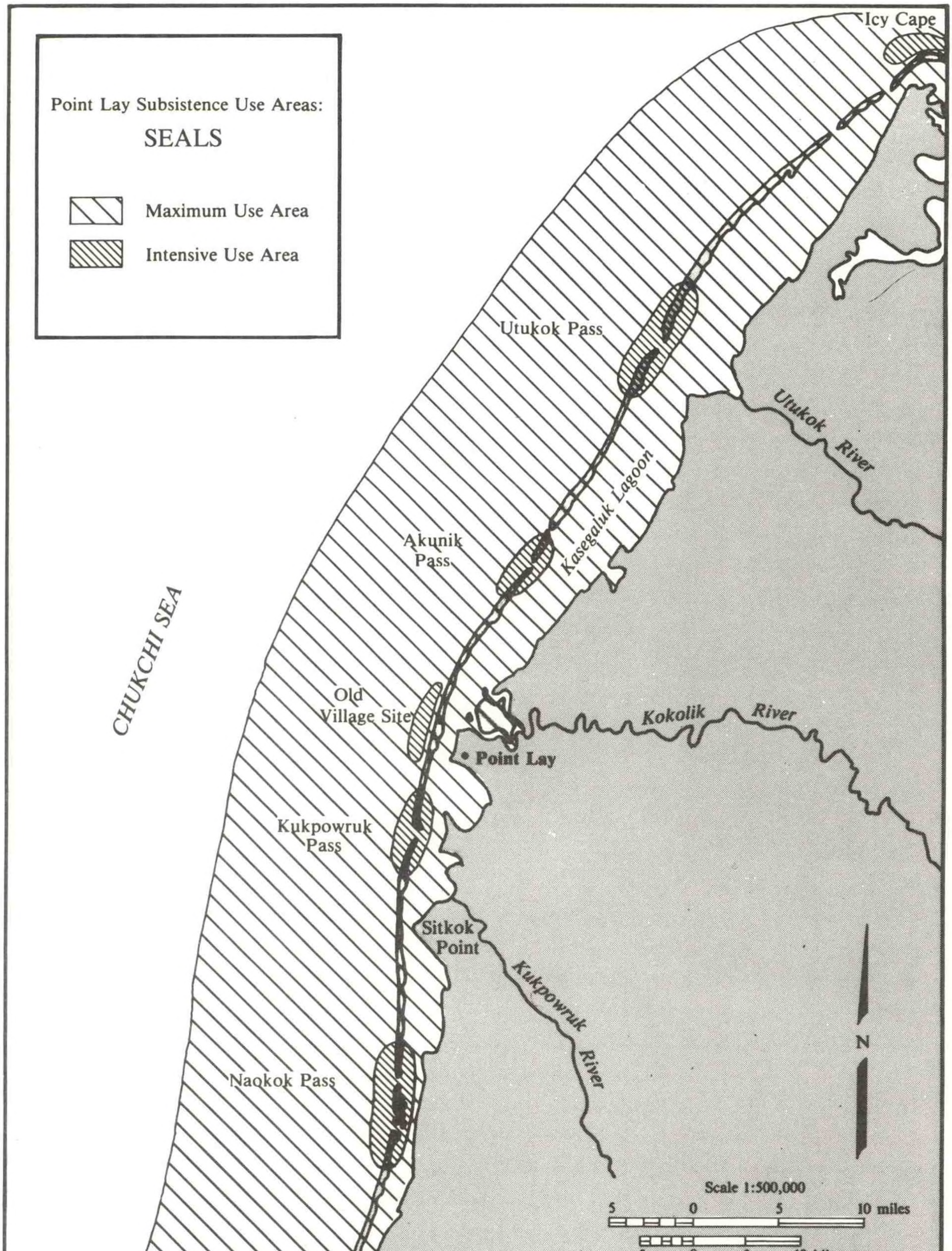

FIGURE 9.10—Point Lay subsistence use areas: seals.

(1983 fieldwork).

Migratory Birds

Migratory birds and their eggs are important subsistence resources in Point Lay. Eiders, geese, brant, loons, and ducks are all harvested, primarily in the spring. Eggs are also gathered at this time. The harvest range for birds is as large as any of the other marine resources because bird hunting is often done in conjunction with other marine resource harvesting (Fig. 9.11). As one resident stated: "I always take my shotgun with me when I am out hunting seals, belugas, walrus, even fishing." Waterfowl hunting is often done from the edge of leads during the month of May when Point Lay residents are hunting seals. What is not eaten immediately is stored in ice cellars for the following winter.

Polar Bear

Point Lay residents occasionally hunt polar bears during the winter along the coast. Villagers reported that they have seen few polar bears during the past year, but that more were available in previous years. The distance hunters travel offshore in pursuit of this species rarely exceeds 2 miles.

9.2.3 Wainwright

The following discussion and maps of Wainwright's contemporary marine resource harvest patterns are based, in their entirety, on Nelson (1981). Two important locally harvested nonmarine resources (caribou and freshwater fishes) are not addressed. Wainwright's marine subsistence activities are focused on the coastal waters from Icy Cape in the south to Point Franklin and Peard Bay in the north. The Kuk River lagoon system, a major marine estuary, is also an important marine and wildlife habitat used by local hunters. Unlike Point Hope or Barrow, communities located on major geographic points, Wainwright (population about 450) is situated in the middle of a long bight which affects sea ice conditions as well as marine resource concentrations.

The seasonal round of Wainwright residents was summarized by Nelson (1981:vi) as follows:

> *Fall.* Fishing in the upper Kuuk and Utuqqaq Rivers is a major activity, with many families staying in fish camps for periods of several days to two months or more. Caribou hunting intensifies as the fall migrations pass in September and October. Other fall activities include waterfowl hunting before freeze-up, and hunting for polar bears when the pack ice first comes ashore.
>
> *Winter.* Fishing activities shift from the upper river to the Kuuk Lagoon near Wainwright, where smelt and tomcod [saffron cod] are abundant. Men travel widely inland and near the coast, trapping foxes and hunting caribou. Polar bears and seals are hunted during times favored by the right weather and sea ice conditions.
>
> *Spring.* Whaling is the hallmark of this season and the most important subsistence activity of the year. Hunters in the offshore camps take bowhead whales, belugas, polar bears, seals, and waterfowl. Some people travel widely inland in the spring, searching for caribou, moose, fox, and other furbearers. These trips may take them as far as the Brooks Range.
>
> *Summer.* Early summer is an important season for hunting seals and waterfowl, and families often move to traditional camping sites along the coast at this time. Camps may be occupied into midsummer, when the main subsistence activities include sealing, fishing, and caribou hunting. Throughout the ice-free season, boats from Wainwright ply the coastal waters and especially the Kuuk River, mainly to set fishnets and hunt caribou. These activities intensify toward late summer and continue until freeze-up in the fall.

Bowhead Whale

The bowhead whale is the most important marine resource in Wainwright's subsistence economy. Culturally and socially the importance of this species is unparalleled. Wainwright bowhead hunting occurs in late April and May as the animals migrate north to summer feeding grounds in the Beaufort Sea. The hunters establish camps along the edge of the landfast ice. During some seasons, these camps are 10 to 15 miles offshore (Nelson 1981). Wainwright residents do not hunt bowheads in open water during the fall migration south. In 1982 and 1983, Wainwright whalers landed two bowheads each year.

Nelson (1981) noted three distinct phases of the bowhead's migration north. The first run usually takes place in late April or early May. This group, the largest number, primarily consists of younger whales running with a few older whales. The second run, which occurs shortly after the first, is smaller and composed of various aged adults, as well as a few young whales, traveling in groups of two or three. The final movement of northward migrating whales occurs in late May or early June and includes many larger whales. Depending on ice and weather conditions, these migrations can be widely dispersed or compressed into a shorter time period.

Ice conditions in the offshore area adjacent to Wainwright are not ideally suited for bowhead whaling (Nelson 1981). The leads often break far from shore and multiple leads are not uncommon. In addition, the leads in the Wainwright area are often considerably wider than the leads adjacent to Point Hope or Barrow. Consequently, there have been changes in Wainwright's hunting patterns in recent years. Among the local adaptations for whaling is the use of aluminum skiffs with outboard motors. These skiffs are effective in the wide leads common

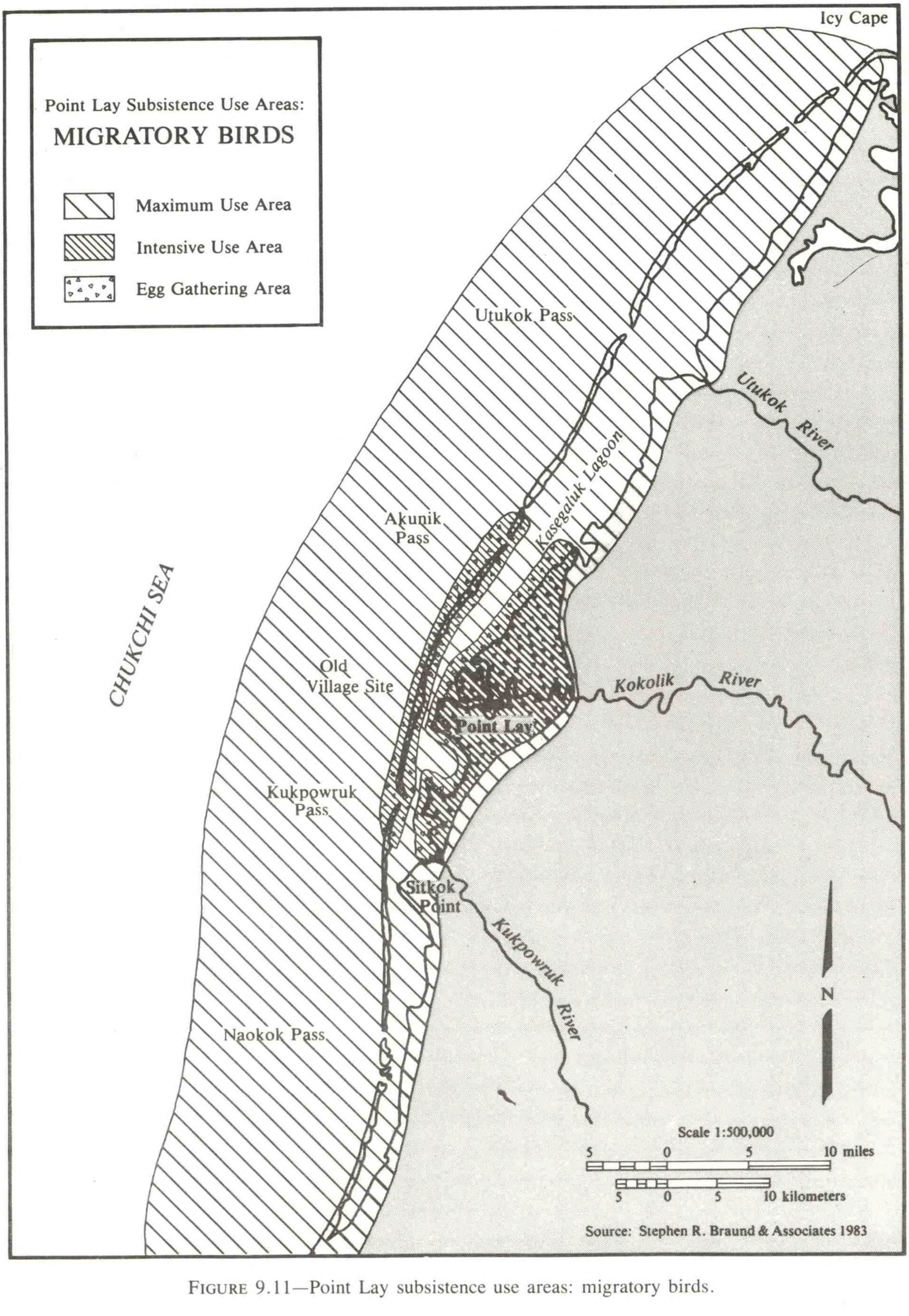

FIGURE 9.11—Point Lay subsistence use areas: migratory birds.

later in the whaling season and allow Wainwright hunters to pursue and harvest bowheads far offshore. Skin boats, better adapted to sea ice (quieter and easier to paddle when whales are confined to narrow leads) are now primarily used during the early part of the season when more ice is present. Wainwright whalers hunt bowheads near their village and as far south as Icy Cape and as far north as Point Franklin (Fig. 9.12).

The bowhead whale is the favorite food source of most Wainwright residents (Alaska Consultants, Inc. and Stephen R. Braund & Associates 1984). No other harvest activity requires the entire community's participation and support, and whaling is integrated with many aspects of Wainwright's social life.

Beluga

The beluga whale is a desired resource in Wainwright but the harvest success and, consequently, the importance to the subsistence economy, is extremely variable from one year to the next (Nelson 1981). This species commonly migrates in the same leads as the bowhead whale and is effectively hunted by whaling crews out on the ice. However, harvesting belugas at this time can potentially jeopardize the bowhead whale harvest and therefore is only done if no bowheads are in the area.

During the summer, belugas are common visitors in the numerous lagoon systems on the Chukchi Sea coast. According to Wainwright elders, belugas were once regular visitors in the Kuk lagoon, but because the animals are sensitive to disturbance and noise, their use of this estuary has diminished (Nelson 1981). During summer, local hunters are occasionally successful at herding significant numbers of belugas into shallow water where they are shot and hauled to shore. This method, however, is not as reliable as harvesting belugas earlier in the year from whaling camps. Wainwright harvest areas for belugas are depicted in Figure 9.13.

Desired for both their meat and muktuk, belugas are enjoyed by Wainwright residents when they are available. As with the bowhead whale, harvests of this animal are usually shared with all members of the community. Because Wainwright residents are reluctant to concentrate on beluga harvesting during bowhead whaling season, they must rely on the unpredictable summer harvest for the major volume of this resource. Consequently, the importance of this species in the subsistence economy varies from year to year.

Seals

There are four species of seal present in the Wainwright area for all or part of the year: ringed, bearded, spotted, and ribbon seals (Nelson (1981). The traditional and contemporary importance of each of these seal species in Wainwright's economy is a function of their overall abundance. The ringed seal is the most common species and is generally available in all but the ice-free months. Bearded seals are available during the same seasons as ringed seals, but not in equally prodigious numbers. These two species are the most commonly harvested seals in Wainwright today. Spotted seals are common in the coastal lagoons during summer and until 1972 (Marine Mammal Protection Act) were actively pursued for their pelts. Today most spotted seals are taken in the Kuk lagoon, with the pelts being used locally for fancy parkas. Ribbon seals are rare spring and summer visitors to this region and few are presently harvested. Focal hunting areas are shown in Figure 9.14.

Concentrations of ringed and bearded seals are largest during June and July, coincidental with the dispersal of shore ice. With the replacement of the dog team by the snowmachine and the availability of other food sources (caribou and bowhead whale), seal hunting has decreased in importance. Today, most seal hunting takes place while the animals sleep on the ice or from boats in open water. Although the importance of seal meat has declined in recent years, seal oil is still a staple food source. Bearded seals are the preferred source of oil, and, of all seals, an immature bearded seal is considered the most desirable as a subsistence food source.

Walrus

Although walruses occasionally overwinter in the Wainwright area, most are present only seasonally. Walrus herds first appear in June, drifting north on ice pans. The greatest concentrations, and peak hunting, occur in July and August in association with the southern edge of the retreating pack ice (Nelson 1981). Hunters travel by boat among the ice floes, sometimes far offshore, in search of walruses. Focal hunting areas are depicted in Figure 9.15. The animals migrate south during the open-water season (late August and September), and Wainwright hunters occasionally harvest them at this time when they haul out and rest on the beaches.

Traditionally, walruses were the main source of dog food in Wainwright. Today, harvest pressure on this marine mammal is limited because there are fewer dogs to feed than in the past. Walrus meat provides variety in the human diet, while continuing to be used for dog food. The tusks are saved and used for carving. The importance of this resource to Wainwright residents could change in the future if dog teams are reestablished in the community, the availability of other resources changes, or the status of the cash economy changes.

