Proceedings of a Synthesis Meeting:

The Norton Sound Environment and Possible Consequences of Planned Oil and Gas Development

Anchorage, Alaska — October 28-30, 1980

Outer Continental Shelf Environmental Assessment Program
Juneau, Alaska

United States
Department of Commerce
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S.T. Zimmerman (Editor)
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United States
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Malcolm Baldridge, Secretary

National Oceanic and
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John V. Byrne, Administrator

Office of Marine Pollution Assessment
R. Lawrence Swanson, Director

United States
Department of the Interior
James E. Watt, Secretary

Bureau of Land Management
Robert F. Burford, Director

NOTICES

PREFACE

The Norton Sound Synthesis Meeting was convened in Anchorage, Alaska, on October 28, 1980. The purposes of this meeting were:

- to synthesize our knowledge of the Norton Sound Lease Area (Sale No. 57) in order to facilitate the preparation of BLM's Draft Environmental Impact Statement due June 1981,
- to assess the likely impacts of petroleum development on the Sale 57 area through the consideration of various oil spill and tract deletion scenarios, and
- to determine needs for further scientific studies in the area.

The agenda was divided into three major sections as follows:

1. An initial plenary session devoted to disciplinary overviews. In order of presentation, these were:
   - Physical oceanography and circulation in Norton Sound by Robin D. Muench;
   - Potential interactions of oil and ice in Norton Sound by Seelye Martin;
   - Sedimentary process and potential geologic hazards on the seafloor of the Northern Bering Sea by Hans Nelson;
   - Status of marine mammal populations in the Norton Sound Basin by Robert Nelson;
   - Fishery resources of Norton Basin, their distribution, abundance and utilization by Robert Wolotira;
   - Toxicity of oil in marine habitats by Donald Malins;
   - Exploration and development techniques for Norton Sound Sale No. 57 by Larry Wolfson;
   - Wind, waves, ice, and other environmental factors affecting oil and gas development in Norton Sound by Walter Spring; and
   - Proposed alternatives and development scenarios by Ray Emerson.

   In the interest of brevity, and because several of the manuscripts are almost exact duplicates of papers already published in OMPA's *The Eastern Bering Sea Shelf: Oceanography and Resources,* it was deemed inappropriate to attempt to reproduce all of the resulting manuscripts here. Copies of each manuscript are on file at the OCSEAP Office in Juneau and are available upon request.
2. Interdisciplinary discussion groups which met in concurrent pairs on the afternoon of the first day (Sessions A and B) and throughout the second day (Sessions C and D). Discussion topics were:
   - Session A. What effects may OCS development have on the Yukon Delta Region?
   - Session B. What effects may OCS development have on the ice front and open water biota, especially the marine mammals and birds.?
   - Session C. What effects may OCS development have on the coastal and nearshore habitats within Norton Sound?
   - Session D. What are the technologies available for OCS development in Norton Sound and how may they be affected by natural hazards?
3. A final plenary session which was held on the third morning in order that interdisciplinary session chairpersons could publicly present the results and conclusions of their groups.

Unlike previous OCSEAP synthesis reports, this document does not attempt to provide an in-depth summary or complete review of the status of scientific knowledge in the Norton Basin. Because this task has so recently been completed with the publication of OMPA's *The Eastern Bering Sea Shelf: Oceanography and Resources* (Hood and Calder, 1981), this manuscript is intended primarily to provide a record of the specific activities of, and the conclusions reached by, the session participants during the interdisciplinary workshops.

Sincere thanks go to the session chairpersons, rapporteurs, and the members of the various groups as identified in the text. Without their hard work this endeavor could not have been completed.

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D.W. Menzel (Chairman)
F.F. Wright (Rapporteur)

With contributions from L. Brooks, C. Evans, R. Griffiths, M. Hayes, J. Hemming, H. Jahns, S. Jewett, R. Jones, D. Liu, G. Martin, R. Muench, H. Nelson, T. Newbury, J. Overland, J. Shantz, W. Spring, S. Starr, W. Stringer, L. Trasky, R. Tripp, W. Turnbull, and R. Wolotira.

A. Introduction

The Yukon Delta is the northwestern portion of the vast Yukon-Kuskokwim deltaic complex extending into the Bering Sea south of Norton Sound. In relation to the proposed OCS development in Norton Sound, the Yukon Delta is defined as the section of the Alaska coastline extending from Stebbins (near Stuart Island) west and south to Cape Romanzof (Fig. 1). All of the major Yukon distributaries and its many minor channels lie in this portion of the lowland.

Off shore acreage coming within approximately 12 km of the northern delta region is scheduled for sale by BLM in September of 1982;[1] oil development is also possible within State waters near the delta and on Native corporation lands on or around the delta. The Yukon Delta is also near probable transportation routes for production from planned OCS sales in the Chukchi Sea and Hope Basin; it is downstream from four other identified OCS lease areas in the Bering Sea: the Navarin, St. George, St. Matthew-Hall, and North Aleutian Shelf. The St. Matthew-Hall OCS Planning Area, containing several small prospective basins, lies directly west of the Yukon Delta. In the draft five-year lease schedule published in April 1981, the St. Matthew-Hall area is proposed for a sale in October of 1985. Thus, although the specific purpose of this interdisciplinary discussion was to examine potential impacts from only the Norton Sound sale, the conclusions are relevant to all oil-related developments that may affect the delta region.

Two fundamental presumptions governed all discussion of OCS impacts in the Yukon Delta region:

1. Although it is understood that shore facility construction in the delta is highly unlikely because of the impracticality of harbor siting anywhere in the area, it was accepted that any onshore construction would be extremely damaging, not only in the sense of physical disruption (dredging, filling, and construction activities) but also in the broad biological sense (habitat destruction, continuing disturbance, and competition with native subsistence activities).
2. The tremendous shorebird and waterfowl populations dependent upon the delta coastline and wetlands are highly vulnerable to oil spills and the importance of these populations, on virtually a global scale, must be considered in any development scheme. Also identified as a major concern, but less clearly defined, was the vulnerability of the Yukon River salmon stock.

Because of these presumptions, the interdisciplinary discussion was limited largely to a consideration of facility siting and oil spills, and the effects these might have on the unique geologic, meteorologic, hydrologic, and biologic features of the Yukon Delta region.

B. The Yukon Delta Environment

The Yukon Delta littoral is one of gentle slopes, both above and below sea level, yielding a broad, often heavily vegetated intertidal zone which is miles wide. The shoreline itelf is often poorly defined, as intertidal plants gadually give way to willow-dominated tundra lowland. Surface slopes are so gentle that thousands of hectares of the low-lying tundra wetland are routinely inundated by storm surges in the late summer and fall and by river flooding (Fig. 2). Clearly visible drift lines of logs and other trash carried by storm surges are seen as far as 40 km from the shore (Bob Jones, pers. comm.; King and Dau, 1981). This recurrent flooding of the delta surface probably means that any oil spill in the region is not likely to be just a simple "edge effect"; a spill could be expected to impact a large part of the delta surface.

Although the Yukon carries much sediment to the Bering Sea, there are large interdistributary sections along the coast (Fig. 2) where the waters are relatively clear and free of high turbidity throughout the summer. Where these clear water zones occur, lush growths of sedges and pond weed occur and provide food and shelter for many of the delta's shorebirds and waterfowl (Bob Jones, pers. comm.).

1. The sale date has changed twice since the Synthesis Meeting was held. The Department of the Interior's most recent schedule (July, 81) indicates a November, 1982, date for the sale of lease tracts in the Norton Sound (Sale 57) area.

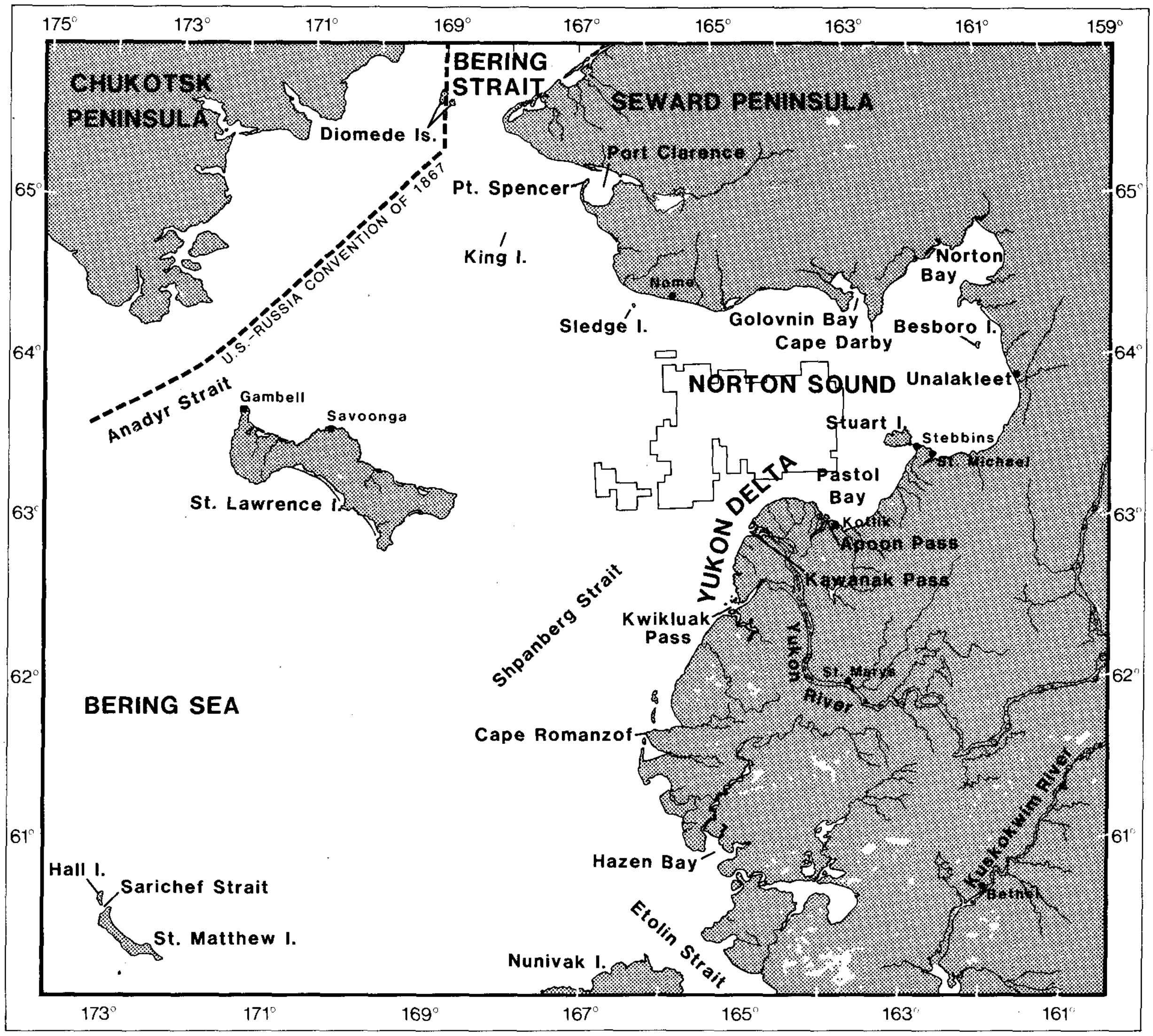


Figure 1. The northern Bering Sea region. Norton Sound Lease areas to be offered for sale are contained within the block diagrams.

The living resources of the Yukon Delta region have been cataloged in a number of recent publications (Gill and Handel, 1981; King and Dau, 1981; Starr et al., 1981; and Gusey, 1979). These reports indicate that the populations of birds and fish which depend upon the Yukon Delta are major components of not only the Bering Sea but also of the North Pacific and entire Western Hemisphere ecosystems.

The birds utilize the delta primarily in the summer and fall for feeding, nesting, moulting, and migration staging. From May through September, approximately 24 million waterfowl and shorebirds are in the area and, depending upon species, forage as much as 50 km offshore (Bob Jones, Bill Drury, pers. comm.).

The major commercial and subsistence fisheries directly dependent upon the delta are for king and chum salmon. Between 74,000 and 300,000 salmon are taken from the Yukon each year (Lance Trasky, pers. comm.). Accurate estimates of the number of shellfish and cisco taken are not available; however, they have been reported to be "stacked like cordwood" (Bob Jones, pers. comm.) during the winter in most Yukon River villages.

Approximately 12,000 people are scattered in villages and summer fishing and hunting camps throughout the region (Lance Trasky, pers. comm.). Subsistence use of the wildlife and fish resources of the Yukon Delta is essential to these local residents. Fish are the most important resource utilized, but geese, ducks, cranes, and certain marine mammals (seals, belukha whales, walrus) are also important in some localities.

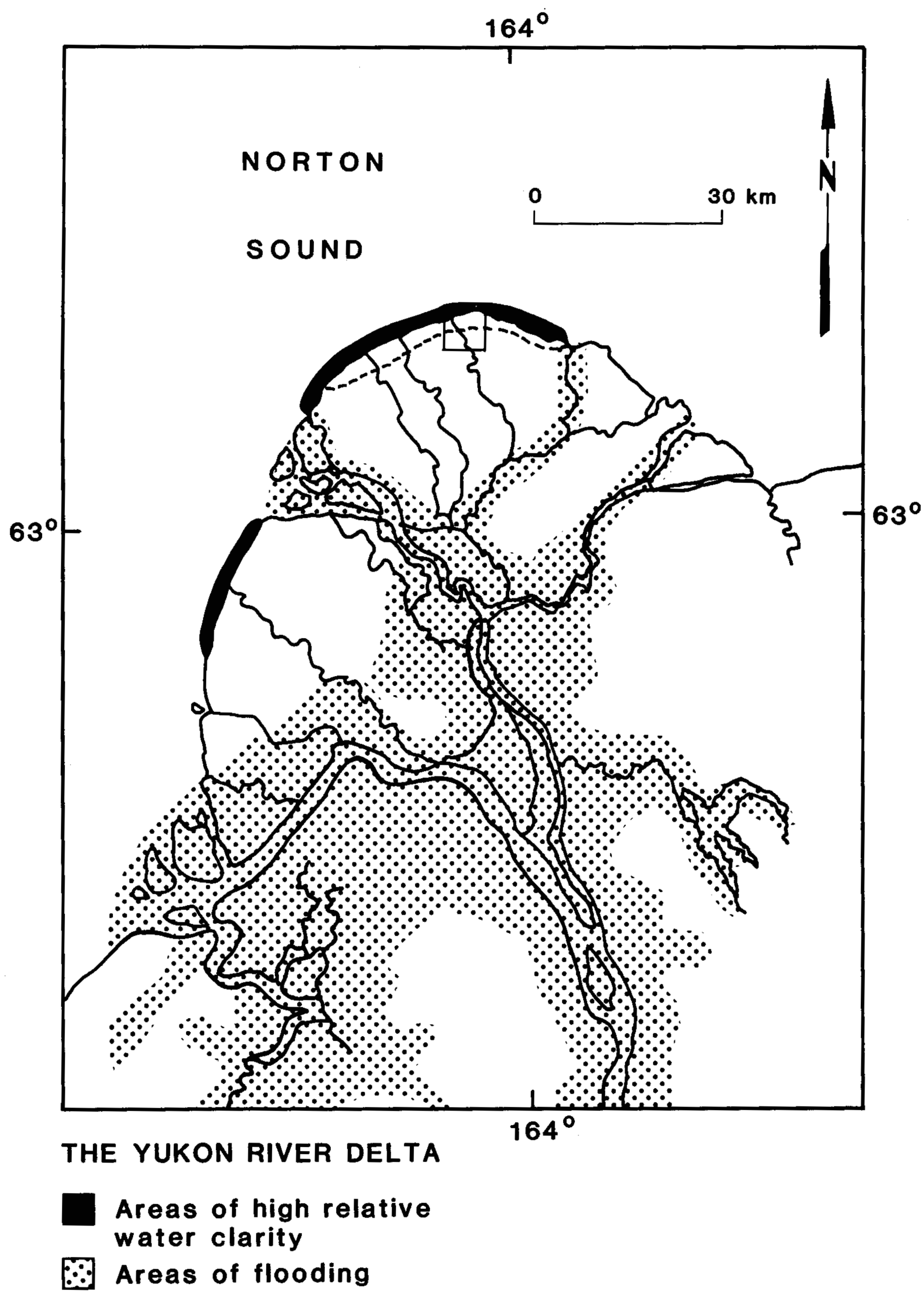


Figure 2. The Yukon Delta region showing interdistributary clear waters and the extent of storm surge flooding (Jones and Kirchhoff, 1977).

There is a moderate-scale commercial salmon fishery in the delta and Norton Sound region. Yukon River stocks are also heavily utilized for subsistence in the interior of Alaska, the Yukon Territory, and British Columbia. Other fish, including herring, smelt, whitefish, saffron cod, tom cod, and Arctic (blue) cod, are taken from the delta region on a fairly large scale, as well as crab, squid and mussels (Ellanna, 1980). Further, Native Alaskans in the Yukon Delta-Norton Sound region are heavily dependent upon these species as an integral part of their cultural patterns (Guy Martin, pers. comm.; Ellanna, 1980).

Two major subenvironments within the Yukon Delta complex were identified as being particularly vulnerable to oil spill impacts: the interdistributary inshore clear water areas; and the actual distributary mouths of the river. These areas will be described individually.

1. Interdistributary clear water zones

Analysis of satellite imagery indicates the presence of two large bands of relatively clear water lying between the extremely turbid waters flowing out of the major mouths of the Yukon River. Although the causative mechanisms leading to formation of these bands are poorly understood, it has been observed that the bands are persistent through the summer months and are critical to a large population of shorebirds and waterfowl (Bob Jones, pers. comm.). The tidal range on the delta is roughly 1.3 m, and slopes there are so gentle that the intertidal zone may be as much as 4 km wide (Dupré and Thompson, 1979). This wide upper intertidal zone is densely vegetated with sedge while the lower intertidal and shallow subtidal zone have extensive stands of pondweed (Jones and Kirchhoff, 1977). A dense population of small invertebrates feeds and shelters in the intertidal vegetation. Although few birds nest on the delta because it is too wet, the broad intertidal areas provide hundreds of square kilometers of good feeding, free from most predation, for both herbivorous and omnivorous birds.

In particular, the interdistributary zones have been shown to be areas where pintail ducks and geese feed and molt. At our present state of knowledge, we cannot predict the effect of an oil spill upon the flora or invertebrate communities, but the negative effect upon bird populations is well known.

2. Yukon distributaries

Because of the subarctic climate of the Yukon drainage basin, discharge of the river is very seasonal. The extent to which a salt water wedge reaches upstream beneath river surface outflow in the major distributaries is not known in detail, but during low discharge, brackish water is found near the surface at St. Marys, approximately 100 miles from the sea (Bob Jones, pers. comm.). By the salt wedge mechanism, the water soluble fractions of an oil spill or of oil absorbed upon suspended sediments could be carried far upstream (Dick Feely, pers. comm.). Thus, when there is flooding, oil-tainted waters could be widely spread over the surface of the delta, damaging large areas of wildfowl nesting areas. Oil in the salt wedge could also be expected to damage the major salmon runs in the Yukon, both by direct toxic effect upon the outmigrating juveniles and by inhibiting upriver movement of spawning adults.

The sensitivity of these two zones convinced the working group that maximum possible precautions must be taken to prevent spilled oil from reaching the Yukon Delta during the open water season.

C. Oil Transport Factors in the Yukon Delta Region

There are a number of unusual factors, some virtually unique, which may influence the movement of spilled oil in the Bering Sea and Norton Sound near the Yukon Delta area.

1. Large-scale offshore circulation

Prevailing offshore circulation in the entire northern Bering Sea is towards Bering Strait. Just off the largest, westernmost mouth of the Yukon the net flow is 10-15 cm/s to the north. This flow would tend to advect any spilled oil past the delta into western Norton Sound, then out of the Bering Sea into the Chukchi Sea. At times, however, particularly in the winter, flow can be reversed for several days or even weeks by large-scale atmospheric conditions (Coachman and Aagaard, 1981). The mean duration of such reversals was 8.7 days and they occurred about 30 percent of the time between September 1976 and March 1977. When reversals occur, they could move any oil that was present onto the delta.

2. Tidal currents

Tides in Norton Sound east of Nome are primarily diurnal, with peak currents of 30-50 cm/s (Pearson et al., 1981). Diurnal excursions within the Sound tend to be narrow elipses extending in the east-west direction over distances of 10-15 km. In the shallow water close to the delta these currents and resultant excursions could be less because of friction, but no direct observations of inshore currents have been made.

Offshore, tidal circulation probably has little net effect upon the movement of spilled oil but might serve to increase lateral spread and possibly vertical mixing of oil in the water column due to current induced turbulence.

3. Estuarine flow

As with all low-gradient rivers flowing into the sea, a deep inflow of marine water extends upstream

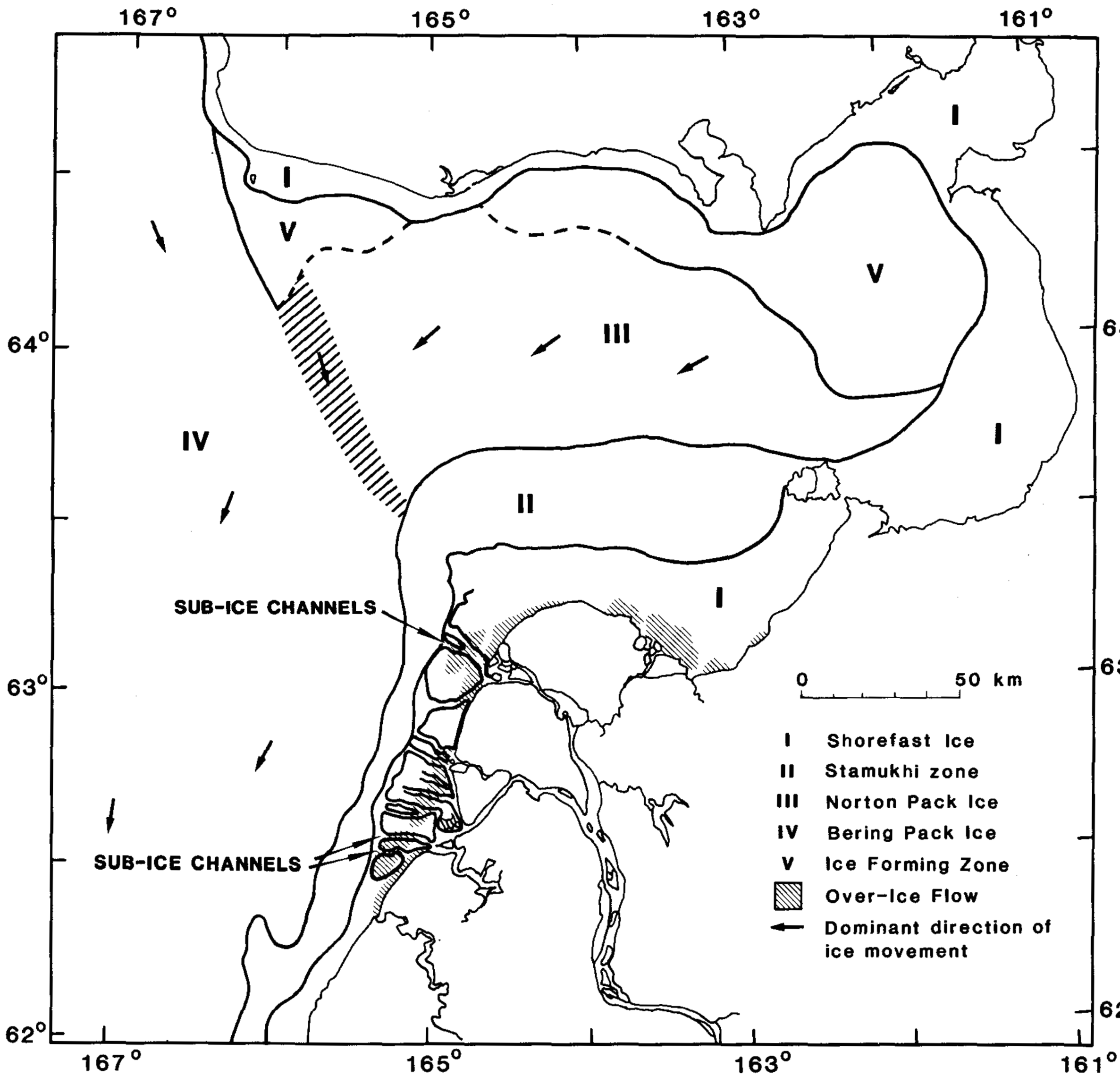


Figure 3. Zonation of ice types in the Yukon Delta/Norton Sound region (Ray and Dupré, 1981; Dupré and Thompson, 1979).

beneath the surface, fresh waters. This mechanism could transport water soluble oil fractions or oil absorbed to sediments a considerable distance upstream. If river flooding or storm surge coincides with pollutant loading in the deep salt wedge, this mechanism could contaminate large upstream areas of the delta surface.