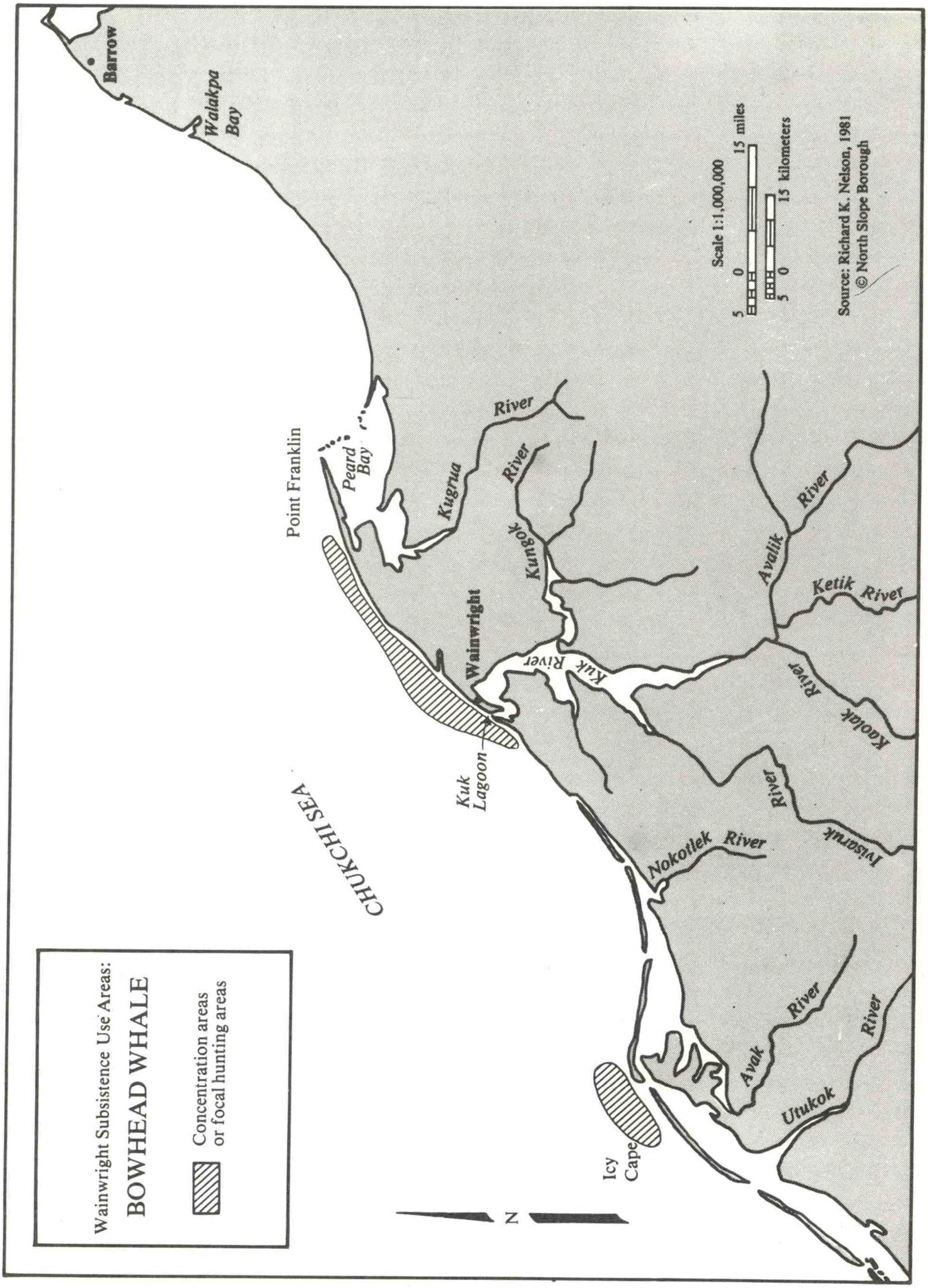

FIGURE 9.12—Wainwright subsistence use areas: bowhead whale.

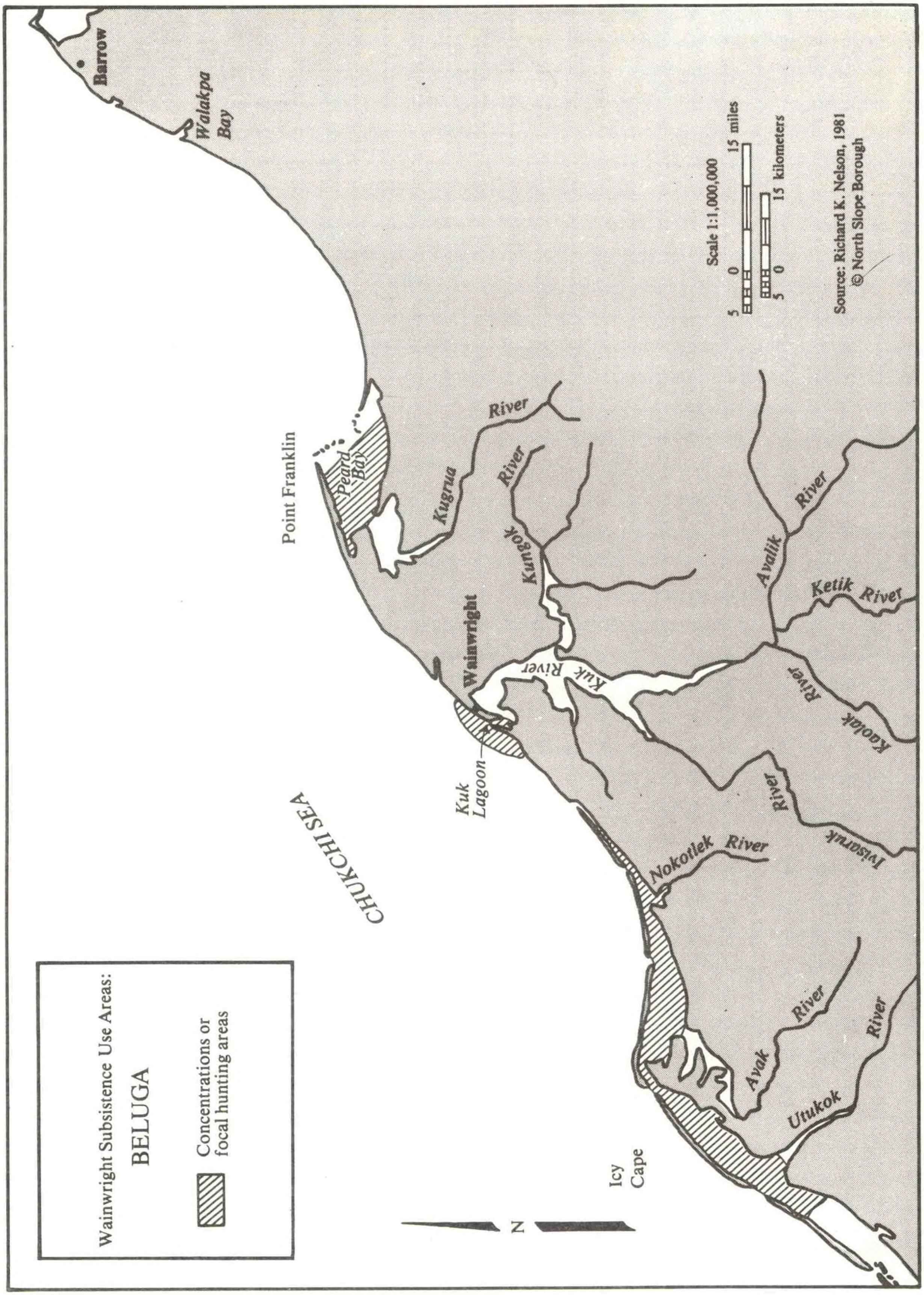

FIGURE 9.13—Wainwright subsistence use areas: beluga.

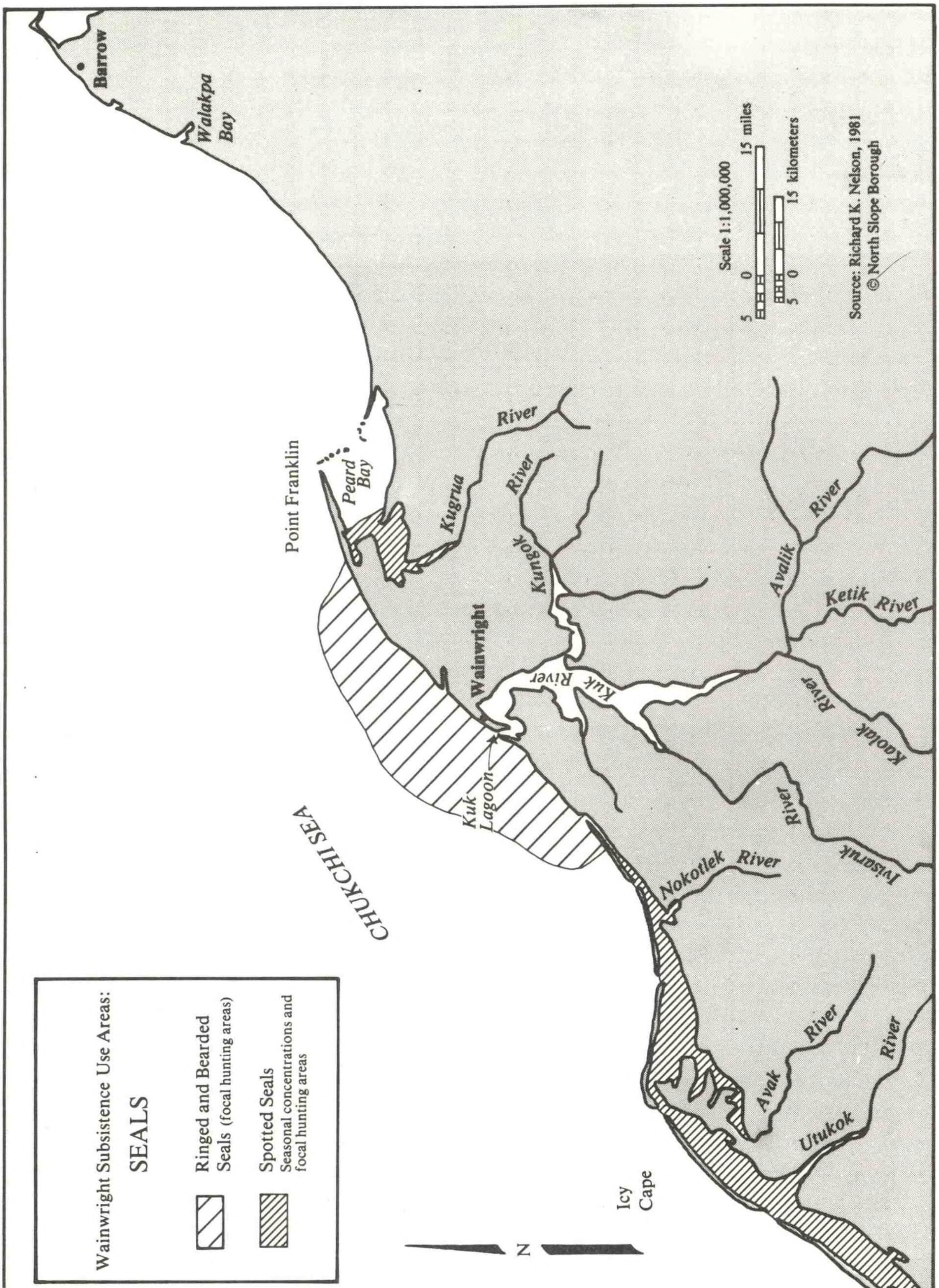

FIGURE 9.14—Wainwright subsistence use areas: seals.

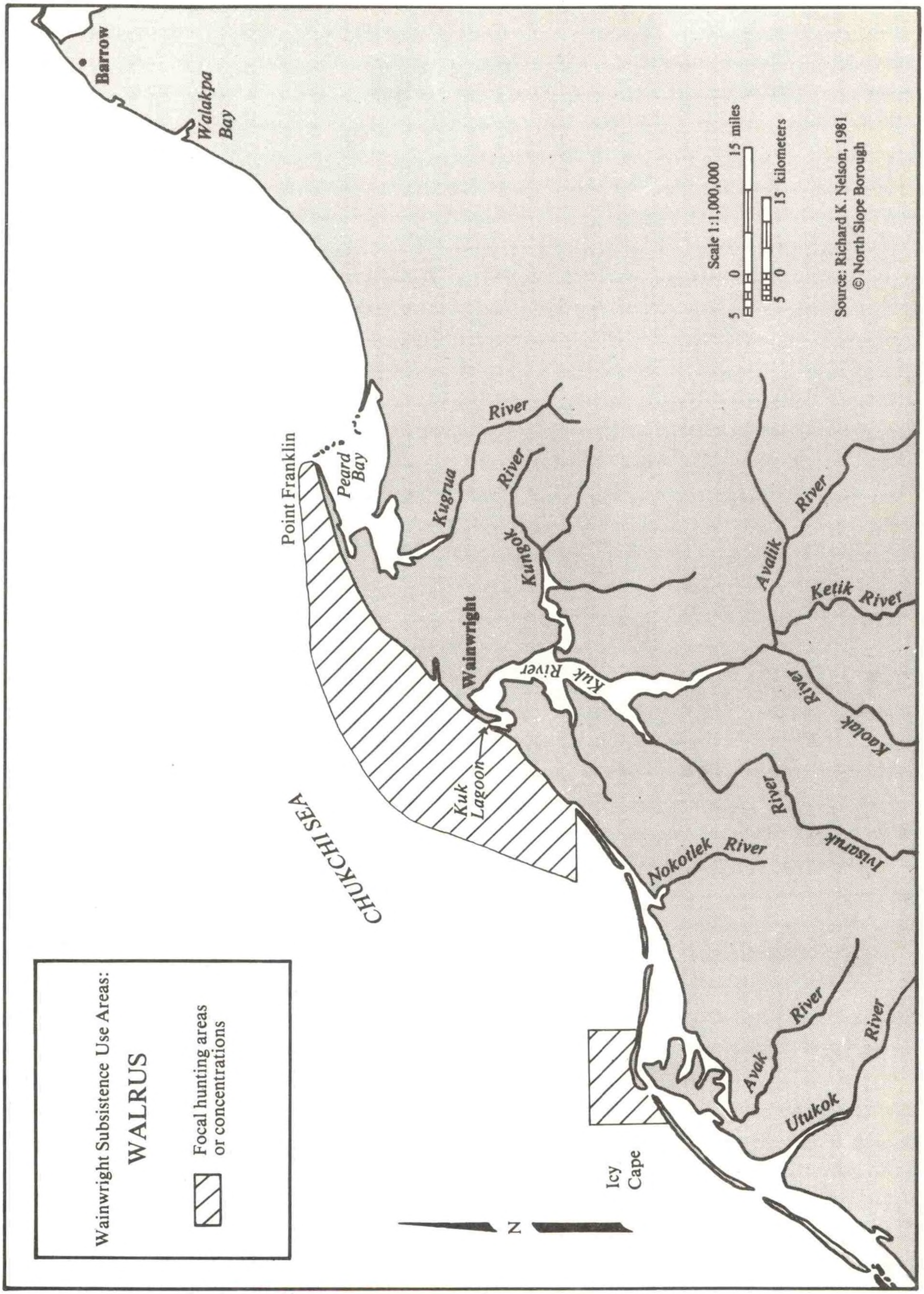

FIGURE 9.15—Wainwright subsistence use areas: walrus.

Fish

Although Wainwright residents fish in most marine and freshwater habitats (open coast, lagoon, estuary, and river), the most important local fish harvest takes place in the fall (September through November) in fresh water (Nelson 1981). Villagers establish seasonal camps in the freshwater portions of the Kuk and other river drainages and fish for several days to several months, depending on the needs and preferences of the family harvest network.

Ice fishing for smelt and saffron cod in the vicinity of the village begins once the Kuk lagoon has frozen but is most common in the winter months of January, February, and March. During the summer, villagers use set gill nets to harvest fish along the coast and along the lower reaches of the Kuk lagoon. Species harvested include Arctic char, chum salmon, and pink salmon, as well as Bering cisco and sculpins.

Marine fishing occurs from Peard Bay to Icy Cape and in the Kuk lagoon (Fig. 9.16). Fishing, both freshwater and marine, provides an important food source for Wainwright residents. Finally, because both women and children are involved in this harvest, social and familial ties are strengthened and young people are introduced to the harvest activity (Nelson 1981).

Migratory Birds

Most bird species commonly harvested by Wainwright residents are migratory, the major exception being ptarmigan which are locally available throughout the year (Nelson 1981). Waterfowl hunting begins in May at bowhead whaling camps on the landfast ice. The northward migration of murres, ducks, geese, and cranes along the coast continues through June and hunting pressure is heavy (Fig. 9.17). The spring waterfowl flyways are narrow and the migration is concentrated in a short time span. Both of these factors facilitate local harvest success of waterfowl. Once the bird populations disperse to summer ranges, harvesting decreases. Because the fall migration occurs over a wide area and continues for several months, harvest success at this time is also limited. The only location in the Wainwright harvest area where significant numbers of birds can be harvested in the fall is Icy Cape.

9.2.4 Atqasuk

Caribou, fish, and migratory birds are the major food sources in Atqasuk's subsistence economy, while marine mammals continue to provide seal oil and other staples in the local diet. During the fieldwork, 12 local hunters and fishermen were interviewed as well as several other members of the community.