4. Local wind-induced flow

The most important and persistent local winds in the open water season near the Yukon Delta are the strong diurnal sea breezes produced by summer heating of the land surface. There are reports of daily onshore sea breezes as great as 30 knots extending 10 km offshore (Bob Muench, pers. comm.). This could be a major mechanism for transporting spilled oil toward the delta during the summer.

5. Sea Ice

The delta is bordered during the winter by a zone of shore and bottomfast ice (Fig. 3) which may extend 30-40 km offshore, over a very gently sloping prograding shoreline with depths of 1-3 m (McNutt, 1981; Thor and Nelson, 1981). Severe barotropic changes during winter storms, however, can cause water level changes that distort or break up parts of the shorefast ice (Ray and Dupré, 1981; Stringer, 1981). Also, sub-ice channels remain open toward the shore, particularly in the area just south of the major distributaries, which serve as pathways beneath the ice. These channels are typically 0.5 to 1 km wide, 5-15 m deep, and are clearly defined as much as 20 km offshore (Dupré and Thompson, 1979).

6. Storm surges

The Yukon Delta and, in fact, the entire Norton Sound region are particularly vulnerable to storm surges (Brower, et al., 1977). Surges are normally the result of wind stress movement of surface waters above the level of normal high tide, and are sometimes reinforced by a rise in sea level due to a reduction in barometric pressure as the low center passes. This effect is fairly common in the northernmost part of the Bering Sea, usually occurring during late summer or early fall and resulting in a sea level rise of 1-3 m. Such a surge — the greatest in recent times — occurred in November 1974, when water levels greater than 5 m above Mean High Water were observed at the eastern end of Norton Sound, and there was about 3.5 m of rise over the northern part of the Yukon Delta (Sallenger et al., 1978).

Sea level changes similar to storm surge have also been observed in the Northern Bering Sea (Bob Muench, pers. comm.). These events, which have been recorded by current meters in Norton Sound, represent large-scale responses of the circulation to regional atmospheric pressure differences. They are believed to move northward to the delta and Norton Sound as solitary waves, resulting in significant flooding of the delta without a directly associated local storm.

7. Delta Geomorphology

The modern subaerial and submarine delta is characterized by extremely gentle slopes, typically 1:1000 or less on the sub-ice platform surrounding the delta (Dupré and Thompson, 1979) and scarcely greater on the delta plain. This gentle slope is the reason moderate rises in sea level may cause such extensive inundation during storm surges or breakup floods. The extensive shallows offshore would facilitate the mixing of oil with sediments for retention or transport.

8. Suspended sediments

The Yukon River carries a great load of suspended particlulate material to the sea, estimated to be 88 x 10^6 tons annually (Larsen et al., 1981). These particulates are primarily inorganic detrital rock debris with a mean size less than 20 *ym* (Dick Feely, pers. comm.). Experiments suggest that such suspended sediments can accommodate up to 11 percent by weight of crude oil, and that mixing with oil would hasten flocculation and sedimentation. This mechanism may remove spilled oil from the sea surface, but it also could load oil into the deeper, more saline water of the salt wedge, which moves upstream during periods of reduced river flow, thus increasing the areal extent of pollution of the delta plain region.

9. Retention, degradation, and clean-up of spilled oil

Because of the subarctic climate, rates of biological degradation of oil around the delta are believed to be very slow. Evidence is subjective — beached fish often dehydrate and become mummified before they can decompose — but it implies tremendous persistence of any oil on the delta (Bob Jones, pers. comm.). Also, the peaty substrate of much of the delta is judged likely to bind oil for a long time (Lance Trasky, pers. comm.). If not degraded, slow leaching of pollutants from the organic debris would cause long-term chronic release of the oil. Vulnerability of the delta region on the Hayes' scale is Class 8 or greater (Hayes and Gundlach, 1980). Cleanup of a spill in the delta area does not appear practical for logistic reasons.

D. Yukon Research Needs

There is no question of the importance of the biological populations associated with the Yukon Delta region, or of their extreme vulnerability during the ice-free season, May through September. The dependence of the native Alaskan population upon an unpolluted, undisturbed environment is also clear. Almost any OCS activity in the region could be seriously damaging, particularly oil spills. In order to avoid or mitigate damage to the delta, participants in the interdisciplinary discussion recommended research into three phenomena which are of particular importance to oil transport in the vicinity:

1. Subarctic sea breeze effects

Virtually every storm-free afternoon in the open water season, some sort of brisk onshore wind develops. This was identified as a probable major mechanism for moving an oil spill into the Yukon Delta. No systematic observations have been made of this local wind system, but reports from the Nome region suggest that the sea breeze can exceed 30 knots and extend at least 10 km offshore. A small program to verify the persistence, extent, and velocity of the sea breeze off the Yukon Delta would be very valuable in defining the desirability of a nondevelopment buffer zone in the delta region. Observation programs should also operate one or more current meters to assess the importance and extent of nearshore tidal and wind driven currents.

2. Estuarine upriver transport

   In the special circumstances of the Yukon Delta region, the transport of oil far into the delta lowlands seems inevitable. Storm surges, sediment loading, and breakup flooding provide mechanisms for spreading pollutants far over the surface of the delta wetlands. A study of the estuarine hydrology of the Yukon distributaries would serve to define the seasonal importance of these phenomena both offshore and upstream, thus providing a firm basis for transportation routing or nondevelopment buffering in the vicinity of the offshore stream channels.

3. Storm surges

   The erratic but not infrequent flooding of the Yukon delta region by storm surges provides a mechanism for tremendous potential damage. By such flooding, a spill could cover not merely the shoreline but the entire region. At present, the phenomenon of storm surge flooding is poorly understood, but discussion during the interdisciplinary session (Muench, Overland, Schumacher) suggests that such events should be predictable from meteorologic observations. A conceptual model relating sea level fluctuation around the delta and Norton Sound to the movement of extratropical cyclones in the North Pacific and Bering Sea was suggested during discussion. The only data needed for such a model are meteorlogic observations from the Navarin Basin sector of the Bering Sea (Overland, pers. comm.). It is recommended that these observations be collected and that a predictive model for storm surges in the northeastern Bering Sea be developed. A warning system for oil development or transport activities based on this model could substantially reduce the likelihood of serious impacts from OCS development upon the Yukon Delta region.

E. Strategies to Mitigate OCS Impacts on the Yukon Delta Region

Based upon the discussions of both the entire interdisciplinary group and a subgroup that met for several hours after the general meeting, a number of substantive suggestions for strategies to avoid or mitigate the impacts of OCS development activities upon the Yukon Delta region were developed. The suggestions were:

- That because of geomorphology, substrate stability, and the critical importance of resident wildfowl populations, no support, loading, storage, or transfer facilities should be permitted on the delta or within 60 km of its shore (50 km is judged to be the maximum feeding radius of delta-based birds).
- That because of massive seabird and shorebird populations during the open water season both on the Yukon Delta and on St. Lawrence Island, tankers should be routed midway between the delta and the island.
- That the storm surge model proposed above (Research Recommendation No. 3) be developed and used to control development activities in the Norton sound region like the hurricane warning system is used in the Gulf of Mexico.
- That there be temporary deletion of any lease tracts within 20 km of the delta shoreline and any offshore Yukon River and sub-ice channels, until the completion of the estuarine circulation and sea breeze research projects suggested above (Recommendations Nos. 1 and 2).
- That an oil spill contingency study group should be convened, with the cooperation of the BLM, the USGS, the USCG and the EPA, to analyze the possible desirability of using dispersants on any sizeable oil spill in the region, and to define conditions so that dispersants could be deployed in time to minimize damage to the biota of the Northeast Bering Sea. Present procedures for authorizing dispersant use are complex and time-consuming; such decision-time, plus the time required to deploy materials, equipment, and personnel could preclude the use of dispersants to protect the delta.

II. Interdisciplinary Sessions B and C: Impacts of Potential OCS Development on the Eastern and Western Norton Sound Regions

Session B — J. Burns (Chairman)
L. Jarvela (Rapporteur)
Session C — W. Drury (Chairman)
L. Thorsteinson (Rapporteur)

With contributions from H. Braham, S. Chang, D. Costa, C. Cowles, G. Divoky, R. Emerson, H. Feder, K. Frost, R. Griffiths, E. Gundlach, S. Jewett, M. Kuwada, S. Korn, J. Leendertse, S. Martin, D. Maiero, R. Nelson, J. Ray, D. Redburn, J. Schumacher, S. Starr, H. Sparck, N. Swanton, D. Thomas, E. Tornfelt, R. Tripp, R. Wolotira, and D. Woodby.

A. Introduction

The Norton Sound Lease Area is a region of shallow water (Fig. 4), varying in depth from less than 10 m in inner Norton Sound to about 50 m north of St. Lawrence Island and in the channel of Bering Strait. This area contains water of two major types: the shallow Alaskan coastal water of Norton Sound itself, which is relatively warm and of low salinity due to the influence of the Yukon and Kuskokwim River waters; and the western, colder, and more saline waters of the Bering Sea shelf (Fig. 5) (Drury et al., 1981).

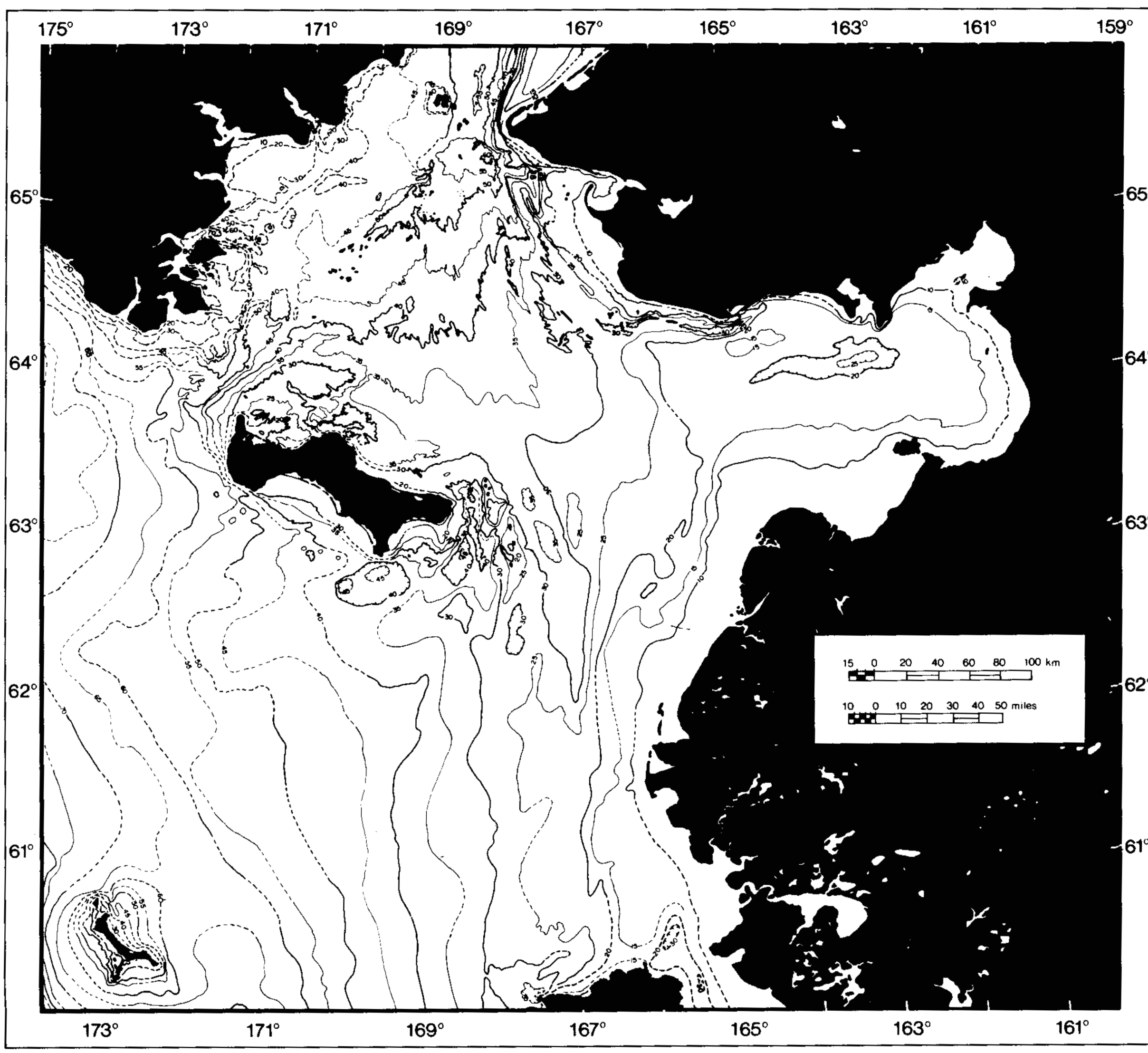


Figure 4. Bathymetry of the Norton Sound region. Depths are in meters.

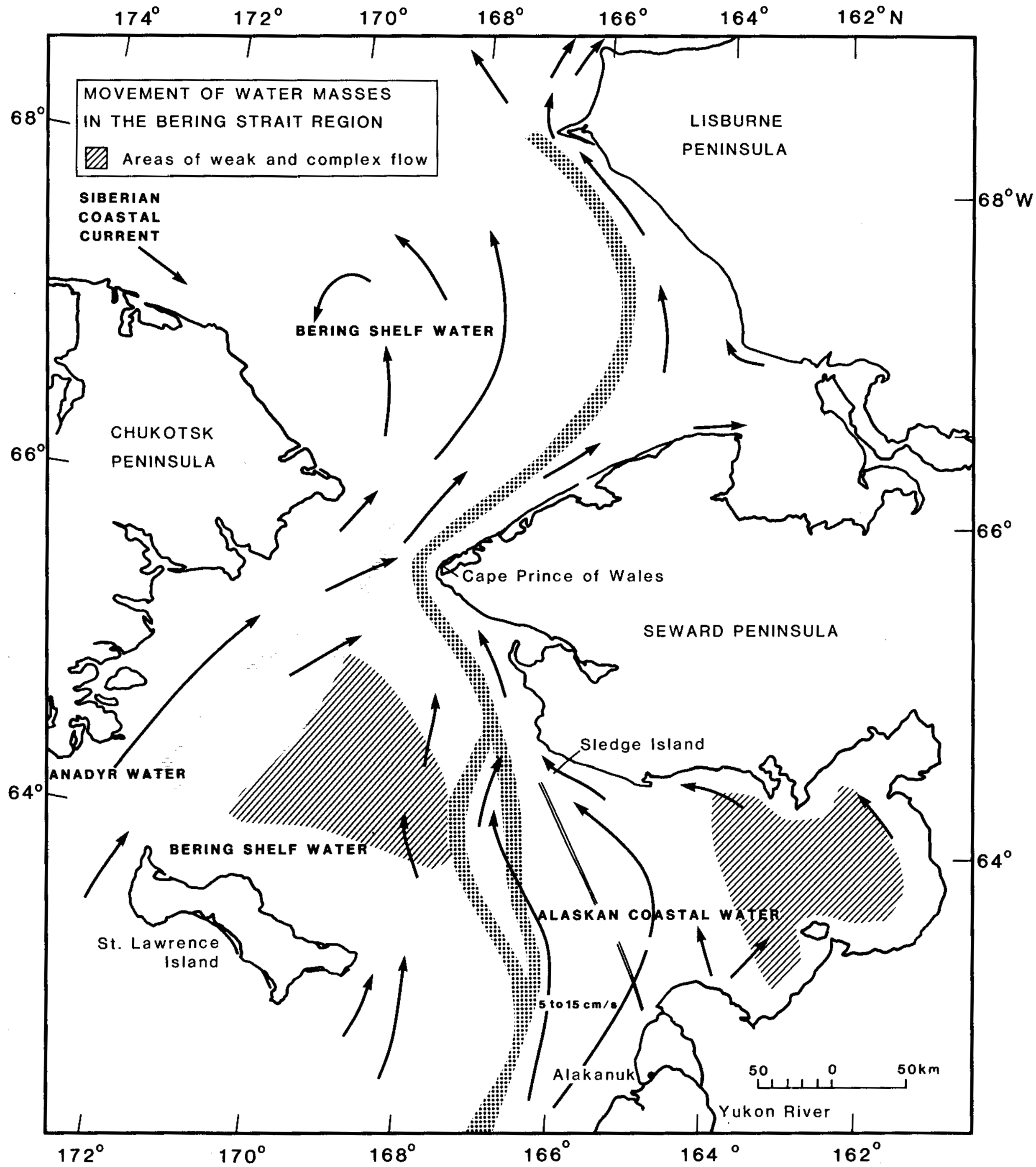


Figure 5. Movement of water masses in the Bering Strait Region (Drury et al., 1981).

The location of the boundary zone between the Norton Sound province and the more oceanic Bering Sea shelf province is variable and dependent upon the intensity of winds and ocean currents, which can result in periodic intrusions or extrusions of waters on either side of the boundary. In the northern sector, this boundary is marked by a zone of rough water which extends from an area south and west of Sledge Island northwestward along the Seward Peninsula to cape Prince of Wales. In the southern sector the boundary extends from the Sledge Island area across the mouth of the Sound to the Alakanuk region, sometimes paralleling the coast as far as the southern mouth of the Yukon River.

A segregation of physical and biological phenomena coincides with the division between water masses. For that reason the discussions of Interdisciplinary Goups "B" and "C" were separated by regions. Session B concentrated on the more oceanic regime to the west; Session C concentrated on the Norton Sound area. In order to provide a unified and coherent synthesis, however, and to eliminate the many areas of overlap which occurred, the reports of Sessions B and C have been combined here.

B. Seasonal Summary of Major Oceanographic and Transport-related Events

Participants in the synthesis meeting were unanimous in their recognition of ice as a dominant component of the Norton Basin environment. During Sessions B and C four yearly "seasons," based on seasonal changes in ice conditions, were delineated as follows:

1. Open water

   July through early November conditions are characterized by the total absence of sea ice. Atmospheric conditions are dominated by southerly winds which result in strong surface-to-bottom currents. These currents flow northerly across the mouth of Norton Sound. Figure 6 shows the release points and recovery sites of surface drift bottles released at different locations on June 25-26, 1979. Accumulation of Yukon River-carried driftwood along the northern shore of Norton Sound also attests to long-term northerly transport (Bill Drury, pers. comm.).

   These observations indicate that oil released from the eastern blocks of the lease area during the open water season would largely be deposited on the northern shore. Spills form the western block of lease tracts would more likely be carried northward with the Bering Shelf water mass.

2. Autumn transition

   November through early December conditions are characterized by storms with winds from variable directions. As the season progresses these storm tracks shift to the south so that winds become more northerly (Overland, 1981).

   Growth and accumulation of ice in Norton Basin involve two highly variable processes: transport of ice into the Bering Sea from the Chukchi Sea, and the local formation of ice. In the western Norton Basin, ice from the Chukchi Sea is transported through Bering Strait to the region around St. Lawrence Island when the current reverses in the Strait (Reimer et al., 1979). Within Norton Sound itself, locally formed ice appears to dominate.

   Early arrival of winter conditions has great significance from the standpoint of ice drift and entrained oil trajectories. Prevailing (northeasterly) winds result in persistent polynya systems immediately south of Bering Strait; in the lee of St. Lawrence Island; along the southern shore of the Seward Peninsula, especially in front of the cliffs at Golovin Bay; and in eastern Norton Sound. Formation of new ice in these systems is rapid and net transport is to the southwest (Pease, 1980, 1981).

   Within Norton Sound, ice may have a long (4- to 6-weeks) residence time. Once net drift has carried ice out of Norton Sound, however, transport rates increase and trajectories veer to the southwest or south. General ice drift trajectories, shown in Fig. 7, are also presented by McNutt (1981).

3. Ice covered

   The January-April period is characterized by relatively stable sea ice, extending to its maximum distribution far south of the Norton Sound lease area. Winds are generally from the north, mainly northeasterly, and ice movement is typified by a southwestward drift (Fig. 7). This drift averages 3.5 km/d or less, but may reach speeds in excess of 15 km/d for periods of less than 3 days.

   The variety of ice habitats which are established and maintained during this period include the thin, new ice zones of the persistant polynyas; regions of shorefast ice; regions of highly divergent ice flow characterized by abundant small openings in the pack; and areas of convergence where ice movement is constrained by narrow passages (i.e., Bering, Anadyr and Shpanberg Staits) or forced against major land features such as St. Lawrence Island or southern Norton Sound.

   The hazards of oil in ice will be greatest in regions of ice convergence. Should an oil spill occur within Norton Sound, ice entrained oil could remain there for several weeks due to the slow rate of drift. Outside of Norton Sound the entrained oil would move more rapidly to the south.

4. Spring transition

   May through early June is again characterized by variable weather patterns. Winds from the north decrease and there is a general shifting toward domination by southerly winds (Overland, 1981). As air temperatures rise, the ice cover usually disappears rapidly and southerly winds push the ice remnants to the north.