Only a small portion of the marine resources used in this village are acquired on coastal hunting trips initiated from Atqasuk. Commonly, village residents travel to Barrow to go sea mammal hunting with their coastal friends and relatives. Close familial ties with Barrow, as well as advances in transportation and communication technology, allow these inland villagers to include the use of marine mammals in their subsistence economy. Because the marine areas which Atqasuk residents use are inclusive of those used by Barrow residents, range and harvest areas are discussed in relation to Barrow land use patterns.

The most important wildlife resource harvested by Atqasuk residents is caribou. Villagers hunt caribou throughout the fall, winter, and early spring, with the fall harvest being the most important. Caribou harvests decline during the late spring and summer, a result of migration patterns and limited hunter access. In recent years, the caribou population on the North Slope has been high, and residents of Barrow and Atqasuk have not generally had to travel far in order to successfully hunt this species.

Both historically and today, a common summer activity of the coastal Eskimo of this region is to travel inland and establish summer fish and caribou camps along the Inaru, Meade, Topogoruk, and Chipp river drainages. Many of the people currently living in Atqasuk were either born or spent their childhood summers in this area. The anadromous nature of the fish species harvested by Atqasuk residents is an important factor when considering the marine orientation of this village.

Fish, while secondary to caribou in quantity harvested, is a preferred food in Atqasuk. Baited hooks, gill nets, and jigging are the common techniques used to harvest ling cod, salmon, whitefishes, and grayling. Fishing with set gill nets begins soon after the ice breaks up but Atqasuk residents stated that the most successful fishing months are July and August when water levels in the Meade River have dropped, and the river has become clearer (free of driftwood). By August, water levels in the Meade River limit boat travel, and residents must travel overland to fish camps. Fishing continues in the fall and winter under the ice in both deep pools of the Meade River and in nearby lakes.

Migratory birds are also an important part of Atqasuk's subsistence economy. This activity is concentrated during the spring months of late April, May, and June, with a secondary season occurring in late August and September during the birds' southward migration. Local residents harvest these birds on the numerous nearby lakes and ponds as well as on the Meade River and its tributaries. They also gather eggs in the immediate vicinity of the village

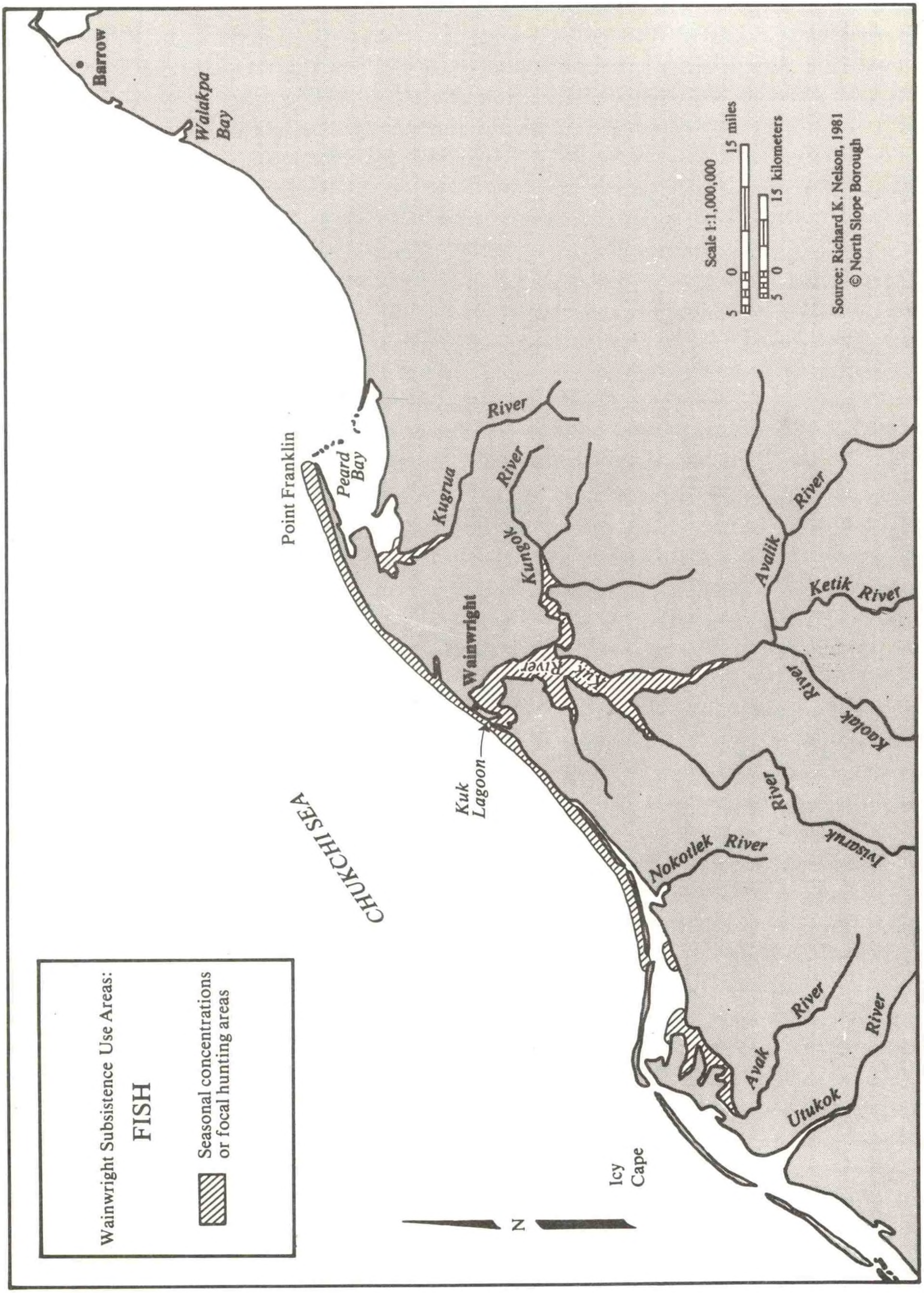

FIGURE 9.16—Wainwright subsistence use areas: fish.

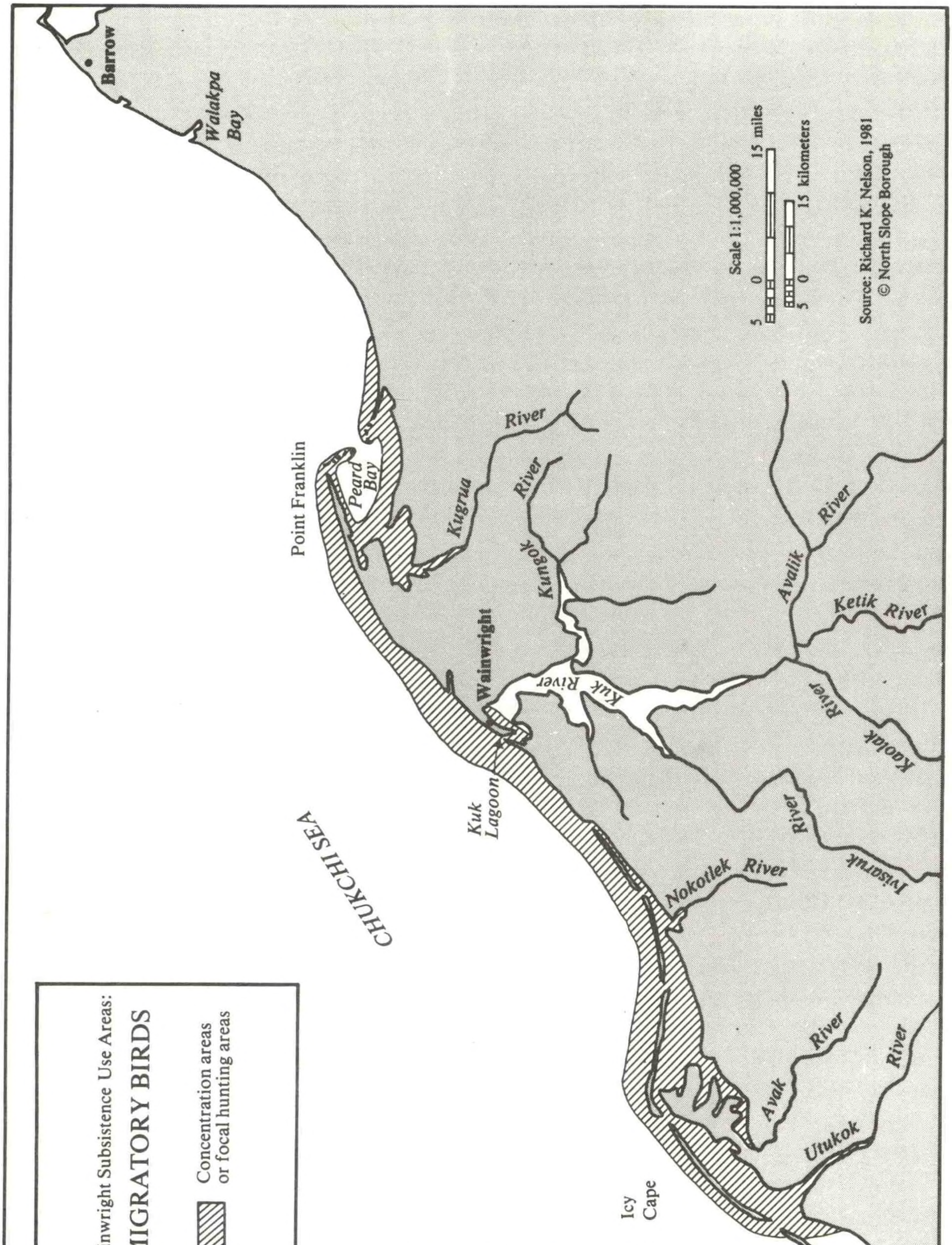

FIGURE 9.17—Wainwright subsistence use areas: migratory birds.

for a short time each June.

There is continual interaction between Barrow and Atqasuk. Twice daily air service (weather permitting) and snow machine access 8 months of the year results in a great deal of interchange between the two communities. Atqasuk families average at least one trip to Barrow a month and, during the appropriate seasons, often go marine mammal hunting. Many Atqasuk residents store their sea mammal hunting equipment with relatives in Barrow so that any trip to that community can become an unscheduled hunting trip.

The importance of marine mammal hunting in the village of Atqasuk is demonstrated by the local interest in the bowhead whale harvest. Between 6 and 10 Atqasuk residents travel to Barrow each spring to join whaling crews. Three Atqasuk men, who were whaling captains when they lived in Barrow, expressed interest in establishing a bowhead whale quota for Atqasuk, further demonstrating local enthusiasm for this activity. Residents stated they always receive a village share from Barrow and Wainwright, and these are divided among all members of the community.

Atqasuk's harvest of other sea mammals (beluga, walrus, and seals) is generally initiated in Barrow as overland travel is limited when these species are available. All resources harvested at this time are either stored in Barrow and retrieved in the winter by snowmachine or are air freighted to Atqasuk. Seals are occasionally purchased from friends or relatives in Barrow and sent to Atqasuk by plane.

9.2.5 Barrow

Barrow is located at the juncture of two distinct physical provinces. The morphology of the marine and coastal environment east of Point Barrow is dominated by the Beaufort Sea while the environment west of the point is governed by the Chukchi Sea. The unique location allows Barrow residents to exploit two seas, a vast lagoon system, four major and numerous minor rivers and streams. The large Inupiat population of Barrow (1,720 persons) combined with the diversity of environments has resulted in Barrow having the largest subsistence use area of any study village. The marine harvest area extends from Pitt Point in the east to Peard Bay in the west and up to 30 miles offshore.

While the Chukchi Sea is largely controlled by the warmer waters of the Alaska coastal current, the Beaufort Sea is dominated by the colder onshore currents of the Arctic Ocean. These cold onshore currents curtail the melting of the Beaufort Sea pack ice, hold the ice much closer to shore, and limit the extent to which the Chukchi Sea becomes ice-free in the Barrow area. Consequently, at Point Barrow the ice is rarely more than 20 to 30 miles offshore, whereas the extent of open water north of Point Hope during a summer of average ice retreat is several hundred miles.

The close proximity to shore of the pack ice in the Beaufort Sea often results in sections of pan ice being driven to shore by onshore breezes and currents. Thus, summer boat travel is very unpredictable as ice sufficient to block travel is never more than a day away with a strong onshore wind (Sonnenfield 1959:6). However, the barrier islands which form Elson Lagoon allow residents to travel by boat within the lagoon even when the ice has been pushed onshore. During the summer months, Elson Lagoon and the associated Dease Inlet and Admiralty Bay are continually used by local residents as a marine highway.

Sea mammal and human distribution patterns are affected by the different physical characteristics of the Chukchi and Beaufort Seas. The availability and concentration of marine resources are greater in the Chukchi Sea than in the Beaufort Sea. The seasonal nature of the ice in the Chukchi Sea results in a greater number of leads and more open water for use by marine mammals throughout the year, whereas the perennially ice covered Beaufort Sea with few leads and areas of open water results in fewer sea mammals. As a result, human population densities have traditionally been greater along the shores of the Chukchi Sea.

In summary, Barrow residents are strategically located at the juncture of the Beaufort and Chukchi seas. The Chukchi Sea, with its seasonal ice and warm currents, provides access to sea mammals throughout the year. With the exception of fall bowhead whaling, Barrow sea mammal hunting activities are generally concentrated in the Chukchi Sea west of Point Barrow. The Beaufort Sea, while not as important in terms of sea mammals, provides Barrow hunters with access to numerous salt and freshwater fishing areas, waterfowl areas, caribou areas, and a safe summer route for travel. This diversity of environmental features allows individual Barrow residents to vary their seasonal subsistence cycle more than most villages. For historical ethnographies of Barrow, see Murdoch (1892), Ford (1959), and Sonnenfield (1959).

Bowhead Whale

Bowhead whale is the preferred food of the majority of Barrow residents (Alaska Consultants, Inc. and Stephen R. Braund & Associates 1984). Unlike the other villages of the study area, Barrow residents hunt bowheads during two distinct seasons, during the whales' annual migration north through the open leads in the spring and again in the fall as the animals migrate south, usually in open water. The areas used to hunt the bowhead and the intensity of effort are different for each season. In 1982, Barrow whalers did not land any whales, while in 1983 they landed two.

Spring Whaling. Spring whaling from open leads in the pack ice continues to be the high point in the yearly subsistence cycle of Barrow residents. Traditionally, whaling camps were established on the ice as early as the third week of April (several weeks later than Point Hope hunters) and occupied until the first week of June when the passage of most of the bowheads and deteriorating ice conditions ended the season. Presently, due to the IWC quota on strikes which limits Barrow residents to fewer strikes than they desire, the whaling season is shorter and usually lasts only several weeks.

The general harvest area for the spring bowhead whaling season extends from Point Barrow to the Skull Cliff area and to a maximum distance of ten miles offshore (Fig. 9.18). In most years, the lead breaks from Point Barrow parallel to the coast and is only 1 to 3 miles from shore. However, occasionally Barrow residents have to travel up to 10 miles offshore to find open water. Due to the limited number of strikes now available, the approximately 30 Barrow crews currently concentrate their hunting effort in one area of the lead in order to minimize the chances of losing a whale once struck. Skin boats are the predominant means of transport; the narrow leads near Barrow are not conducive to the use of aluminum boats and outboard motors presently used with success by Wainwright whalers.

Barrow residents also harvest other wildlife species while at whaling camp. However, with the use of citizens' band radios, the hunters limit extraneous hunting activity to periods when there are few or no bowheads in the area. Although belugas and seals are available, they are only occasionally harvested because local hunters do not want to jeopardize the bowhead hunt with unnecessary noise. The most important hunting activity that occurs in conjunction with whaling is eider hunting. During periods when there are no whales migrating, hunters actively pursue these migratory birds to supplement the camp food supply.

There is some evidence that the present shortening of the whaling season has altered harvest patterns for other marine species. When whaling continued until the first few weeks of June, other sea mammals, especially bearded seals were harvested from whaling camps. Now, most residents leave the ice after the quota has been reached and harvest ringed seals later in the summer.

Fall Whaling. Barrow residents also hunt bowhead whales in September. While the fall whaling effort is rarely as successful as the spring whale hunt, it is an important aspect of many Barrow residents' seasonal round. The harvest area for fall whaling is generally east of Point Barrow (Fig. 9.19). According to the 1983 fieldwork, technological advances (aluminum boats and powerful outboard motors) as well as few whale sightings near shore (i.e., along the barrier islands which form Elson Lagoon) has expanded the harvest range in recent years.

The timing of the fall whaling effort is dependent on the migration schedule of the bowhead as well as weather conditions. Fall whaling usually begins during the last few days of August or the first week of September and continues until ocean boat travel is made impossible by the final encroachment of the pack ice, usually around the first of October. The actual number of days the whalers are able to hunt often is less than this entire period as drifting and wind-blown ice can force them to shore at any time.