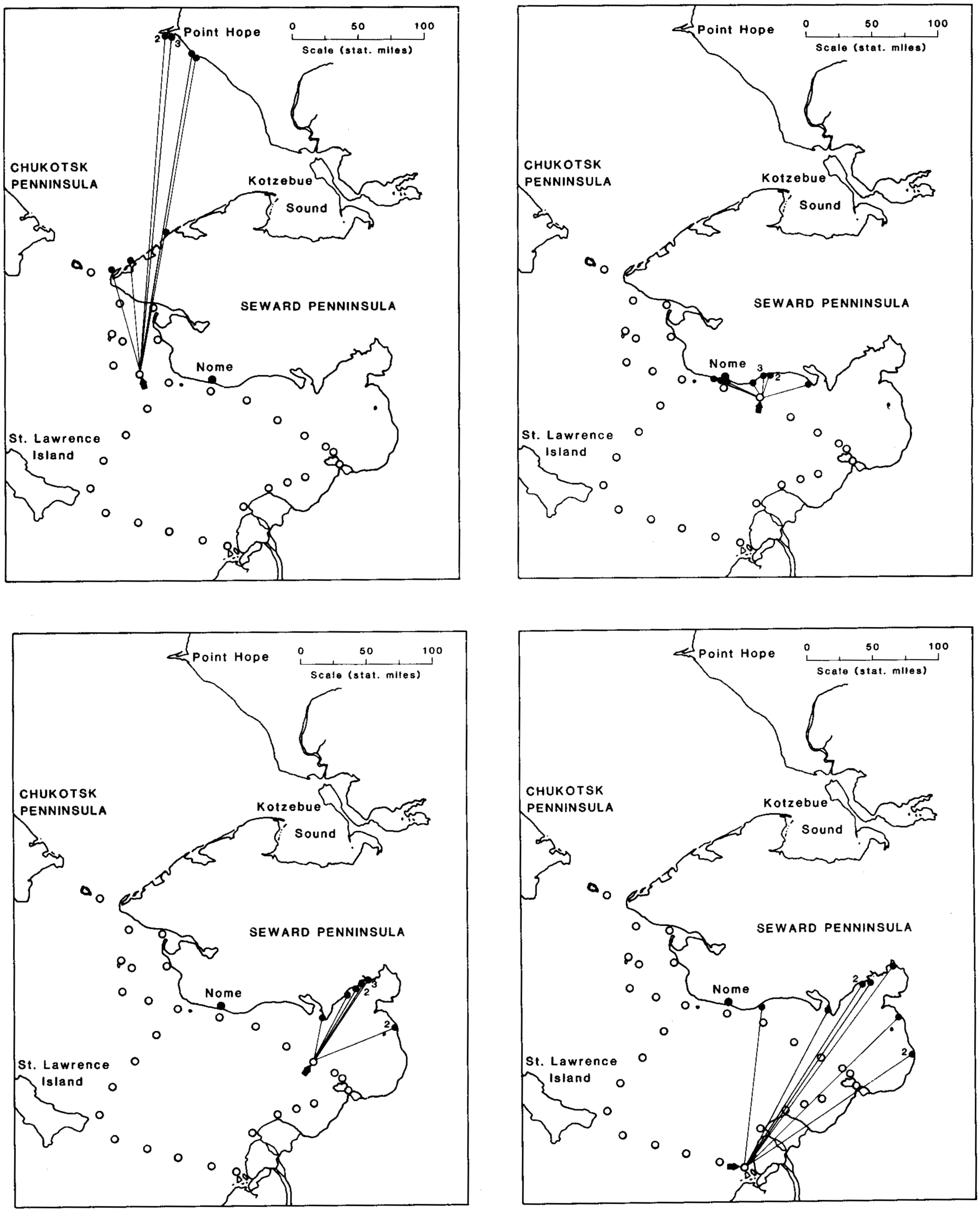


Figure 6. Representative drift bottle release and recovery sites in the Norton Sound area. Releases were June 25 and June 26, 1979 (Burbank, 1979).

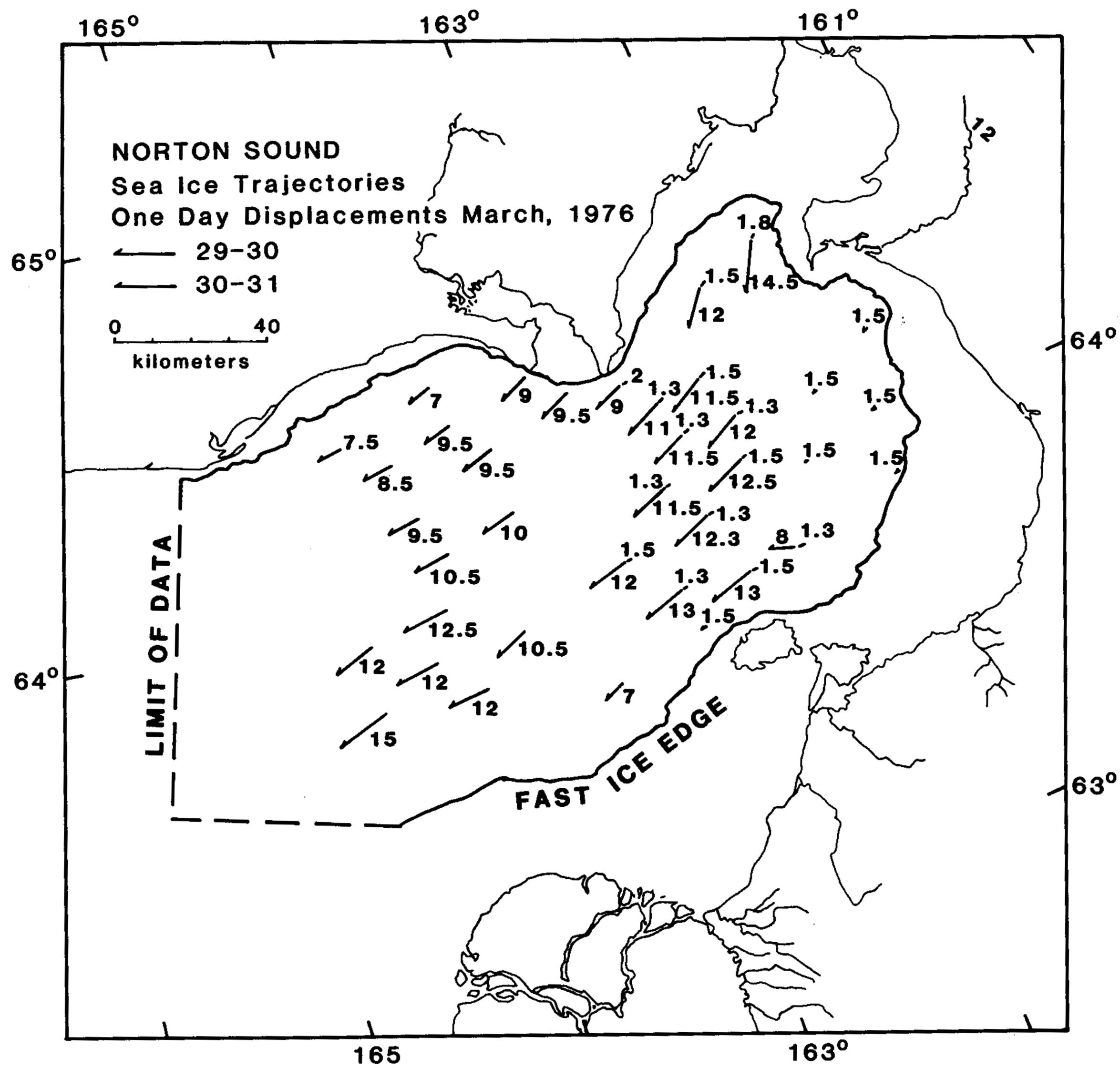


Figure 7. Norton Sound ice floe trajectories observed between March 29 and 31, 1976. This figure, recopied from Stringer and Henzler, 1981, (their figure 13) indicates the considerable difference in displacement which may occur from day to day.

A significant feature of the spring transition season is the extent, location, and orientation of lead systems which parallel the coast, especially along the aforementioned boundary between the eastern and western sectors of the Norton Sound lease area. These lead systems are a major migration corridor for marine birds and are also extensively used by marine animals.

During this season, oil spilled in eastern Norton Sound would tend to remain there, eventually being deposited onshore. Oil released in western Norton Sound would be transported toward Bering Strait. In either case, the relatively light and variable winds would allow the oil to accumulate in the expanding leads — the very areas of maximum importance to the tremendous spring influx of birds and mammals.

Session participants agreed that both transition seasons (ice formation and ice disintegration) were the most variable and difficult to characterize. These seasons are dominated by highly variable weather patterns which may shift dramatically within any one season and may differ greatly from year to year. As an example, during the spring of 1980, a mass of ice blocked Bering Strait and prevented the northward drift of ice out of the Bering Sea. This disrupted the normal migration patterns of birds and mammals and resulted in the taking of a bowhead whale by hunters from Shaktoolik — the first time in known history that villagers from eastern Norton Sound had taken this species. Also, residents of Wales reported finding numerous dead or dying Eider ducks that had apparently starved because the ice conditions had prevented them from obtaining food.

C. Distribution of Organisms

1. Primary and secondary productivity

Few phytoplankton studies have been conducted within Norton Sound. It is believed, however, that the shortened period available for primary production and the heavy suspended load of river sediments in the southern portion of the sound, combine to reduce the importance of water column productivity. Geological observation, as well as observations on the types and distributions of benthic fauna and the stomach contents of bottom feeding fishes, corroborate this opinion. Benthic invertebrate species in Norton Sound appear to be dependent on the flow of carbon from the Yukon Delta, the many rivers within Norton Sound, seagrass beds, and marine algae to sustain their populations (H. Feder, pers. comm.).

In the more oceanic, western sections of the Norton Sound lease area, primary productivity associated with the retreating ice front (and its associated water column stability) has been reported to be quite high. Intense phytoplankton blooms, accounting for a significant proportion of the total annual primary production, occur each spring as the ice front recedes (Alexander and Cooney, 1979).

The differences in primary productivity regimes between inner and outer Norton Sound are reflected in the types of biological systems which they support. Inner Norton Sound is basically a detritus-based system, leading to large populations of deposit and detrital-feeding benthic species. Zooplankton are typically small (e.g., the copepods *Acartia, Centropages, Eurytemora*), while larger zooplankton (amphipods, euphausiids) are inconspicuous (H. Feder, pers. comm.).

Western Norton Basin is characterized by a more pelagic biological system. In this area large copepods (*Calanus, Eucalanus*) are fed upon by chaetognaths, euphausiids and amphipods, which in turn become food for large populations of plankton-feeding vertebrates such as Thick-billed Murres, and Parakeet, Crested, and Least Auklets. These species do not commonly occur east of the boundary zone even though appropriate nesting sites are available (W. Drury, pers. comm.).

2. Benthos

The marine benthos of the Norton Sound lease area tends to reflect overlying water mass transport and productivity regimes. In the sluggishly rotating eastern sector of Norton Sound, where large amounts of detrital organic carbon from the Yukon River and other sources accumulate, soft organic sediments rich with microbial populations are found. In this area, deposit feeders (e.g., polychaete worms, small clams, cockles) and associated predators (large snails, crabs, bottomfishes) are common.

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

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

Collectively, the invertebrate epibenthos in Norton Basin is dominated by echinoderms. This group comprises 80 percent of the invertebrate biomass, and over 60 percent of the combined invertebrate and demersal fish biomass, reaching their highest biomass on the Alaska Continental Shelf in the Norton Sound lease area (Fig. 8). Sea stars dominated by *Asterias amurensis,* are the primary group of echinoderms present. Wolotira et al. (1977) estimated sea star densities of greater than 100,000 t for this region. (See also Jewett and Feder, 1981.)

Gastropod mollusks, especially the whelks *Neptunea,* are the most abundant invertebrates of potential commercial importance in the area. Wolotira et al. (1977) estimated their biomass at over 9,000 t. *Neptunea heros* is the most abundant species, accounting for 75 percent of the region's snail biomass with an estimated population size of 50,000 individuals (Wolotira, MS presented at the Norton Sound Synthesis Meeting).