The fall bowhead migration usually occurs in open water. Consequently, the fall whale hunters use aluminum and wood boats powered by outboard motors in order to travel freely over large areas in search of whales, an entirely different technique than the man-powered umiaks used in the narrow spring leads. The area used for fall whaling extends from the Barrow vicinity in the Chukchi Sea to Cape Simpson in the Beaufort Sea (Fig. 9.19). The hunters travel as far as 30 miles offshore. The limited amount of open water in the Beaufort Sea is an advantage to the whale hunters as it tends to limit the dispersion of the bowheads. Once the whales have reached the Chukchi Sea, they become hopelessly spread out, minimizing any chance of a successful hunt. Hence, fall whaling is the only Barrow marine mammal hunting activity concentrated in the Beaufort Sea.

Traditionally and currently, the fall whaling effort has been a land based activity; the hunters search for whales during the day and return the land-based camps at night. Historically these shore camps were located at the very tip of Point Barrow, but in the more recent past they have been situated on Cooper and Tapkaluk islands, two of the islands which form Elson Lagoon. During the 1983 fieldwork Barrow whalers noted that bowheads are no longer migrating near shore but now pass by Point Barrow well offshore and in some cases hunters travel as far as 30 miles offshore.

The level of effort and success of fall whaling in Barrow is limited by several factors, including the availability of other wildlife resources (i.e., caribou and fish), the reduced number of crews that participate (i.e., 11 to 15 crews), the diffused nature of the fall whale migration, and the restrictions of the quota system. Because fall whaling during September when other resources are available and many residents have been able to stock up considerable amounts of other foods during the summer, it is not as communally

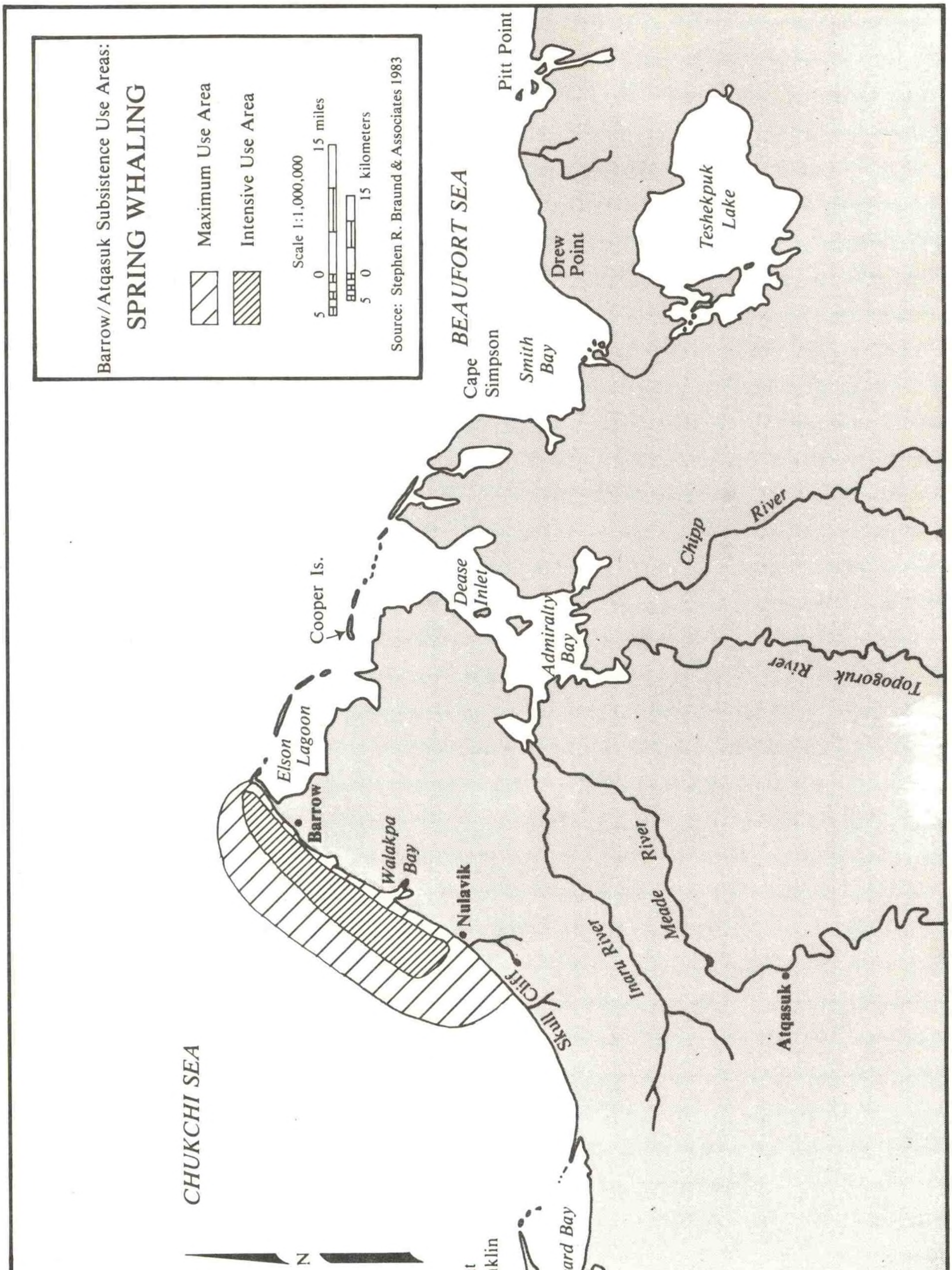

FIGURE 9.18—Barrow and Atqasuk subsistence use areas: spring whaling.

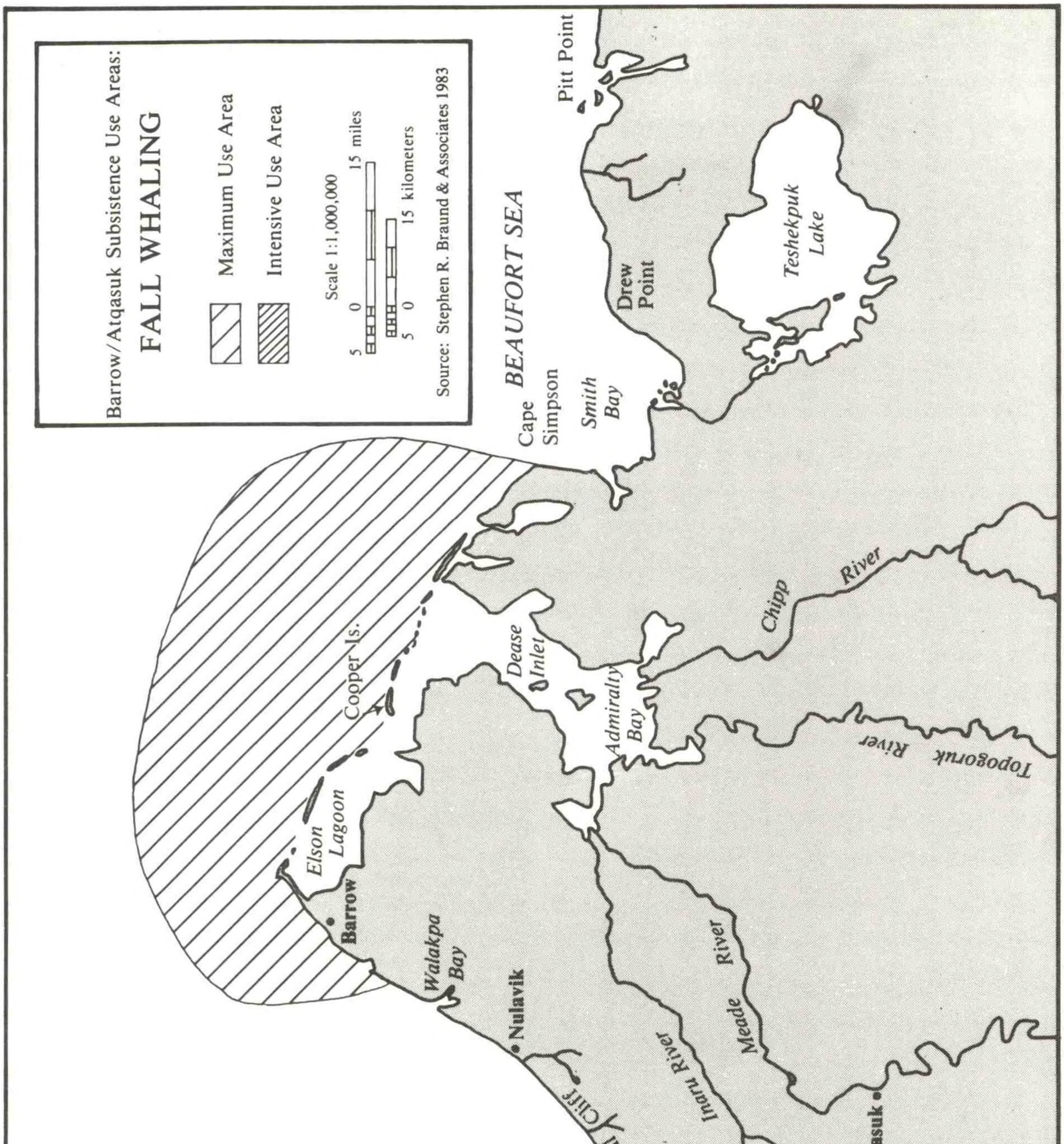

FIGURE 9.19—Barrow and Atqasuk subsistence use areas: fall whaling.

important as the spring bowhead hunt. However, if the spring whale hunt was unsuccessful, or Barrow has some strikes left on its quota, the fall hunt can be an important source of the highly preferred bowhead whale meat and muktuk.

Beluga

Unlike the village of Point Lay, which relies upon the harvest of belugas each spring as a major source of food, Barrow residents consider this species of secondary importance. As a result, the harvest of belugas is opportunistic in nature rather than the planned organized hunt practiced in Point Lay. Belugas commonly migrate with the bowheads during April and May but, because of the shortened whaling season and the unofficial community decision to limit beluga harvesting at this time (for fear of scaring bowheads), few are taken. Belugas are available through the month of June and are occasionally spotted during the ice-free months of July and August.

Harvesting areas for belugas include the areas used for spring bowhead whaling, as the animals are occasionally taken by whaling crews or by families who remain out on the ice (Fig. 9.20). Beluga hunting also occurs from spring camps established along the shore of the Chukchi Sea between Point Barrow and Skull Cliff. Some families establish spring camps near Peard Bay and harvest belugas in this area. Later in the summer, belugas are occasionally harvested in the vicinity of the barrier islands of Elson Lagoon as they feed on anadromous fish. Unlike Kasegaluk Lagoon near Point Lay, the numerous passes as well as the large size of Elson Lagoon make herding belugas difficult. Finally, because belugas are available at the same time as more desired species (seals, bowhead, and waterfowl), they are of secondary importance in Barrow's subsistence economy.

Seals

Barrow residents' harvest area for hair seals and bearded seals (ugruk) is shown in Figure 9.21. The maximum use area for these species is greater than that of any other marine resource harvested by Barrow hunters. The size of the harvest areas is largely a result of the opportunistic nature of the Inupiat hunters, who commonly harvest these animals while they are engaged in other subsistence activities. The intensive use areas discussed below are more representative of the harvest areas commonly used for these species.

In general, ringed seal hunting is concentrated in the Chukchi Sea, but some seal hunting occurs directly off Point Barrow and along the barrier islands which form Elson Lagoon (Fig. 9.21). While some Barrow residents harvest ringed seals throughout the winter, especially during February and March when sufficient light has returned to the area, many Barrow hunters now engage in caribou hunting at this time of year. Some ringed seals are taken each year from the ice during whaling, but the majority of sealing now takes place in the late spring and early summer. At this time many families establish camps along the Chukchi Sea coast (as far as Peard Bay) from which local hunters harvest waterfowl and seals.

The intensive use areas directly off Point Barrow and the nearby barrier islands are good for seal hunting later in the summer. At this time, the necessary ice pans and floes are more abundant in this area than along the Chukchi Sea. Winter lead formation in the areas immediately adjacent to Barrow north to Point Barrow makes this area a favorable sealing location during the winter. Those families who continue to harvest a significant number of seals during the winter harvest more ringed seals than the spring and summer hunters who concentrate on bearded seals.

Spotted seals are available only during the ice-free months of summer and are harvested at this time incidental to other subsistence activities. Summer boat travelers in Elson Lagoon occasionally harvest spotted seals on the barrier islands. The most important spotted seal harvest areas identified by interviewed hunters was Oarlock Island in Admiralty Bay, a common feeding area for these animals during summer.

The bearded seal, always an important subsistence resource because of its dual role as a food source and as material for the equipment and clothing of the coastal Eskimos, presently appears to be the most important seal harvested in Barrow. This probably results from the change in winter subsistence emphasis from seal to caribou and fish, as well as the present importance of spring and early summer waterfowl and sea mammal hunting camps. Bearded seals, rare in winter, are common during the spring and summer when they are associated with the broken ice margins of the pack ice. For this reason and because of the larger size of bearded seals (resulting in a higher catch per unit effort), Eskimo hunters concentrate on this species at their early summer camps along the Chukchi Sea coast. In addition, Barrow whaling captains need six to nine skins each for their skin boats. Bearded seals are also harvested on sea mammal hunting trips initiated in Barrow throughout the summer. The large harvest range is made possible by the improved speed and durability of modern boats. Barrow-based bearded seal hunting continues throughout the open-water season. Walrus hunters as well as fall whaling crews often harvest this species, which is also available on occasion in Dease Inlet and Admiralty Bay.

In summary, with the changes in hunting emphasis, the bearded seal has become the most important seal resource. The quantity of each seal species harvested

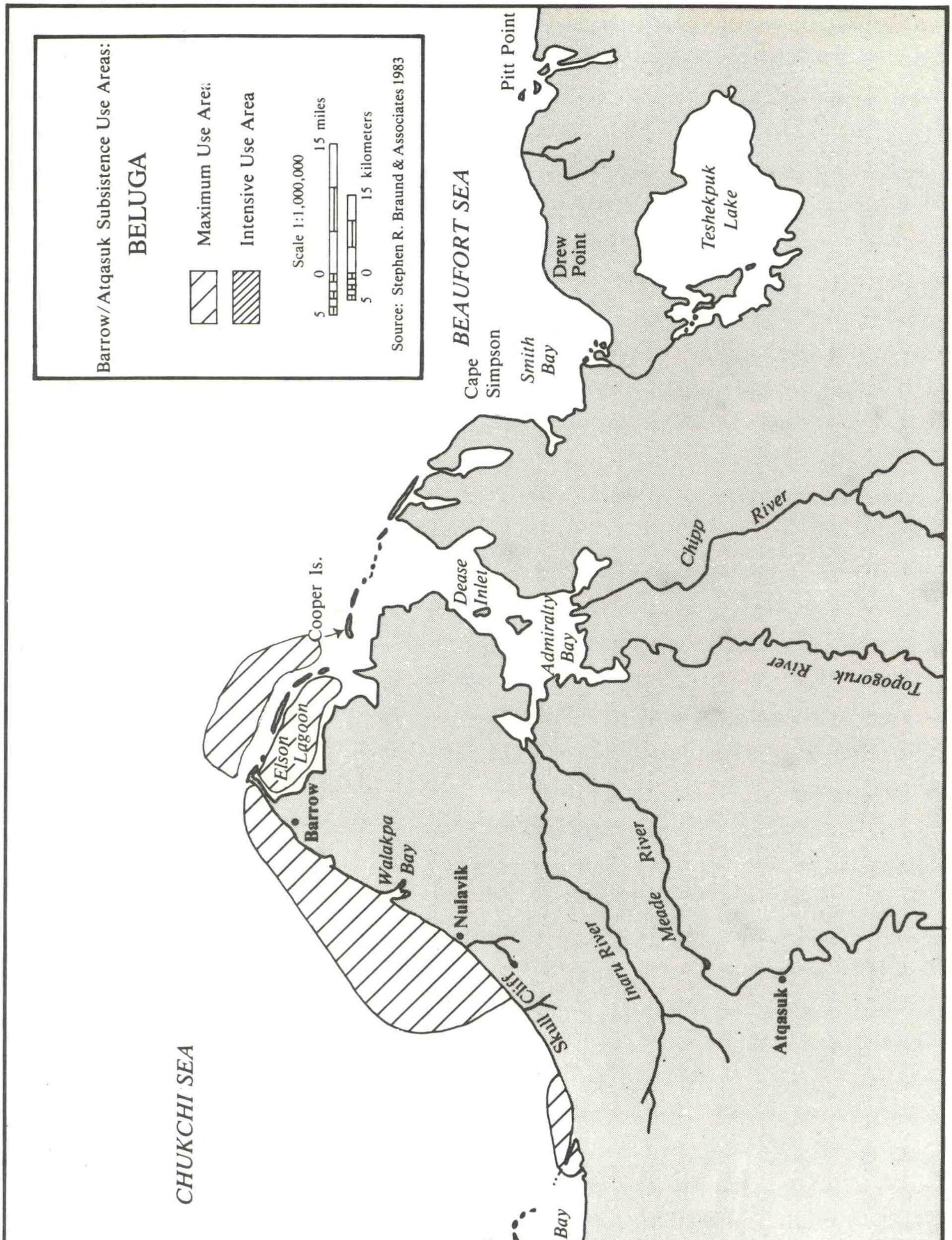

FIGURE 9.20—Barrow and Atqasuk subsistence use areas: beluga.