The Tanner crab *(Chionocetes opilio)* is the most abundant crab species in Norton Basin (52 million crabs, 1,400 t — Wolotira et al., 1977). Nearly all crabs encountered in the basin were juveniles, however, indicating that the region's population originates outside the area. (See Jewett, in press, for a discussion of some aspects of the reproductive biology of female *C. opilio.)*

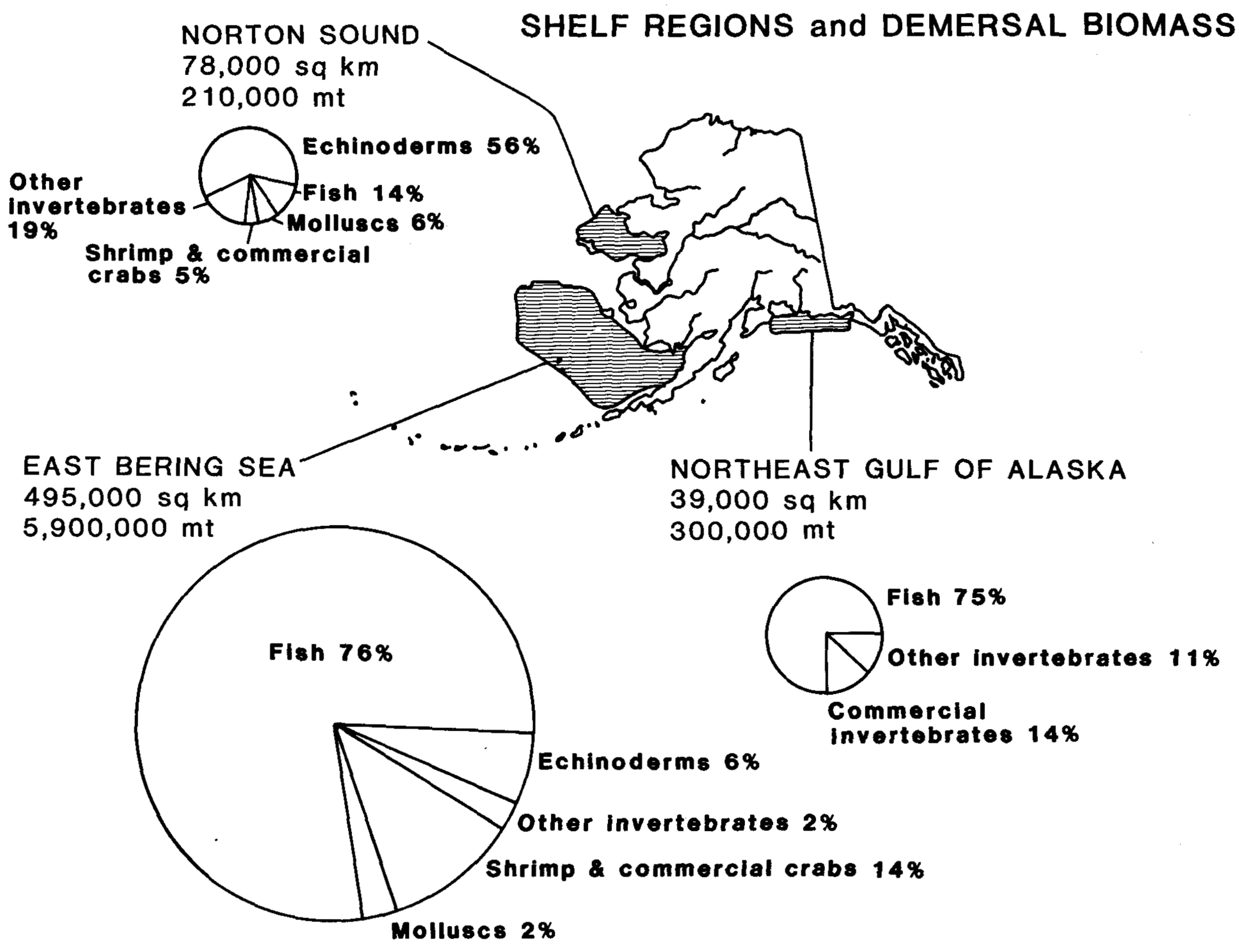


Figure 8. A comparison of demersal fishery resources for regions of the Alaska Continental Shelf (Wolotira et al., 1977; Kaimmer et al., 1976; Ronholt et al., 1978). Figure provided by R. Wolotira.

Two species of king crab also occur in the Norton Basin. Blue King crab *(Paralithodes platypus)* abundance has been estimated at 1,500 t (3.4 million crabs — Wolotira et al., 1977) and is centered in the western areas of the basin (Fig. 9). Red king crab *(P. camtschatica)* are more abundant than blue king crab (5 million crabs, 3,500 t — Wolotira et al., 1977) and are located in the more central and eastern parts of the basin (Fig. 10). Both species appear to have much slower growth rates than in other Alaska shelf regions. Otto et al. (1979) noted that females were maturing at sizes 30 percent smaller than other populations in the southern Bering Sea. Fully 90 percent of all king crab collected during the 1976 demersal survey (Wolotira et al., 1977) were smaller than the minimum sizes associated with commercial fisheries in other regions of Alaska.

The king crab fishery (mainly *P. camtschatica*) in Norton Sound has been underway since 1977. Areas of most intense fishing pressure are in the northern portion of the Sound — particularly the region between Cape Rodney to Rocky Point and extending west to 63°. The region 25 km south of Cape Nome is also a region where king crab and many other epifaunal species (sea stars, urchins, shrimp [*Argis*], two species of hermit crabs, the crab *Hyas,* and gastropods) occur in high abundance (Jewett and Feder, 1981).

The reasons why the Norton Sound area supports regions where such large populations of crabs and other epibenthic species occur are not currently known. Some insight can be gained, however, by looking at the food dependencies of similar species from other regions (see Feder and Jewett, 1981). Many similar epifaunal species in other areas heavily utilize deposit-feeding infauna which appear to be common in Norton Sound. The interactions leading to these apparently richly productive communities of infauna are yet to be determined, however, and are necessary to comprehend the benthic system of Norton Sound.

Additional distributional information on the benthic invertebrates of Norton Sound Basin may be found in Feder and Jewett (1977), Feder and Mueller (1974), and Jewett and Feder (1980).

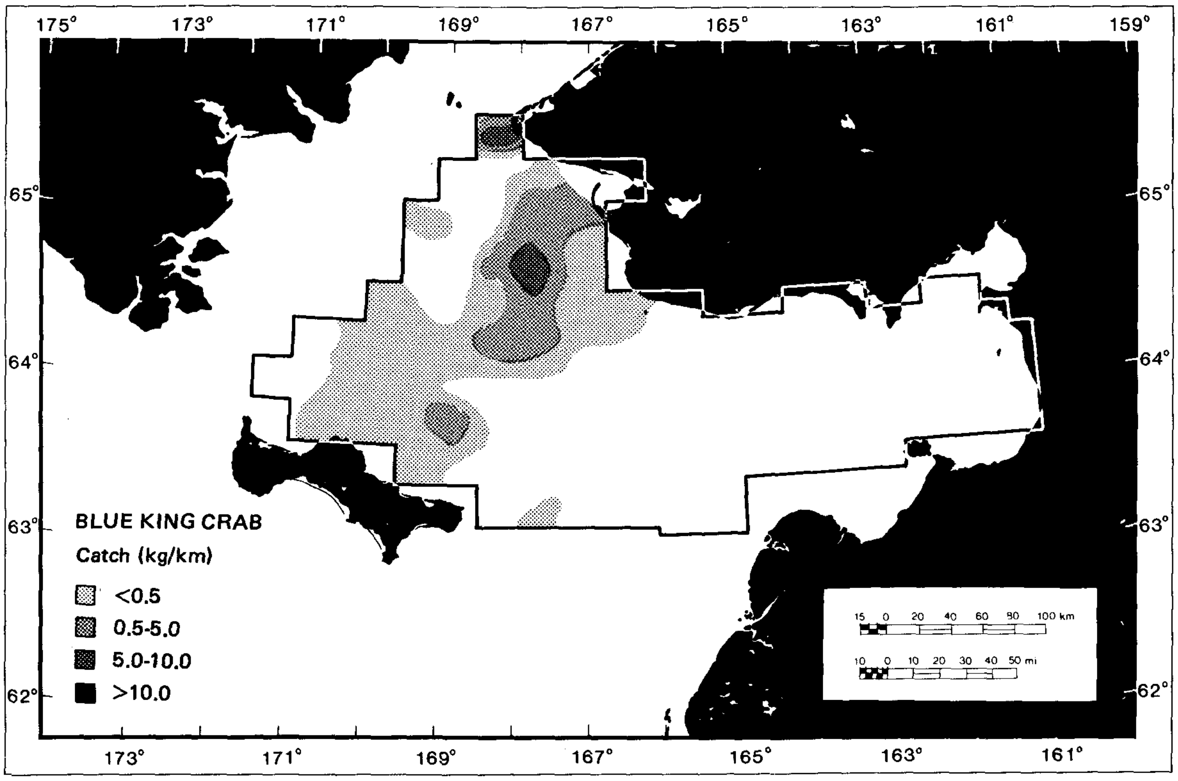


Figure 9. Distribution and relative abundance of blue king crabs in Norton Basin (Wolotira et al., 1977).

3. Fish and fisheries

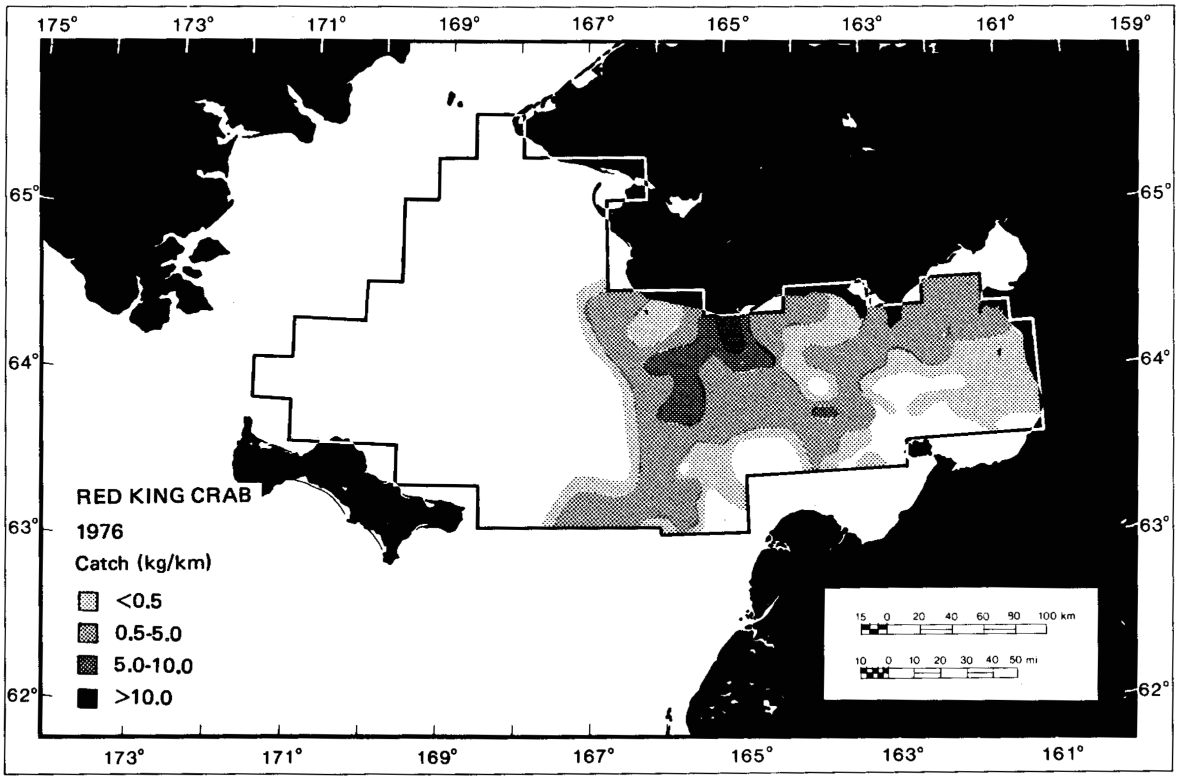
 a. Demersal fishes

Despite the abundance of benthos, bottomfish in Norton Basin are substantially less abundant than in other Alaskan regions (Fig. 8). That is, while containing approximately 15 percent of the continental shelf of the eastern Bering Sea, Norton Sound bottomfish make up less than 3 percent of the potential eastern Bering Sea bottomfish resource (Kaimmer et al., 1976); while containing almost twice the continental shelf area as the northeast Gulf of Alaska, Norton Sound bottomfish resources are estimated to be equivalent to only 65 percent of the northeastern Gulf bottomfish resource (Ronholt et al., 1978).