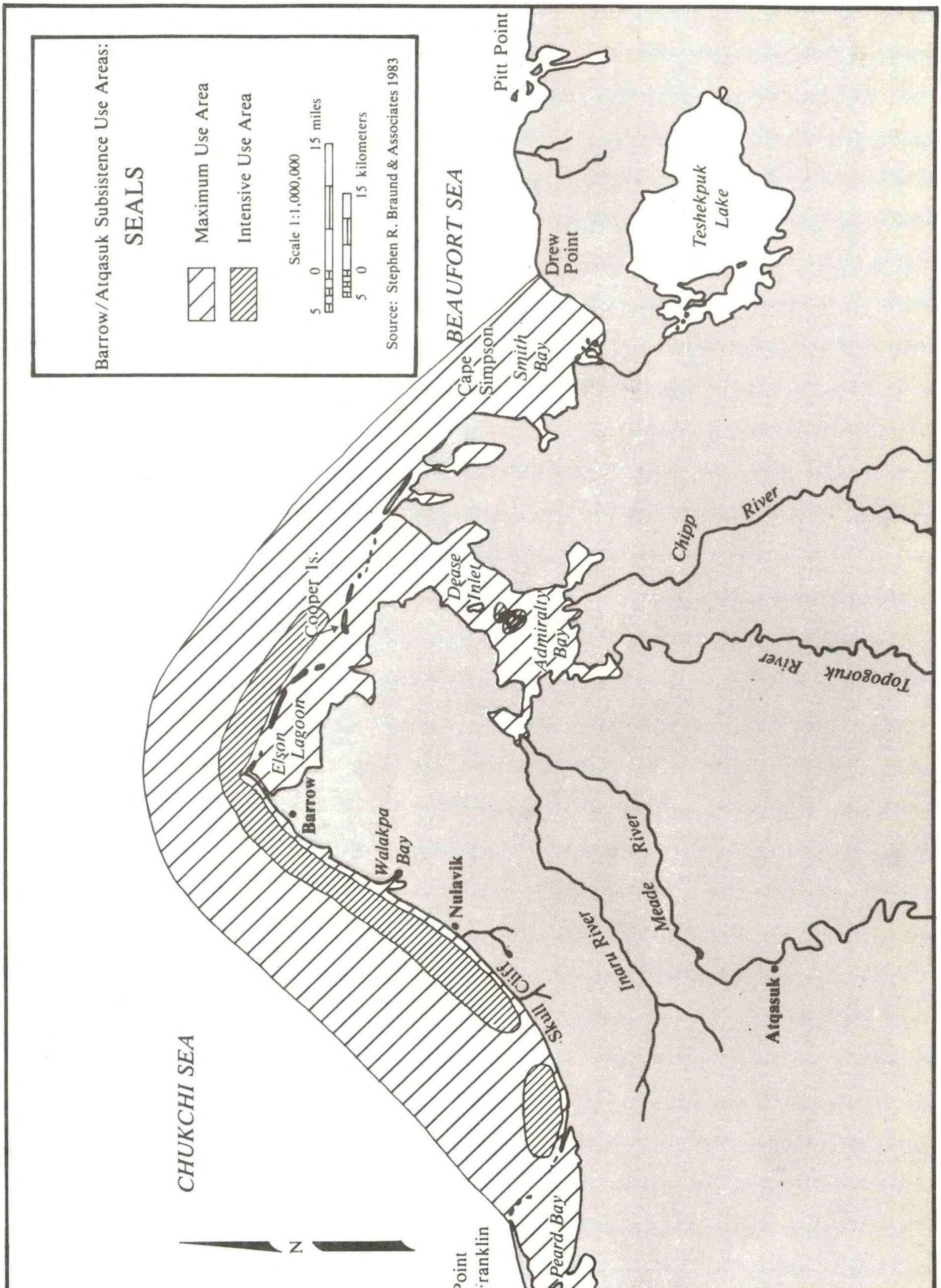

FIGURE 9.21—Barrow and Atqasuk subsistence use areas: seals.

varies from family to family, but all Barrow whaling captains, who must regularly replace the skin covering of their umiaks, harvest bearded seals in greater numbers than most residents who need only a few to supplement their diet and to provide the necessary seal oil. Dependence on seals could change with fluctuations in the population and local availability of caribou and other inland resources.

Walrus

Although the walrus harvest has declined since the replacement of the dog team by the snowmachine, it remains an important wildlife resource for some Barrow families. Barrow's large population, as well as the diversity of resources available, has resulted in differences in dependence on particular resources among family groups within the community. Thus, while some families are harvesting walrus, others are at inland fish camps stocking up on whitefishes, salmon, and grayling. The average harvest of eight hunters interviewed in Barrow who indicated that they regularly go walrus hunting was one to three animals per hunter per year. One hunter who was also a fall whaling captain stated that he usually harvests six walruses a season. According to Stoker (1983), Barrow's 9-year harvest average (1970–79) was 57 walruses per year. Thus while some families spend considerable time and effort pursuing walruses, other families do not participate in this activity.

Barrow residents hunt walruses from boats, often the same ones used for fall whaling. The hunters travel in and among the ice floes searching for animals resting or sleeping on the ice. The timing and seasonality of this harvest is therefore dependent on broken ice conditions and, as the boats must be launched from the shore, upon the dispersal of the shorefast ice. The landfast ice usually breaks free during mid-July, and the potential walrus hunting period continues from this time until September when the last of the walruses migrate south. Barrow hunters noted that ice conditions were generally best suited for walrus hunting during August, particularly the middle 2 weeks of the month.

The area Barrow residents use for harvesting walruses is immense, second only to the areas used for seals (Fig. 9.22). Barrow hunters stated that they generally travel farther in the pursuit of walruses than they do for seals but noted that the latter are often taken when the hunters are looking for walruses. Walrus hunting rarely occurs east of Point Barrow, but the range extends west of the point all the way to Peard Bay. The distance offshore varies from hunter to hunter, depending on the individual's knowledge of the ice and the reliability of his boat. However, the majority of hunters stated that 15 to 20 miles offshore was usually the maximum distance necessary. Because of the variable concentrations of both ice and walruses within this area, the hunters did not note any intensive use areas.

Fish

Barrow residents' dependence on fish fluctuates with the availability of other more desired resources. While both coastal and riverine fishing activities regularly take place, Barrow residents rely on freshwater fishes to a greater extent than on marine fishes. Much of the marine fishing that does occur is harvesting anadromous fishes caught at inland locations. Barrow residents harvest capelin, char, cods, grayling, salmon, sculpin, trout, and whitefishes. As is the case with many other wildlife resources, dependence on fish as a food source varies among families.

The harvest area used for fishing is extensive (Fig. 9.23), primarily because it is a common practice among local residents to supplement the food supply with fish whenever they are out hunting. The marine fishing use area extends from Peard Bay to Pitt Point. Fishing along the coast between Barrow and Peard Bay is a common secondary activity at the spring and summer waterfowl and marine mammal hunting camps concentrated in this area. Fishing along the Beaufort Sea coast and within Elson Lagoon, Dease Inlet, and Admiralty Bay occurs during the summer and fall from caribou hunting camps, fall whaling stations, and other temporary camps as residents travel to and from the rivers which flow into Admiralty Bay. Also, some families annually establish fish camps at traditionally important coastal points of land or river mouths.

The intensive marine fishing spots are primarily in the Barrow vicinity. The area of the Chukchi Sea immediately adjacent to Barrow is heavily used for fishing. During the summer months, people jig for fish in the small cracks and breaks in the ice, and during the winter they fish from ice holes in the same area. The shore of Elson Lagoon nearest Barrow and both sides of the barrier islands which enclose this lagoon are also intensive marine fishing areas. Gill nets are placed in these areas during late summer and fall to harvest salmon, char, and whitefishes. During the fall when fishing is best, some residents engage in fishing as their primary subsistence activity.

While marine fishing can be an important source of fish, most fishing, both in terms of quantity and effort, occurs at inland camps. Some families spend their entire summer and fall at fish camps in the Inaru, Meade, Topogoruk, or Chipp river drainages. These inland fish camps are often traditional family sites situated to take advantage of the plentiful fish resources. Commonly, these camps are located at the mouth of tributary streams or at deep sections of the major rivers so that, as the fish migrate out

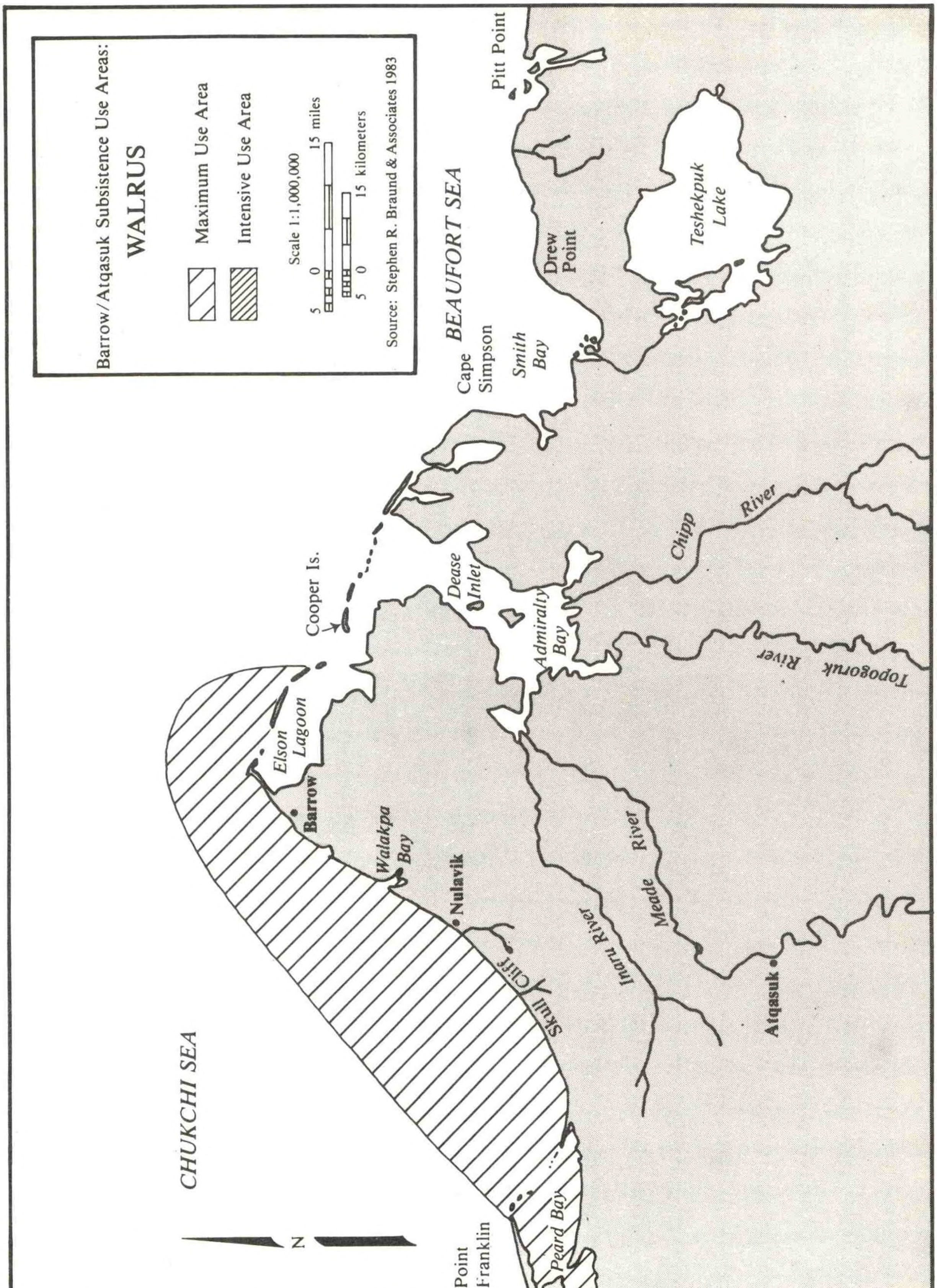

FIGURE 9.22—Barrow and Atqasuk subsistence use areas: walrus.

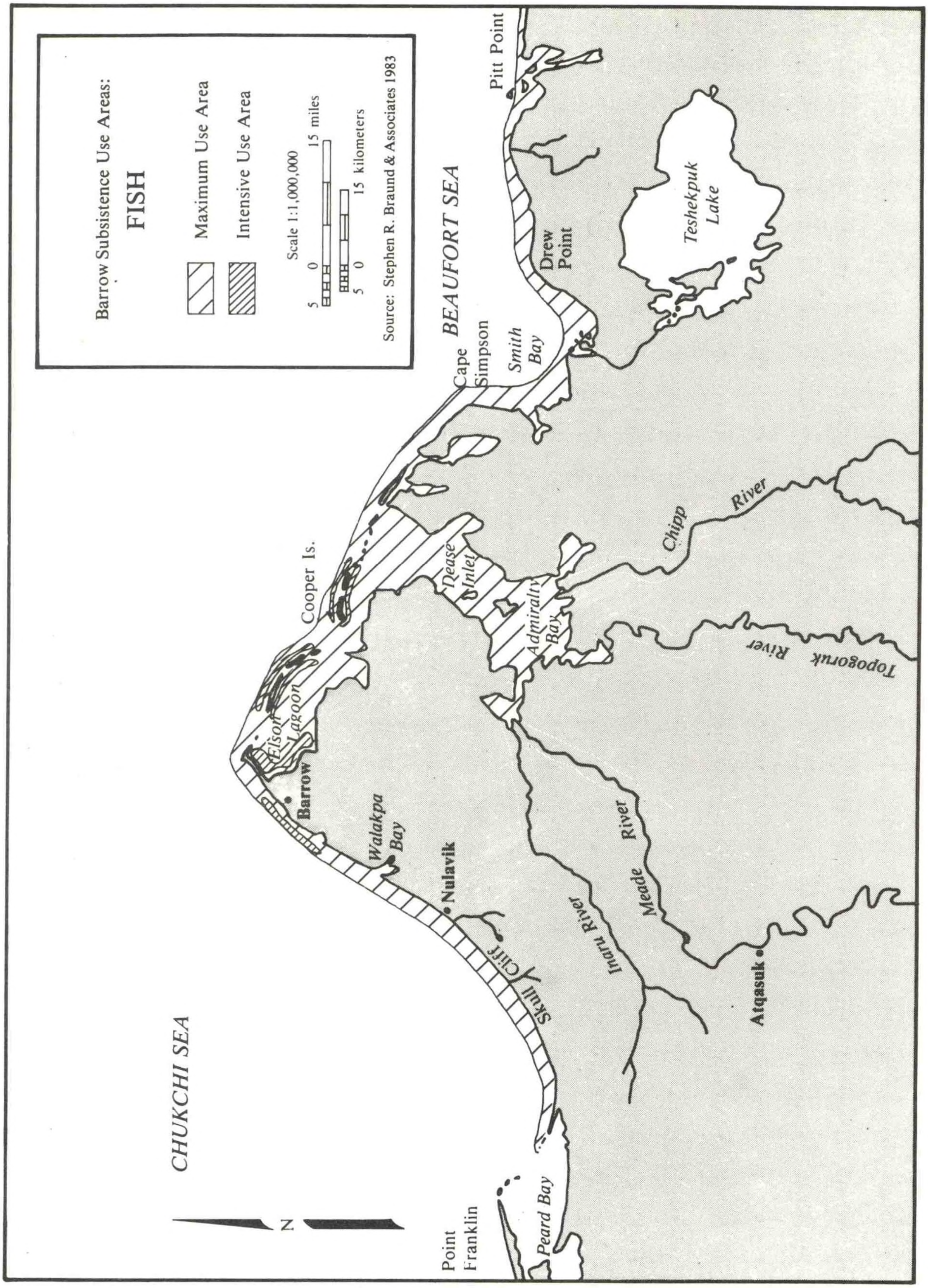

FIGURE 9.23—Barrow subsistence use areas: fish.

of the numerous lakes and shallow streams to winter in areas that will not freeze, they can be harvested in quantity. In addition to offering successful fishing, these inland camps also provide Barrow residents with access to caribou and migratory birds.

Migratory Birds

Migratory birds, especially eider ducks and geese, are an important part of Barrow's subsistence economy. Local residents reported that the harvest of geese was more successful inland along open rivers, whereas eider and other ducks were most successfully harvested on the coast. As noted in the section on spring whaling, waterfowl often provide an important food supplement at whaling camps. Snowy owls, once harvested in substantial numbers, are now rarely taken. Eggs are still gathered occasionally, especially on the offshore islands where foxes and other predators are less common. The extent to which waterfowl hunting is pursued differs among family groups, with this hunting being most zealously practiced by the younger male members of the community.

Migratory bird harvesting begins out on the ice at whaling camps during late April or early May. Once bowhead whaling season is over, the harvest of waterfowl increases as do the numbers of birds migrating through the area. Both geese and ducks are heavily hunted during the second half of May and the month of June. Some birds are harvested during the rest of the summer, but usually incidental to other subsistence activities. Hunting pressure increases during a brief period in late August and early September as the ducks and geese migrate south. When the last of the waterfowl migrate out of the area in late September, migratory bird hunting is over until the following spring.

Figure 9.24 shows Barrow's harvest area for migratory birds. The majority of goose hunting occurs inland, while most eider and other ducks are hunted on the coast. The coastal hunting area for migratory birds extends from Point Franklin (southwest of Barrow) to the waters of Admiralty Bay. Once spring whaling is over, families disperse and some go inland to concentrate on geese while others spread out along the coast. Waterfowl are initially the most important resource at the numerous spring camps along the Chukchi Sea coast, seals becoming more important later in the season.

The most important coastal migratory bird hunting area is the "shooting station" located at the narrowest point of the barrier spit which forms Point Barrow and separates the Chukchi Sea from Elson Lagoon. During both the spring migration north and the fall migration south, this is a highly successful hunting area. Proximity to Barrow makes it readily accessible to all members of the community. Many families have cabins in the area and spend evenings and weekends there during the bird migrations.

9.3 POTENTIAL IMPACTS OF OFFSHORE OIL DEVELOPMENT ON SUBSISTENCE USE PATTERNS

Table 9.2 summarizes the potential effects of oil development on the major marine resources important to present subsistence activities of the Chukchi Sea Inupiat. Offshore oil development could affect the biota in three general ways that could cause changes in subsistence use patterns of these resources:

1) Noise and disturbance that accompany seismic tests, air and boat traffic, and other industrial activities could displace fish and wildlife species, making them more difficult to harvest.
2) Spilled oil could cause mortality or decreased productivity in fish and wildlife species which would in turn affect harvest success.
3) Development of shore-based facilities could reduce hunter access to fish and wildlife or reduce resource populations to the extent that subsistence activities would be affected.

The following discussions focus on the potential impacts on subsistence activities that could result from one or more of these development activities. Effects of the development activities on the biota are evaluated largely on the basis of information provided during the human resource use sessions of the Barrow Arch Synthesis Meeting and edited to be consistent with Chapters 4 through 8.

9.3.1 Noise and Disturbance

Bowhead whales may respond to noise and disturbance in a manner that would affect the hunting of this species. Seismic testing, boats and motors, and low-flying aircraft have the potential to disturb these animals and displace them from normal migration patterns. Displacement may affect the ability of hunters to harvest whales, because of how the whales are harvested. Generally, the narrow lead spring whaling is done very quietly in man-powered skin boats. Because of double leads, young ice, and changing weather conditions, gaining access to leads suitable for bowhead hunting dictates the success of North Slope whale hunters. If noise and disturbance related to oil development displaced the bowheads by as little as 2 to 3 km, such that the whales migrated in offshore leads inaccessible to the Inupiat hunters, local access and harvest success could be affected.

Beluga whales are also sensitive to noise and may be displaced from traditional harvest areas by heavy boat traffic. Although there is evidence that belugas will accommodate or acclimate to a particular pattern of noise after extensive exposure, such acclimation

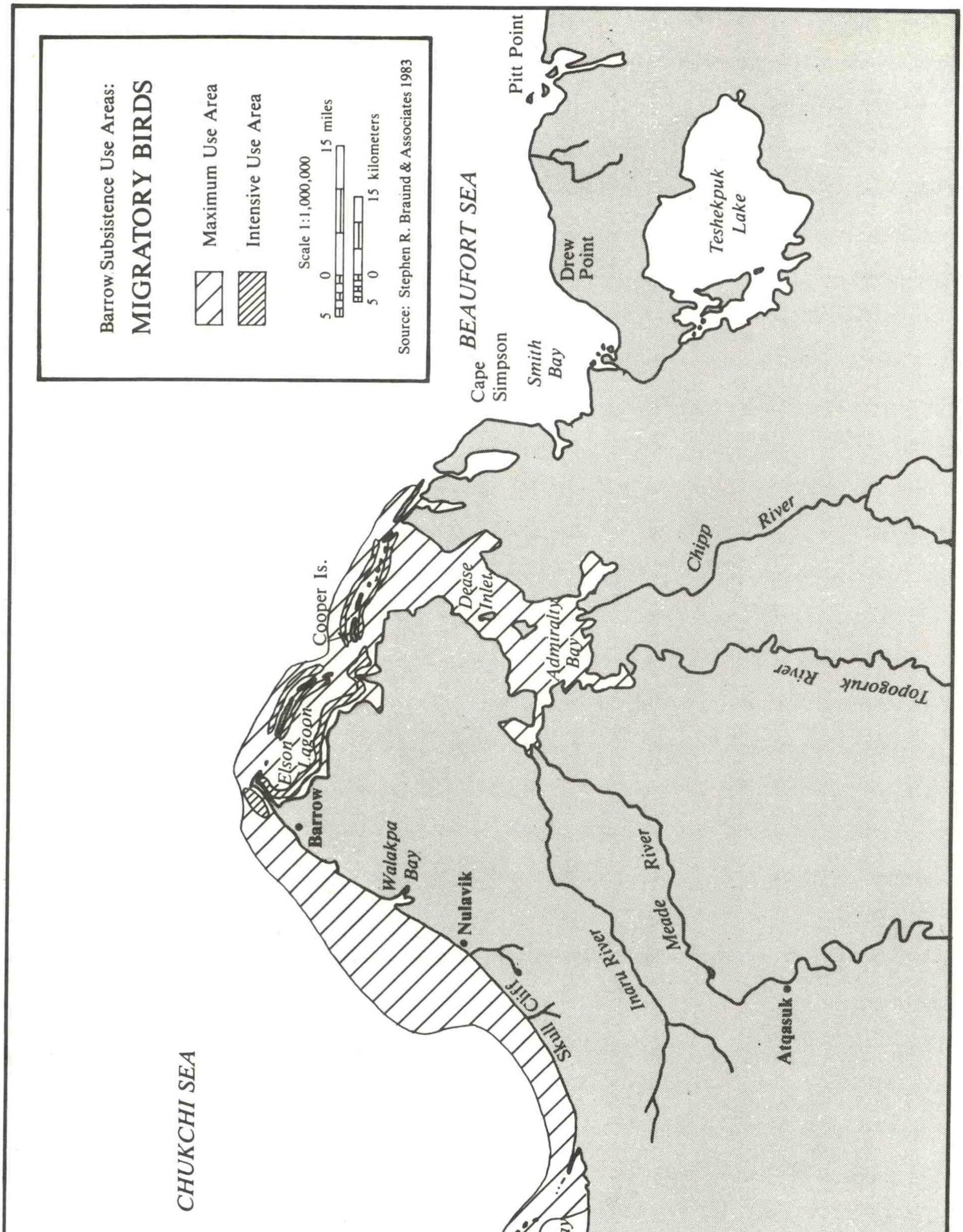

FIGURE 9.24—Barrow subsistence use areas: migratory birds.

TABLE 9.2—Potential impacts of offshore oil development on marine subsistence resources, eastern Chukchi Sea, as discussed at the Barrow Arch Synthesis Meeting.

	Potential Effects From—		
Target Species	Noise and Disturbance	Spilled Oil*	Coastal Development
Bowhead whale	Possible "displacement" of migrating whales caused by seismic activity on ice, ships in the leads, and drilling.	Most vulnerable in spring leads, less so in fall.	Probably negligible effects.
Beluga whale	Possible displacement by, or habituation to, noise, increased human and boat traffic.	Most vulnerable in spring leads, less so in summer and fall.	All marine mammals: More sensitive to moving sound sources than stationary sources. Displacement usually site-specific (e.g., shore facility located adjacent to a concentrated area.)
Ringed seal	Seismic activity on shorefast ice in spring might cause local displacement with no effect on seal population.	Ringed and bearded seals and walrus: Populations not too vulnerable because they are dispersed. Oil contact for adults is a minor problem; pups are more susceptible.	
Bearded seal	Minor displacement effects; dispersed and more solitary than walrus.		
Walrus	Sensitive to noise (aircraft and boat). Stampeding results in separation of cow and calf, especially for terrestrial haulouts. Cape Lisburne is a major haulout.		
Spotted seal	Haul out in quiet, isolated areas. Sensitive to human activity, disturbance, and boat traffic.	Do not pup in the area, therefore a minor problem.	
Polar bear	Possible displacement of denning along the coast, concentrated near Icy Cape and Point Franklin.	Both adults and young are very sensitive to oil. Population widely dispersed and thus not particularly vulnerable.	Polar bears are concentrated at Point Franklin and Icy Cape; shore activity there would likely cause conflict between bears and people.
Fish	Localized and short-term effects. Potential small impact from seismic blasting where fish are in confined areas such as lagoons or inlets.	Cleanup dispersants toxic to fish. Oil spilled in estuaries may locally affect pink salmon.	Causeways, dredging, and gravel mining cause minor displacement of populations.
Eiders	Vulnerable to local noise and roads that would provide fox access to nesting islands.	Many vulnerable to oil in the leads during spring, and to oil in molting areas near Icy Cape in July–August.	
Geese & brant	Brant at Icy Cape in the fall sensitive to noise and aircraft.	Combination of a storm surge and an oil spill would result in loss of salt marsh habitat.	Development at Icy Cape could conflict with brant and associated habitat.
Murres	Activities at nesting cliffs may disturb eggs and young.	Potential large mortality near nesting cliffs in June–August; in leads in April–May.	If industry disturbs cliffs, it would affect nesting murres.

SOURCE: Stephen R. Braund & Associates from information presented at the Barrow Arch Synthesis Meeting human resource use workshop, edited to be consistent with material in Chapters 4–6.

* May lead to noise and disturbance effects through cleanup activities.

could also affect Inupiat hunter access. For example, Point Lay residents rely on the harvest of belugas more than any other Chukchi Sea village and at the present time are very successful herding these animals by boat in Kasegaluk Lagoon. If local boat traffic increased and the belugas acclimated to the noise, there is the possibility that this herding technique would be less successful.

Effects of noise and disturbance on seals, walruses, waterfowl, and fishes are likely to have less important subsistence use effects than is the case with whales. The most likely effect of noise and disturbance on seals is local displacement, in which the animals avoid areas of increased human activity. This could negatively affect localized subsistence hunting areas. Impacts to walrus subsistence harvest activities are most likely to occur during summer when the animals migrate into the Barrow Arch area. Low-flying aircraft and boat noise at this time might disturb walruses resting on ice pans. The common method Eskimos use to hunt walrus is to approach the herds as they rest on ice pans in the broken ice margin of the pack ice. If increased noise, traffic, and development caused the dispersal of these herds, the hunting success of local residents could be detrimentally affected. The impacts of noise and disturbance in offshore areas on waterfowl and fish harvests would likely be minimal.

9.3.2 Spilled Oil

The effects of oil spills on subsistence use patterns would be in direct proportion to the effects on population levels or productivity of traditionally harvested species. The potential effects of oil on subsistence uses that might occur because of oil contaminating the harvested resource and thereby making it less desirable for consumption are not discussed here.

Potential effects of oil on bowheads and beluga whales are an important concern. The whales would be particularly vulnerable to oil spilled in the ice lead system in spring, at which time virtually all the bowhead population and most of the hunted beluga population pass through this spatially restricted habitat. Whales are less vulnerable at other seasons (*see* Chapter 4). Mortality of any of these animals, particularly bowheads, might result in decreased harvest levels.

Effects of oil on other marine mammals are probably less likely to affect subsistence use patterns. Oil-caused mortality of seals and walruses is not likely to be extensive in space or time. Polar bears, though apparently highly sensitive to being oiled, occur in such low densities that oil-caused impacts on the polar bear harvest are likely to be minimal.

Subsistence use of fish is likely to be affected only if large amounts of oil reach environments where anadromous fish populations are concentrated, such as in lagoons or bays where fishes concentrate at specific times of year. Juveniles are probably most sensitive to the effects of oil (*see* Chapter 6); large amounts of oil in lagoons or river deltas in summer when juvenile salmon occur there might adversely affect local salmon runs in future years. In general, any effects of oil spills on fish harvests are likely to be very localized and short term, lasting at most a few years.

Seabird and waterfowl populations are probably more vulnerable than those of most mammals and fishes to the effects of oil, and thus the potential effects of oil on subsistence use of these birds may be higher. However, as with most of the other subsistence species considered, the impacts of oil on populations of seabirds and waterfowl, and thereby on subsistence harvests, would be localized in space. Perhaps the greatest potential effects would be on harvests of cliff-nesting seabirds. Populations of these are highly concentrated, so an oil spill could potentially affect a large proportion of the regional population. Further, the birds reproduce slowly, and recovery from large-scale mortalities would be slow.

9.3.3 Coastal Development

Coastal construction activities ancillary to offshore oil development also have the potential to affect subsistence use of marine resources. Impacts on harvests of mammals, fishes, and birds are possible.

In the case of marine mammals, the most likely impact would be caused by changes in distribution as a consequence of onshore noises. Such changes could alter hunter access. Most important are the potential impacts of onshore development in areas directly adjacent to areas where marine mammals concentrate. For example, both Peard Bay and Icy Cape are areas where marine mammal concentrations are important to local subsistence harvesters. If onshore development displaces marine mammals from these areas, local subsistence harvest patterns would be affected. Both spotted seals and walruses are known to use coastal haulout sites during the ice-free months. If coastal development occurs in the vicinity of these haulout locations, displacement of some mammals could occur. During winter, polar bears are concentrated at Point Franklin and Icy Cape, and onshore activity in these areas might cause conflicts between polar bears and people that would ultimately affect the polar bear harvest.

Fish harvests could be affected by onshore activities such as dredging, gravel mining, and road building, which could cause local impacts in fish populations through the destruction of fish habitat and temporary siltation of adjacent streams. These problems would likely be localized.

If onshore development displaced migratory birds from important feeding and staging areas, the populations and harvests of the populations could be affected. If coastal development affected seabird nesting colonies, the success of local Inupiat hunters and egg gatherers might be affected. Effects would likely be very localized and small.

9.3.4 Conclusion

Offshore oil development could potentially affect the subsistence harvest of marine resources in three ways. First, noise and disturbance in the marine environment, while not necessarily biologically detrimental, could alter marine animal migrations and movements and thus reduce ease of hunter access. Second, oil spills could locally or regionally reduce resource populations which could in turn affect harvest success of local residents. Third, coastal development, especially near important hunting areas, could displace desired marine resources and affect local hunting access.

It is important to note that the majority of the locally harvested marine resources are migratory. They tend to concentrate at particular times and places in response to physical habitat factors or ecological factors (e.g., feeding areas). In their seasonal round of harvest activities, Inupiat hunters incorporate knowledge of resource location and migration timing. They concentrate on particular hunting activities when the desired subsistence resources are temporally or spatially concentrated.

Detrimental impacts to the subsistence harvest cycle are most likely to occur when the desired resource, the local subsistence harvesters, and the potential impact occur in the same area at the same time. For example, an offshore oil spill in December, when subsistence activities are concentrated inland (i.e., on caribou) and the majority of marine resources are further south, would probably cause a far less significant impact on subsistence activities than an oil spill near Point Hope during the spring bowhead whale hunt.

The subsistence harvest network of the Inupiat is extremely resilient. Hunters are usually able to adapt their seasonal round of subsistence activities to accommodate changes in resource abundance and availability. In most instances the impact of oil development would be short term and localized, and therefore hunters could likely adjust to these changes. However, as discussed above, there are important subsistence harvest areas and marine resources which are particularly sensitive to potential impacts of oil development. Impacts on these areas or resources could negatively affect the subsistence use patterns and economy of the North Slope Inupiat.