Cods and flatfishes comprised over 75 percent of the demersal fish biomass collected in the region by Wolotira et al. (1977). Saffron cod and starry flounder were the predominant forms.

Saffron Cod accounted for nearly one-half of the demersal fish biomass of the Norton Basin region. It was frequently encountered in the nearshore areas during the summer; highest abundances were in the Pt. Clarence-Brantly Harbor area and in Golovin Bay (Wolotira et al., 1977, Fig. 11). Offshore summer concentrations have been located in outer Norton Sound in areas west of 163°W out to the 25 m isobath. Winter distributions are not known although this species is a major food item of marine mammals occurring in nearshore fast ice, and of coastal peoples who fish for this species through the ice. Larvae are encountered during early summer (Barton, 1978).

Arctic cod was the second most abundant fish taxa collected in this region. Estimates of this species abundance (Wolotira et al., 1977) are probably low, however, because the semi-pelagic habit of this species leads to underrepresentation in demersal trawls.



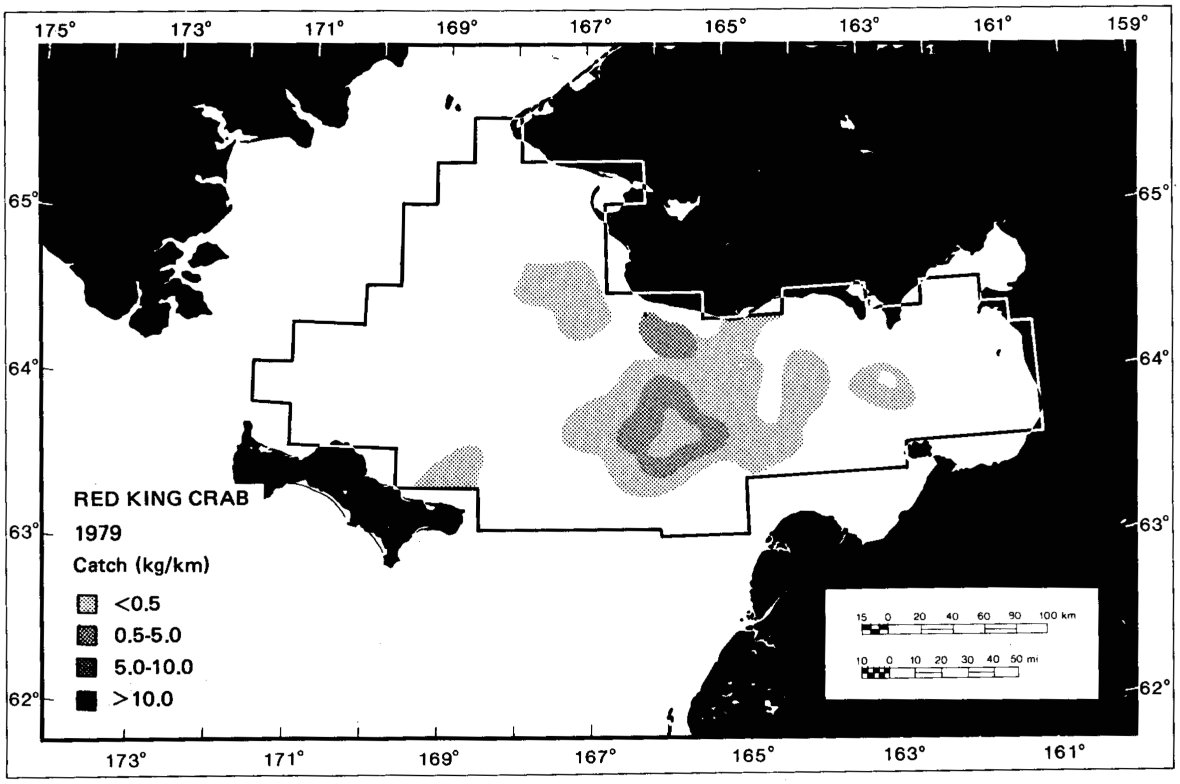


Figure 10. Distribution and relative abundance of red king crabs in Norton Basin (Wolotira et al., 1977; Sample and Wolotira, in prep.).

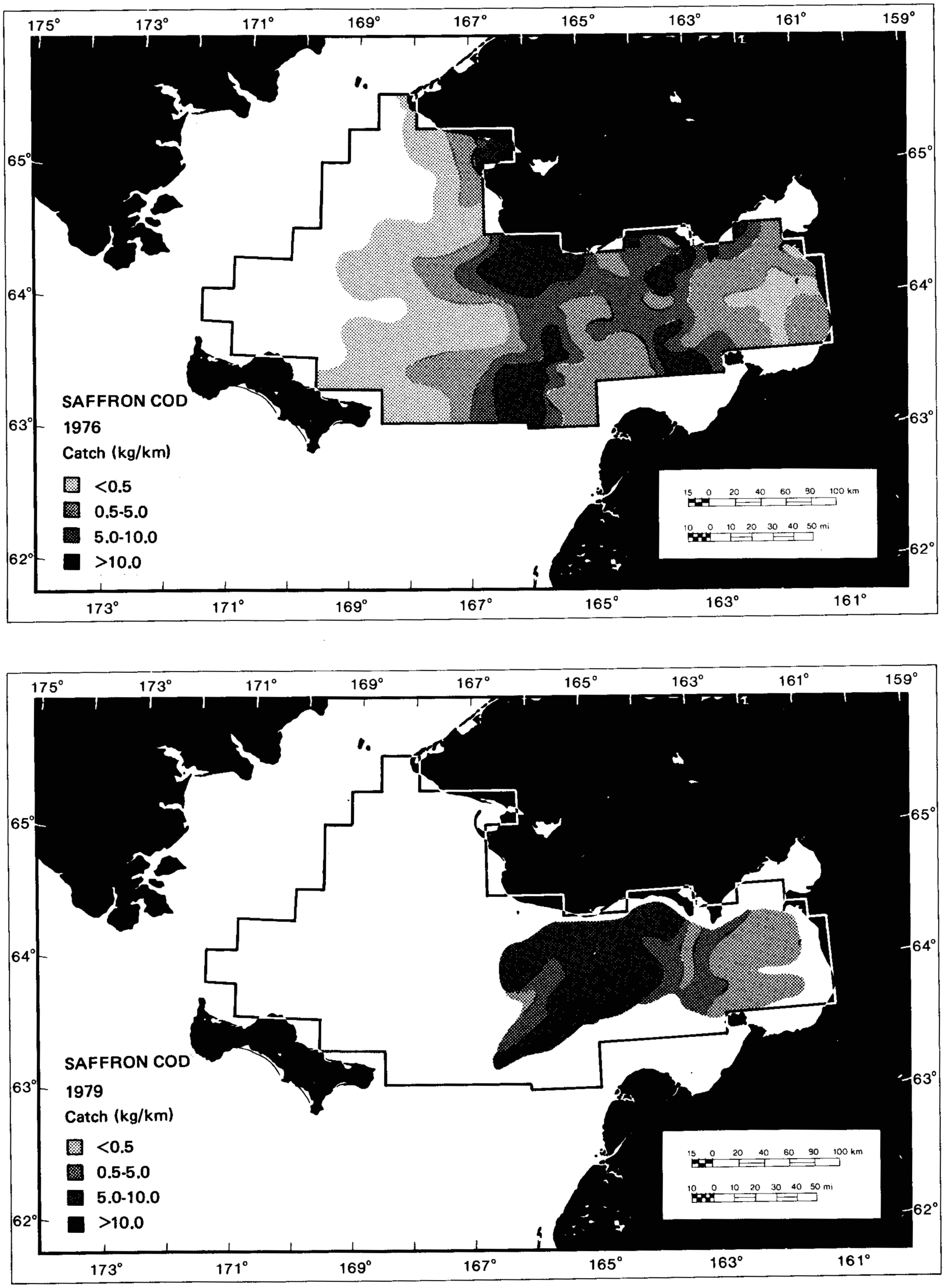


Figure 11. Distribution and relative abundance of saffron cod in Norton Basin (Wolotira et al., 1977; Sample and Wolotira, in prep.).

Starry flounder, the most abundant flatfish in Norton Basin, accounts for approximately 10 percent of the total demersal fish biomass (Wolotira et al., 1977). This species was collected inshore wherever sampling was performed. Offshore concentrations appeared to center in the outer portion of Norton Sound, although very few individuals were taken in the waters offshore from St. Lawrence Island to Bering Strait (Fig. 12). Winter distributions have not been determined. Spawning is believed to occur in June, based on data from the Gulf of Anadyr (Pertseva-Ostromova, 1960). The major food groups consumed by adult starry flounder in Norton Basin are similar to food groups taken by the fish in other geographic locations (Jewett and Feder, 1980). The main prey items taken in Norton Basin were the brittle star *Diamphiodia craterodmeta* and the deposit-feeding clam *Yoldia hyperborea.*

Other relatively abundant demersal fish species in the region include the short-horn sculpin, yellowfin sole, and Alaska plaice. These and other demersal species in Norton Sound were abundant in the area northwest of the Yukon River Delta, the areas west of Stuart Island and Rocky Point, the Cape Rodney to Cape Nome area, and the Port Clarence area. Inner Norton Sound (E of 163°W) and the waters west of 167°W are areas of relatively low density.

b. Pelagic fishes

Because of the ability of pelagic fish to avoid trawls, and their wide ranging movements, relatively little is known about the magnitude of these fish resources in Norton Basin. Multiyear catch statistics suggest that the pelagic resources of Norton Basin are less than other Alaskan regions. For instance, the Norton Basin salmon harvest averages only about 13 percent of the amounts harvested in the Yukon-Kuskokwim region, 6 percent of catches in Bristol Bay, and 2 percent of amounts for both the Gulf of Alaska and southeastern Alaska (International North Pacific Fisheries Commission Statistic Yearbooks, 1972-1976). Low sea water temperatures are believed to be the cause of the apparent paucity of commercial fish stocks in Norton Basin.

Salmon. All five species of salmon occur in the Norton Basin region; however, only pink and chum salmon are relatively abundant. Adults of all species are found nearshore or in bays or estuaries from the time of ice breakup until mid-August. Principal salmon rivers in the region include the Unalakleet, Shaktoolik, Koyuk, Kwiniuk, Tubutulik, Kachavik; the Niukluk-Fish rivers which drain into Norton Sound; and the Kuzitrin, Agiapuk and Pilgrim rivers which flow into Port Clarence.

Pink Salmon are harvested primarily in the Unalakleet, Golovin Bay and Moses Point districts, while chum salmon harvests are relatively similar throughout most of the Sound. Sockeye salmon are found almost solely in the Port Clarence area — the northernmost occurrence of this species in North America (McLean and Delaney, 1977). Juvenile pink and chum salmon appear in nearshore coastal waters at the onset of ice breakup (Barton, 1978). They move offshore in mid-July and remain in the offshore waters of Norton Sound through late September.

The commercial salmon fishery in the region did not start until the 1960's. Early operations were sporadic, due in part to a lack of consistently available processors or buyers and inadequate tendering service. The development of local cooperatives in recent years has helped stabilize commercial activities.