9.4 SUMMARY

Increased local employment opportunities have affected subsistence activities of North Slope Borough residents in two ways. First, higher employment has increased the amount of money readily available for investment in subsistence equipment. Second, employment has reduced the amount of time available for the pursuit of subsistence activities. The two impacts have resulted in changes in harvest techniques, the timing or scheduling of specific harvests, the amount of time necessary for the successful harvest of specific wildlife resources, and, in some cases, they have influenced hunting ranges and changed the hunting emphasis on specific resources. On the other hand, techniques used and the range and timing of the harvest have remained the same for some species.

The major technological innovations of the past 20 years which have become commonly available and used largely as a result of the increased buying power of local residents include the replacement of dog teams by snowmachines; the use of wood and aluminum boats with increasingly powerful outboard motors; and the addition of the three-wheeler and, in some communities, the airplane to the repertoire of subsistence harvest tools.

These modern subsistence tools have increased hunters' speed, mobility, and hauling power and enabled villagers to balance local employment and subsistence pursuits. The increase in mobility has made weekend and evening hunting feasible and productive. North Slope Borough residents stated that not only does employment have little effect on hunting participation, but weekends and evenings, in combination with a few longer seasonal trips (i.e., bowhead whaling and fall fishing), provide sufficient time to harvest the desired amount of wildlife resources. Thus, increased cash provided by employment is seen as a complement to subsistence pursuits.

Considering the cash requirements for contemporary subsistence activities, the availability of local jobs, the seasonal or temporary nature of much of the employment, and the generous policies related to annual and subsistence leave for permanent workers, the recent employment opportunities in the North Slope are compatible with current subsistence activities. In fact, the subsistence harvest of marine resources continues to be an integral part of Chukchi Sea village Inupiat life.

Harvest ranges and the quantity of each species harvested are dynamic factors affected by species abundance, changes in harvest technologies, and physical parameters such as weather and ice conditions. An assessment of recent changes in the coastal harvest ranges of the Chukchi Sea villages indicated that recent technological improvements have allowed subsistence hunters to travel to harvest areas much faster and cover more area while hunting. Present hunting ranges have not diminished and are similar to traditional use areas. In some cases, the range has expanded (e.g., fall whaling in Barrow). Although the recent technological improvements have not necessarily altered the range of species harvested, they have, in some cases, caused a shift in the intensity of utilization among species. The commonly harvested marine resources include bowhead whales, beluga whales, ringed, spotted, and bearded seals, walruses, fishes, and birds.

The effects of proposed oil development on marine subsistence harvest activities were divided into three categories: noise and disturbance, oil spills, and coastal development. Because the primary subsistence resources are migratory and tend to concentrate at particular times and places, the potential subsistence impacts of oil development are dependent on two variables: the time of year and the location. The effects on local subsistence users would be most significant if the desired marine resource is concentrated spatially in the vicinity of an oil spill. In most instances the effects of oil development on local residents' harvest success should be short term and localized. A potential major exception would be related to the bowhead whales that migrate in the narrow spring leads. A spill within this lead system, should it affect the majority of the bowhead population, would dramatically affect local subsistence economies.

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10

Socioeconomic Issues

by Jack A. Kruse

With contributions from S. R. Braund, C. Courtnage, H. Luton, and D. Schmidt. Meeting Chairman: J. A. Kruse.

This chapter summarizes the results of the Barrow Arch socioeconomic synthesis workshop; Kruse *et al.* (1983); Alaska Consultants and Braund (1983); and the preliminary work products for ERE Systems (1984) concerning the transportation requirements to support petroleum activities in the Chukchi Sea. The first goal of the workshop was to identify and describe the principal social and economic local effects of proposed exploration, development, and production activities. The second was to describe remaining uncertainties which preclude us from making reliable projections and, if possible, to identify research methods which could reduce these uncertainties. The technical reports and preliminary work products listed above served as the principal research base for the synthesis discussion. Each technical report, however, draws on the extensive North Slope socioeconomic research literature; therefore, synthesis findings are intended to reflect not only recent research efforts but also past research.

To achieve the two stated workshop goals, we adopted five workshop objectives:

1. Modify and extend an analytical framework developed at the 1982 Beaufort Sea Synthesis Meeting.
2. Describe alternative combinations of industry transportation and support systems on a location-specific basis in order to identify potential impacts at the village level.
3. Project the social and economic conditions likely to exist in North Slope villages in the 1990's when development activities would most likely occur.
4. Project the interactions between industry activities and prevalent local conditions, focusing in particular on Native employment behavior.
5. Identify uncertainties which limit our ability to project social and economic effects and to suggest research activities which could reduce such uncertainties.

The socioeconomic synthesis workshop did not explicitly treat the issue of subsistence impacts because this issue was the subject of a subsequent workshop. However, since social and economic conditions on the North Slope are the product of substantial interactions between the subsistence and cash economy, we have included subsistence variables in our analytical framework and synthesis discussion. The remainder of this chapter is organized around the five objectives listed above.

10.1 ANALYTICAL FRAMEWORK

Two sets of circumstances on the North Slope cause its mix of potentially significant impacts of oil development to differ from that observed in the Lower 48 or even elsewhere in Alaska. First, energy development on the North Slope does not result in rapid population increases in existing communities, attendant increases in service demands, and lags in the availability of public revenues necessary to meet such demands. While this has been the usual experience of western U.S. boomtowns, the dual factors of remoteness and regional taxing powers cause a completely different outcome. With no village located near Prudhoe Bay and no permanent roads connecting the development site with any Inupiat settlement, industry developed a virtually independent infrastructure from that supporting the North Slope traditional villages. Population increases directly induced by development thus occurred in enclaves, not in communities. Service demands in North Slope villages rapidly increased due to rising expectations, not rising populations. The formation of the North Slope Borough coincident with the multibillion-dollar capital investments of the oil industry permitted the Inupiat to pay for these new services through a regional property tax. Although there was some lag in revenue-generating ability due to court challenges, the North Slope Borough was ultimately successful in mounting a capital improvements program now worth over $1 billion. The important point, however, is that the western boomtown model of impacts does not apply to the North Slope.

The second major set of circumstances differentiating the North Slope and other rural Alaskan regions from regions outside of Alaska experiencing energy impacts is the widespread use of and value attached to the wildlife resources of the region. Well over 90% of the Inupiat residents of the North Slope regularly consume wild foods (Kruse 1982). As the traditional economic base of the region, these wild foods and the attendant harvesting activities are the object of the most important social and cultural values, values which have persisted despite a decline in the economic importance of wild foods. (We should note, however, that wild foods continue to support a significant proportion of the Inupiat mixed economy [Kruse 1982].) Potential impacts involving subsistence resources are, therefore, clearly key topics to be addressed in North Slope impact studies.

Starting in the lower left corner of Figure 10.1, we see that both petroleum development and other forces of change—normal animal population fluctuations or the International Whaling Commission, for example—may affect the net supply of subsistence resources available to Inupiat hunters. These forces of change may operate in six ways: (1) direct mortality (or reduced fertility) of fish and wildlife, (2) habitat destruction, (3) dislocation of fish and wildlife as a result of noise or visual disturbance, (4) physical disruption of access to fish and wildlife, (5) regulatory restriction of access to fish and wildlife, and (6) increased human competition for fish and wildlife.

The top left corner of Figure 10.1 illustrates our conception of the demand side of subsistence resource consumption. The size of the population consuming subsistence resources, both on a regional and a community basis, will affect total demand, as will the level of economic need. Demand for subsistence resources can also be affected by change in the social system. Key elements of the social system with respect to subsistence are cooperative hunting relationships, normative sharing patterns, language, mechanisms for transferring knowledge, social values associated with subsistence activities and products, and spiritual beliefs. Finally, changes in the amount of capital available for subsistence (and hence in subsistence technology) and in individual tastes and preferences can alter demands for subsistence resources.

In the lower right corner of Figure 10.1 we show the second major link between petroleum development and social and economic change on the North Slope. Sixty-seven percent of all North Slope Borough general fund revenue comes from property taxes paid by the oil industry. The amount of money that the borough can obtain through taxation to fund its operation is currently limited by state law. Changes in this limitation or expansion to limit the borough's ability to sell bonds or to service the debt for capital construction can dramatically affect borough revenues and, hence, expenditures, employment, and local services.

In addition to providing a tremendous property tax base, the petroleum industry creates a demand for support services which may be met in part by Native regional or village corporations or by the North Slope Borough. For example, the borough is currently constructing a service center for the Kuparuk field, and a Native corporation, Pingo, provides services at Prudhoe Bay. The involvement of the North Slope Borough and Native corporations in petroleum lease development activities may enhance Native employment opportunities.

Currently, the largest employer of North Slope permanent residents is the North Slope Borough. A substantial proportion of all borough jobs are associated with its Capital Improvements Program (CIP). Completed CIP projects generate additional demands for operations expenditures. Since these funds are limited by state law, there is a limit on the amount of new construction that can be operated and maintained, hence, the reason for the feedback loop from local services to borough revenues and expenditures in Figure 10.1.

The supply of Inupiat labor (top right of Figure 10.1) is affected by population size, economic needs, the social system, and tastes and preferences. The supply of Inupiat labor is rapidly growing due to two major factors: (1) the aging and entry into the labor force of a large number of Inupiat born in the 1950's and 1960's and (2) the entry of a large number of women into the labor force (Kleinfeld 1981). Comparing 1970 and 1980 census data, Inupiat men do not appear to be participating in the wage economy in greater proportions than they did before the petroleum industry and the North Slope Borough became active on the North Slope in the 1970's. Men clearly prefer current, local job opportunities over nonlocal petroleum industry employment, however.

The development and funding of the North Slope Borough not only increased local employment opportunities but also substantially expanded and improved

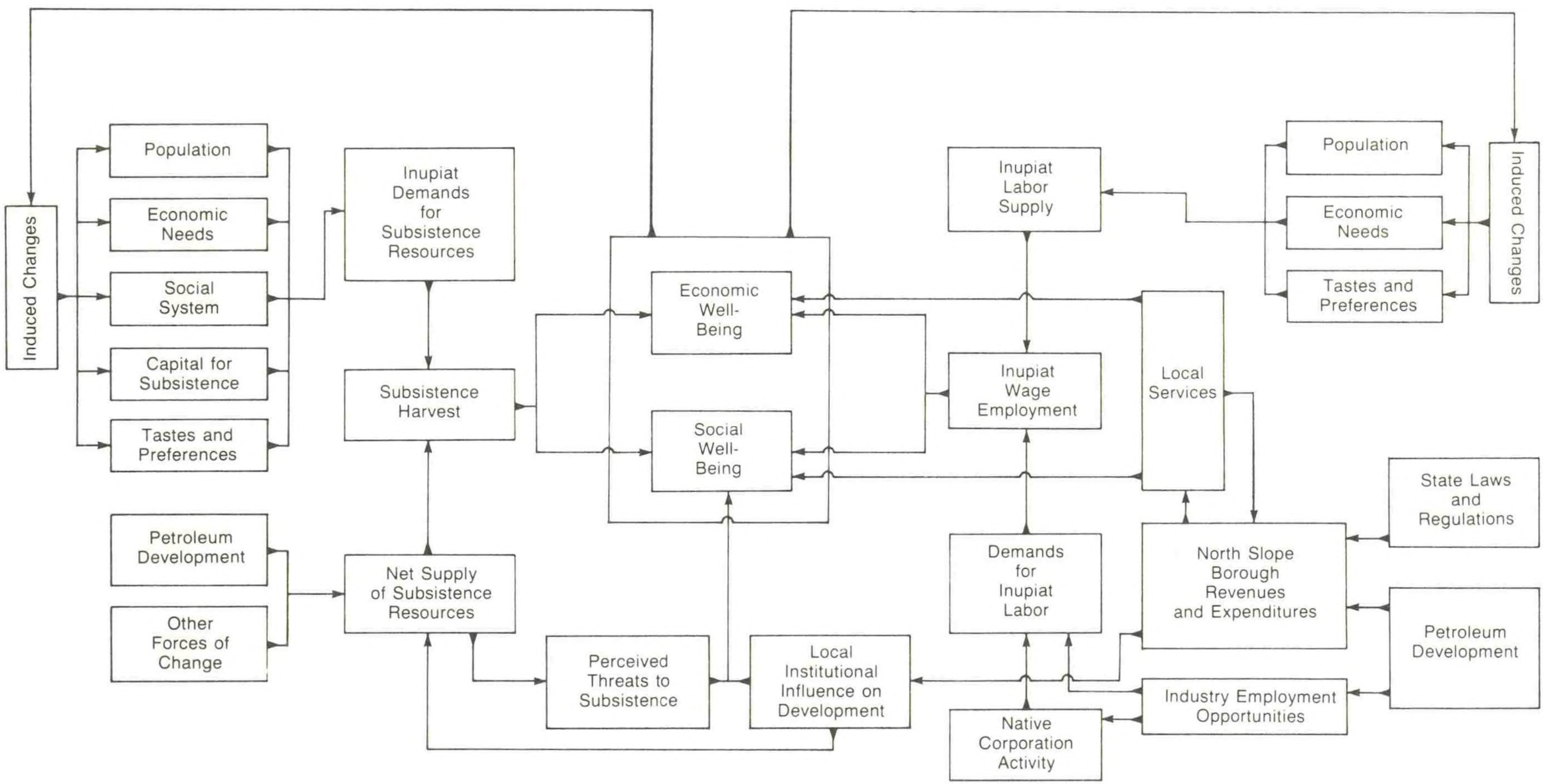

FIGURE 10.1—Dynamics of social and economic change on Alaska's North Slope.

the quality of local services. The local service system is not complete; moreover, some completed service components are vulnerable to failure or are inadequate. In addition to borough effects on employment and local services are the borough's potential influences on development activities and indirectly on perceived threats to subsistence.

Subsistence harvest, Inupiat wage employment, local services, perceived threats to subsistence, and local institutional influence on development are the major factors which affect Inupiat economic and social well-being, the core of the analytical framework. Figure 10.1 does not identify the numerous components of social and economic well-being, but we intend the core to encompass both individual and societal well-being. Thus, for example, economic well-being refers not only to individual income levels but also to the distribution of income within the population as a whole. Social well-being not only includes perceived satisfaction with individual circumstances but also the ability of existing social systems to adaptively handle changes in individual behavior and in environmental conditions.

The analytical framework depicted in Figure 10.1 is not static within a given set of external forces of change. Changes in one or more components of economic and social well-being may induce changes in the factors which affect Inupiat demands for subsistence resources or for employment. Persistent changes in these factors can be significant cultural changes.

10.2 DEVELOPMENT SCENARIO

D. Schmidt extended the basic development scenario used by all scientists at the Barrow Arch Synthesis Meeting to specifically address transporation issues which could determine village-specific impacts. During exploration, supplies could be stored offshore near the drilling site; nearshore, perhaps off Point Belcher or in Peard Bay; or even outside the region. If supply barges were moored near the village of Wainwright, supply boats would probably frequently run from the coast to offshore drilling locations.

Exploratory drilling could involve one of several different kinds of drilling rigs. The extent to which drill crews work on a rotation schedule varies in part by the type of rig used; if most of the crew works on a rotating schedule, air traffic through Barrow and Wainwright could increase. Normally, crew members would not stop overnight in a North Slope village en route to the drilling rig; in inclement weather, however, stopovers are possible.

Development of an oil field in the Chukchi Sea could start as early as 1991. It would generate a large increase in barge traffic along the coast, perhaps 75 barges over a 3-year period. Development activities would include the drilling platforms themselves, subsea pipelines, a pipeline landfall, shore base, and an overland pipeline to the Trans-Alaska Pipeline System. A desirable location for a pipeline landfall and associated shore base appears to be Point Belcher, approximately 20 miles from Wainwright.

Development-related transportation construction would likely include an airstrip near the shore base and a private road from the shore base along the pipeline to the existing North Slope haul road. Although not required, a road could be constructed from the shore base to Wainwright.

The existence of an overland pipeline through the National Petroleum Reserve–Alaska (NPR–A) might make it economically feasible to develop oil fields in NPR–A, should they be discovered yet be of insufficient size to develop in isolation.

10.3 NORTH SLOPE ECONOMIC CONDITIONS IN THE 1990'S

The economic well-being of permanent North Slope residents dramatically improved during the last 10 years. The median income in Inupiat households increased by 56% in constant dollars between 1977 and 1980. Almost 40% of the current housing in North Slope villages is less than 10 years old. In addition, the western arctic caribou herd has rebounded from a population crash that occurred in the mid-1970's. The only significant existing limitation in resource availability is the regulatory restriction on bowhead harvest set by the International Whaling Commission.

Increases in local employment, income, housing, and public services have been only indirectly associated with North Slope petroleum development. The petroleum facilities themselves are located in enclaves rather than in or near traditional villages. Few Inupiat work in the oil industry or for supporting industries. There is little contact between North Slope residents and enclave workers. The importance to local residents of petroleum development to date on the North Slope is tied instead to the taxable property value of the development. In the 5-year period ending on 30 June 1983, the North Slope Borough collected more than $350 million either for debt service on bonds sold to finance capital construction or for borough operations. Over 90% of these revenues are generated by the oil industry. In addition, the borough has raised almost $900 million from general obligation bond sales that were only possible with the huge oil and gas property tax base, which is now worth over $7.7 billion.

Since a substantial amount of the capital investment required for offshore development occurs outside the taxing jurisdiction of the North Slope Borough, OCS development will not generate anywhere near the property tax base resulting from onshore development, particularly in view of the likelihood that offshore finds will be much smaller than the Prudhoe Bay field. However, there are more important reasons why OCS development in the Barrow Arch could not substantially increase North Slope Borough revenues. The state currently limits the amount of property taxes the borough can collect for its operations. The state limit increases as a function of the growth in *state* per capita assessed valuation and growth of the *North Slope* population. Development of the Chukchi Sea OCS will not produce substantial increases in either variable, although it could delay their decline.

Although the borough is not currently limited in the property taxes it can collect to pay for the principal or interest on bonds sold to finance capital construction, the limit on operating revenues will constrain the borough's ability to continue its massive capital construction program. New facilities inevitably add to the demand for operating funds.

The constraint on future capital spending is even more severe in North Slope villages than it is for the borough as a whole. The borough is constructing a service base for the Kuparuk oil field, which will cost over $70 million. This project and capital expenditures in the borough-operated service district at Prudhoe Bay will consume a substantial proportion of available CIP funds.

Finally, the borough already has the highest per capita debt of any jurisdiction in the United States. Although existing and planned petroleum developments constitute a solid tax base to retire these debts, the borough has encountered some difficulty in maintaining a strong credit rating in bond markets. Other Alaskan taxing jurisdictions, including the state itself, have begun to discuss legislation which would limit the borough's ability to sell more bonds. The result could bring the borough CIP to a virtual standstill.

Based on the foregoing considerations, the North Slope Borough has announced that it will reduce its rate of debt formation, which would cut its rate of capital expenditures by about two-thirds. A reduction in CIP activity will clearly decrease village construction employment. In addition, despite massive expenditures for local services such as schools, water, electricity, roads, waste disposal, health clinics, fire stations, fuel storage, and housing, villages are still vulnerable to service disruption or failure without further capital expenditures. In general, village service capacities are inadequate to handle the future demands which will inevitably occur as facilities currently under construction are completed. Whether or not the borough will be able to expand village service capacities will depend on the availability of CIP funds.

10.4 WAINWRIGHT CASE STUDY

The outlook for village employment and service conditions in the 1990's is, therefore, significantly worse than present conditions. In order to trace the specific implications of these changes with regard to local responses to OCS activities, synthesis workshop participants considered the case of Wainwright, the village most likely to be near development activities associated with Lease Sale 85.

Since 1973, a community building, a public safety building, a fire station, a health clinic, a high school, an elementary school, a water system, an electric power plant, and a fuel storage facility have been built in Wainwright, a village with a population of about 500. Since 1971, 81 housing units have been constructed, representing 72% of the occupied housing stock (Alaska Consultants and Braund 1983). Alaska Consultants observed the following service conditions in Wainwright:

1) *Power plant*—existing plant in unsafe location and capacity inadequate to handle new facilities.
2) *School*—warehouse needed to permit adequate maintenance.
3) *Water system*—one of two tanks deteriorating; second partially usable.
4) *Fuel storage*—inadequate capacity to ensure supply.
5) *Waste disposal*—gray water dumped beneath houses; no safe system for handling honey bucket waste; no accessible solid waste disposal site.
6) *Fire station*—new, extremely sophisticated facility requiring expert maintenance.
7) *Clinic*—same as fire station.
8) *Storage facility*—no heated facility for repair of large equipment.

Reductions in CIP expenditures are likely to delay or perhaps even preclude the modifications and replacements necessary to ensure service delivery in Wainwright. Therefore, residents may experience service breakdowns or curtailments in the 1990's.

Alaska Consultants and Braund (1983) identified a total of 138 full-time equivalent (FTE) employment positions in Wainwright in 1983, of which roughly 14 were filled by transient workers. For discussion purposes, synthesis workshop participants projected a 60% decrease in CIP employment and assumed that minimal operations employment could be funded. The resulting projected FTE employment in the early 1990's was 95. Applying current labor force participation rates to the projected adult population of Wainwright (assuming no net migration), an estimated 159 Wainwright residents will be in the labor force in the early 1990's, compared with 132 in 1983. Based on these projections, there will be a 40% decline in the number of FTE positions to be shared by the same number of Wainwright residents.

10.5 PROJECTED INTERACTIONS BETWEEN OCS ACTIVITIES AND SOCIOECONOMIC CONDITIONS

The following is a summary of points germane to our discussion of the interactions between development activities stemming from Lease Sale 85 and projected social and economic conditions.

1) The most likely drilling areas in the Barrow Arch OCS Planning Area are well offshore.
2) Exploration activities could involve mooring supply barges near the village of Wainwright and boat traffic between the barges and the drilling sites.
3) Exploration activities could also involve substantial traffic of offshore workers through Wainwright and Barrow.
4) Development activities could include a pipeline landfill near Point Belcher and an associated shore base.
5) A large number of barges—perhaps 75 over a 3-year period—would be needed to deliver supplies and equipment during development.
6) An overland pipeline and associated road would run between the landfall at Point Belcher and the Trans-Alaska Pipeline System. A spur road could connect Wainwright with the pipeline road.
7) The total number of onshore jobs directly associated with development would be between 300 and 400, of which 40 positions or less could be filled by local residents under some circumstances.
8) OCS development will not substantially increase North Slope Borough revenues.
9) Factors other than OCS oil and gas development are likely to result in major reductions in local employment and may reduce the quality of local services.

Figure 10.2 displays the analytical framework presented earlier and identifies the direction of changes in each dependent variable expected to result from changes in each independent variable. All variables which have a vector originating from them are independent variables, and all variables which have a vector terminating at them are dependent variables. Most are both independent and dependent variables since they fall within a postulated causal sequence. Dashed vectors indicate highly uncertain relationships. The left side of Figure 10.2 concerns subsistence-development relationships which are the focus of Chapter 9. We should note here, however, that the possible location of supply barges near shore during exploration and the location of a pipeline landfall and service base near Wainwright during development could disrupt coastal subsistence activities and thereby reduce subsistence harvests. Since these relationships are uncertain, however, they are indicated in Figure 10.2 with dashed lines.

Based on research reported by Kruse *et al.* (1983), the prospect of offshore development is certain to generate an increase in perceived threats to subsistence resources and a consequent reduction in social well-being. Kruse *et al.* (1983) also observed that local institutions would be unlikely to greatly influence offshore development activities and, therefore, would not significantly affect the net supply of subsistence resources. A lack of local institutional influence, however, would tend to increase social stress and, therefore, reduce social well-being.

For the reasons cited earlier, we do not expect offshore petroleum development will significantly increase North Slope Borough revenues or expenditures (right portion of Fig. 10.2). Rather, borough revenues and expenditures may be reduced by state actions. If so, some local services are likely to decline in quality. In any case, existing limits on operating revenues and the capital expenditure requirements to complete the borough's Kuparuk service base will lead to both a decline in village CIP expenditures and a reduction in local employment opportunities.

Industry employment opportunities for North Slope residents, however, may increase. While the number of industry jobs added by offshore development would constitute only a small proportion—less than 10%—of the total industry work force, three factors may act to make both existing and new industry jobs more attractive and accessible to Native workers. First, the North Slope Borough and several Native corporations are becoming actively involved in industry support activities. While neither the borough nor the Native corporations are totally free to set their own employment policies if they are to remain competitive, they are likely to institute policies which are more compatible with Inupiat employment preferences. Given the probable decrease in village employment opportunities, marginal changes in employment policies may be enough to attract Inupiat labor.

The second reason Inupiat participation in petroleum-related employment may increase is directly related to the Barrow Arch lease sale but is much more uncertain. If a shore base is located near Point Belcher, the employment opportunities there may attract some Wainwright residents. Again, the decline of village job opportunities is likely to be a strong incentive for village residents to seek employment outside the village. The Point Belcher site would effectively be within commuting distance.

We have illustrated the possible shift in Inupiat employment preferences which may result from

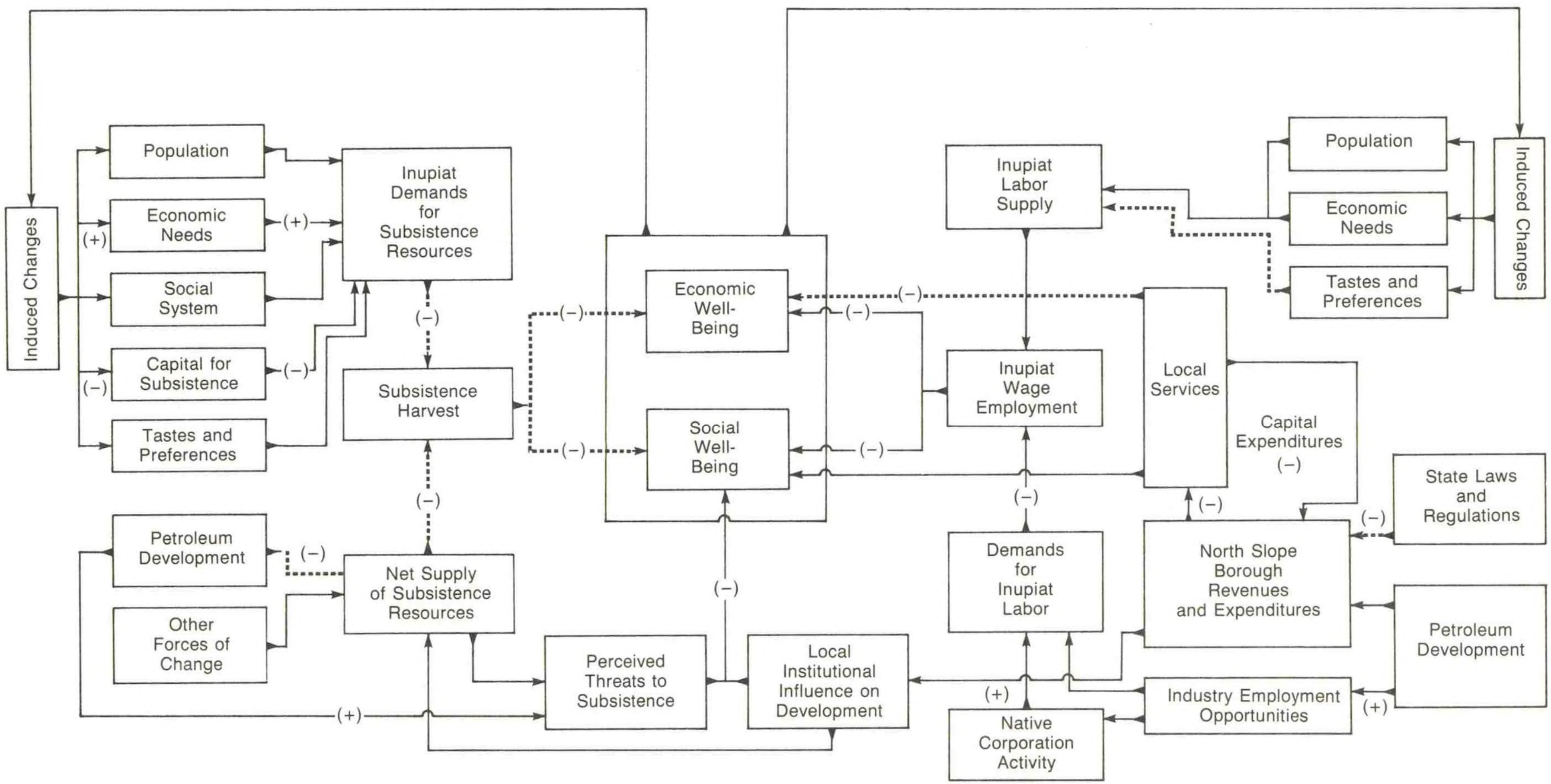

FIGURE 10.2—Major socioeconomic impact relationships.

changing job opportunities as a dashed line in the upper right of Figure 10.2. Even if Inupiat job preferences shift, however, many constraints to Inupiat participation in petroleum-related employment opportunities are likely to remain. These constraints include lack of required skills or certification of skills, union membership, miscommunication during the job application or hiring process, inflexible or inconvenient work rotation schedules, and social differences between non-Native and Native workers. Therefore, we would expect that the North Slope Inupiat will experience a net reduction in weeks worked and in income in the 1990's, with obvious adverse effects on social and economic well-being.

One of the consequences of a decline in earned income may be a reduction in the capital available for the purchase of subsistence equipment and supplies. As discussed in Chapter 9, plentiful job opportunities and relatively high cash incomes have been accompanied by increased reliance on purchased goods and equipment. In addition, hunting activities which benefit most from western technology have become more popular. A decrease in capital for subsistence activities could force reductions or modifications in current activity patterns. Whether this would reduce subsistence harvest is unknown (*see* Section 10.6).

A decline in income can also seem to increase the economic importance of subsistence harvests. It is unlikely that subsistence harvests would increase as a result, however, since bowhead harvests are limited by International Whaling Commission quotas and the current caribou harvest is quite large due to their present abundance. The amount of subsistence resources harvested will depend primarily on the availability of fish and wildlife and on the availability of cash to finance subsistence activities.

As Figure 10.2 shows, our analysis suggests that none of the factors affecting social and economic well-being are likely to act to increase Inupiat well-being. Declines in village employment are unlikely to be completely offset by increased Inupiat participation in petroleum-related employment opportunities. Local services are unlikely to be improved substantially from current levels and may, in fact, remain the same or deteriorate. Perceived threats to subsistence that stem from anticipated OCS activity already negatively affect social well-being and are likely to persist for some time. Local institutional influence on development is unlikely to increase, thus creating another source of social stress.

The role of OCS development in the foregoing analysis is threefold. First, employment and business opportunities associated with petroleum development may mitigate declines in village employment and income. This outcome is highly conditional and may prove to be negligible. Second, OCS development is perceived by most Inupiat testifying on the subject primarily as a threat to subsistence resources. Finally, OCS development could, in fact, reduce the net supply of subsistence resources.

10.6 RESEARCH NEEDS

From a social science perspective, the principal uncertainties are the probabilities and magnitudes of potential adverse effects of OCS development on subsistence resources. In particular, we see the need for research on the effects of noise, visual disturbance, and incidental releases of environmental contaminants on marine mammals, waterfowl, and fishes.

A second major uncertainty concerns the liklihood that Inupiat residents will seek jobs associated with petroleum development activities if local employment opportunities diminish. In our view, the only effective means of reducing the uncertainty is to design and implement a cooperative research effort with employers which tests the effects of various combinations of hiring and training practices and work rules.

Finally, social scientists face a severe lack of time-series data on employment conditions, subsistence harvests, community service conditions, household costs, key indicators of cultural change such as sharing patterns and subsistence skill levels, and measures of social well-being. Each of these components is subject to rapid change; an ongoing data collection effort is needed, both to monitor the effects of development activities and to establish an accurate context within which the effects of future development activities can be projected.

10.7 SUMMARY

Participants in the Barrow Arch socioeconomic workshop revised an analytical framework developed at the Beaufort Sea subsistence workshop. The analytical framework serves as a useful tool for integrating socioeconomic and sociocultural studies and as a heuristic device for planning future studies.

Participants concluded that the baseline conditions existing at the projected time of Barrow Arch exploration and development activities will differ significantly from current conditions. North Slope Borough Capital Improvement Program activity is expected to decline by 60%, resulting in reduced local employment opportunities and delays in upgrading or completing community services. North Slope institutions are likely to increase their involvement in petroleum development activities. As a result, the number of attractive jobs related to petroleum development may increase for Inupiat residents.

Workshop participants concluded that the major potential effect of a Barrow Arch lease sale is disruption of coastal subsistence activities, particularly near Wainwright. The form, likelihood, and magnitude of such effects continue to be highly uncertain. Petroleum exploration and development activities at Point Belcher near Wainwright could increase employment opportunities within commuting distance of the village. Constraints to Inupiat participation in petroleum-related employment opportunities continue to exist, however. Workshop participants thought it unlikely that additional petroleum-related employment would be likely to prevent a decrease in Inupiat employment and income.

Three major research needs were identified in the workshop. First, participants saw a need for more research on the effects of noise, visual disturbance, and incidental releases of environmental contaminants on marine mammals, waterfowl, and fishes. Second, a cooperative research effort with employers is needed to reduce the uncertainty about the relationship between petroleum development and Inupiat employment. Finally, participants identified a critical need for basic time-series data to describe baseline conditions, develop impact projections, and monitor development effects.

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