During recent years, total salmon harvests in the Norton Basin region have ranged from 100,000 to nearly 600,000 fish (Table 1). The average harvest for 1969-1978 was about 300,000 salmon. There has been a general trend toward increased salmon catches throughout the region in recent years. The 1978 and 1979 harvests are the largest on record. Subsistence salmon harvests in most parts of this region are small in comparison to commercial harvests, with exceptions at Nome and Port Clarence.

While the magnitude of salmon resources in Norton Basin are small in comparison to other Alaska regions, their importance to the local economy is substantial. A greater proportion of salmon harvested in this region is used for subsistence than in most other areas of coastal Alaska. In recent years (1967-1976) an average of more than 15 percent of salmon harvested in Norton Basin were used for subsistence (Table 1). This proportion is more than double that for the Bristol Bay region. The only region with a higher subsistence use proportion is theYukon-Kuskokwim area where 18-20 percent of annual harvests are used for this purpose.

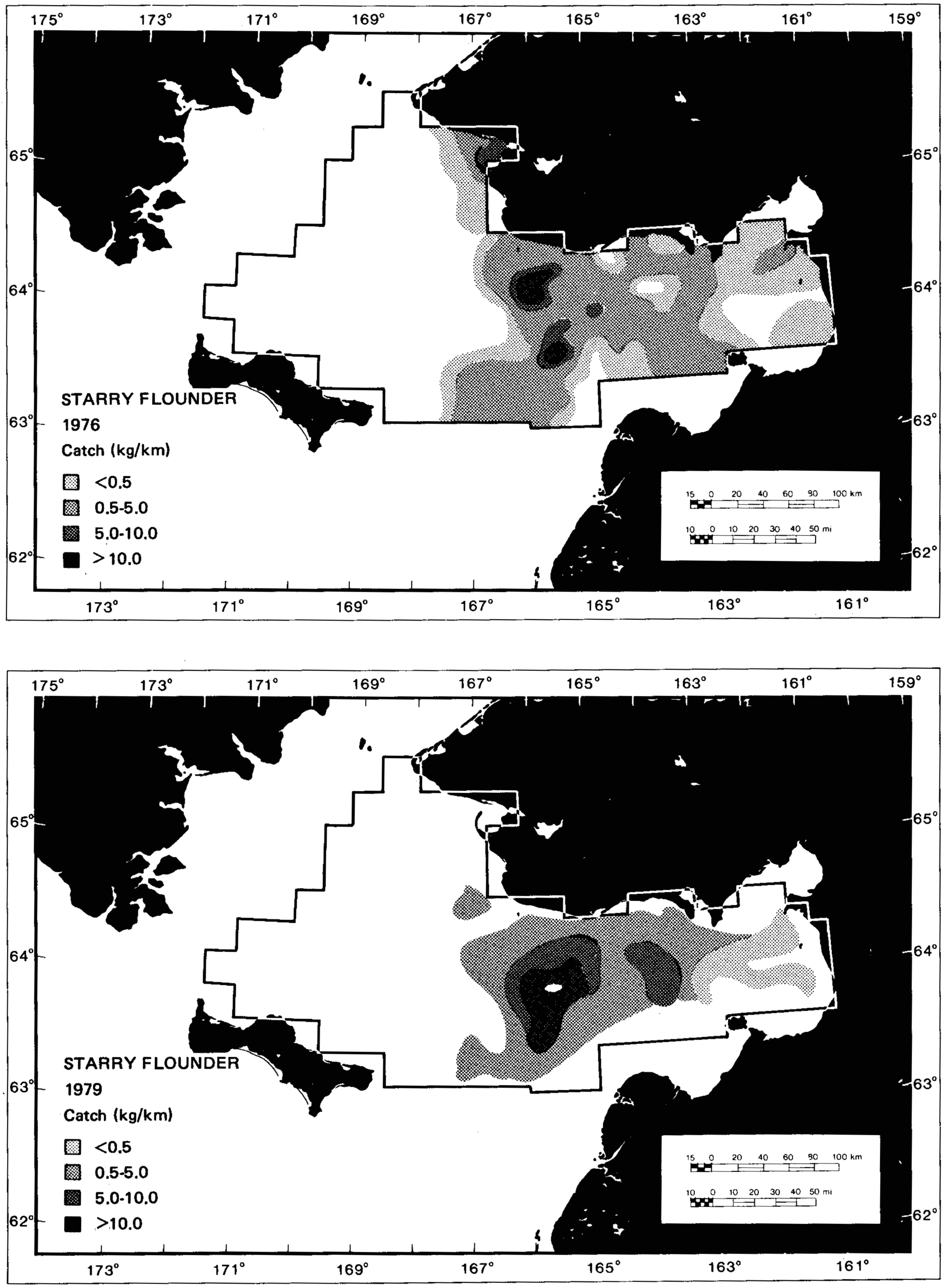


Figure 12. Distribution and relative abundance of starry flounder in Norton Basin (Wolotira et al., 1977; Sample and Wolotira, in prep.).

Table 1. Commercial and subsustence salmon harvests (number of fishes) by year in Norton Basin, 1961-1979 (Alaska Department of Fish and Game, 1979a).

Year	Commercial	Subsistence	Total
1961	101,711	—	101,711
1962	232,431	—	232,431
1963	233,863	41,805	275,668
1964	164,671	27,982	192,653
1965	40,524	61,224	101,748
1966	101,561	44,327	145,888
1967	74,818	46,431	121,249
1968	124,499	54,872	179,371
1969	178,972	38,493	217,465
1970	178,218	61,328	239,546
1971	141,977	44,581	186,558
1972	149,494	34,588	184,082
1973	176,797	25,201	201,998
1974	315,829	24,635	340,464
1975	251,861	26,886	278,747
1976	193,060	33,753	226,813
1977	257,325	50,189	307,514
1978	531,948	60,611	592,559
1979	350,344	49,176	399,520

The proximity of the Yukon River to Norton Basin requires mentioning the river's salmon harvests. During the period 1960-1979, salmon harvests for the entire Yukon River system averaged about 860,000 fish or 3,600 t (Alaska Department of Fish and Game, 1979b). This amount is nearly three times the average amounts for the Norton Basin region. After entering the Yukon River, salmon are harvested internationally since a considerable part of the upper river is located in Canada. Canadian harvests usually range between 8,000 to 38,000 fish, about 3 percent of the total Yukon River catch.

The extent to which Yukon River salmon utilize Norton Basin during the marine segment of their life cycle is not known.

Herring. Pacific herring is the most important marine pelagic species in Norton Basin. Information from commercial and subsistence catches suggests that this species moves into inshore waters in dense schools during ice breakup (early June). Spawning occurs in the littoral zone, among *Fucus* and eelgrass beds, and the eggs hatch in about three weeks. Reported spawning areas include Bluff, the region from Cape Darby to Moses Point, inside Norton Bay, from Cape Denbigh to Arctic Hills, and east of Saint Michael/Stuart Island. Most Pacific herring overwinter offshore to the south of Norton Sound. Those which remain in the area appear to have growth and spawning characteristics that differ from other stocks. Barton (1978) has hypothesized that this indicates the presence of two independent stocks: one that occurs in Port Clarence and northward into the Chukchi Sea, and another that is found in Norton Sound and southward into the eastern Bering Sea.

Rainbow smelt. This species is quite common in the Norton Sound area: nearshore surveys found individuals at nearly every station sampled; offshore surveys collected them at most stations shoreward of the 25 m isobath (Wolotira et al., 1977). Spawning migrations of this anadromous species occur in the fall. Eggs are released to cling on rocks and aquatic plants in freshwater streams and estuarine areas of low salinity. The resulting larvae have been collected throughout the nearshore areas of Norton Sound (Barton, 1978).

Capelin. The abundance of capelin varies greatly from year to year. Spawning adults are found at ice breakup in nearshore waters of relatively high salinity. The eggs remain buried in sandy intertidal areas for two weeks or more.

Because of the detritally-driven nature of the Norton Sound food web, all aforementioned pelagic fish to some degree assume the feeding behavior of demersal fish. Such organisms as polychaetes, oligochaetes, detritus-feeding *Neomysis*, and other such benthic prey are important in the diets of pelagic fish which normally would be feeding on cladocerans and copepods.

c. Sandlance

Although Pacific sandlance is considered to be a demersal fish by most fishery biologists, the species is a major item in the diet of surface-feeding seabirds and therefore could be treated as a pelagic species also. Nearshore data indicate that Pacific sandlance are present in substantial numbers in the region. They were the most abundant fish captured during nearshore studies in 1977, being especially numerous in Golovin Bay and widely distributed throughout Port Clarence and Grantly Harbor (Barton, 1978).

According to the behavior of seabirds and the occurrence of sandlance in the diets of other organisms, the fish apparently move onshore in late July and progress eastward as the season passes. The reproductive cycle of Pacific sandlance in northern waters is not known. However, larvae of this species have been encountered in surface waters at several offshore locations in Norton Sound during early summer (Barton, 1978). This suggests that spawning may occur in late May-early June.

4. Avifauna

a. Winter

Generally, only small numbers of Black Guillemots *(Cepphus grylle)*, murres, and Oldsquaws *(Clangula hyemalis)* overwinter in the polynyas of the Norton Sound lease area, although populations of up to 100,000 eiders have been observed in the open waters south of St. Lawrence Island (Fay and Cade, 1959) and similarly high numbers of murres were seen distributed on the ice during March 1968 (Irving et al., 1970). Glaucous Gulls *(Larus hyperboreus)* may linger near human settlements. Virtually all other seabirds migrate south out of the area during September and October.

b. Spring transition

Breakup of the ice opens the first habitats available to migratory water birds. Murres begin to return north along the leads in late April. In early May, King Eiders *(Somateria spectabilis)* appear, concentrating in leads along the mouth of Norton Sound and at the mouths of rivers where they make up the bulk of early migrating waterfowl. Other early arrivals include Pigeon Guillemots *(Cepphus columba)* and Oldsquaw.

With the appearance of early spring migrants, the leads in the ice along shore and at rivermouths become critical habitats. Thousands of seabirds and waterfowl, representing breeding populations which will eventually fan out to cover immense areas of northern Alaska, Russia, and northwestern Canada, congregate in the open water areas. These leads in the ice become especially critical when migrating birds meet inhospitable weather. Major sites where such early openings in the nearshore ice consistently appear include Agiapuk Delta in Imuruk Basin, the base of Point Spencer, off Woolley Lagoon, off the Sinuk River, Safety Sound, the mouth of the Snake River, the mouth of the Fish River on Golovin Sound, the Koyuk River mouth, Reindeer Cove, the mouth of the Unalakleet River, and the mouths of the Yukon River.

c. Open Water

The avifauna of western Norton Sound Basin is comprised mainly of seabirds — cormorants, Short-tailed Shearwaters *(Puffinus tenuirostris)*, Fulmars *(Fulmarus glacialis)*, Glaucous Gulls, kittiwakes, jaegers, Arctic *(Sterna paradisaea)* and Aleutian *(S. aleutica)* Terns, murres, Pigeon Guillemot, puffins, and three species of auklets. Least Auklets *(Aethia pusilla)* are the most numerous species. Murres contribute the greatest biomass.

Major nesting sites for seabirds in the western part of the lease area include St. Lawrence Island, the Diomedes, King Island, and Fairway Rock. Estimates of species populations on Little Diomede Island, King Island, and Fairway Rock indicate that over a million auklets and murres nest on these three small islands alone (Table 2). Throughout most of the open water season these birds are found from close proximity to the nesting cliffs out to 100 km. Other species such as the widely distributed circumboreal seabirds (Glaucous Gulls, Black-legged Kittiwakes *[Rissa tridactyla]*) and the widely distributed North Pacific seabirds (Horned Puffin *[Fratercula corniculata]*, Tufted Puffin *[Lunda cirrhata]*, Cormorant *[Phalacrocorax pelagicus]*) are more uniformly dispersed in the Sound but become concentrated in large numbers at nesting sites during breeding season (see review in Drury et al., 1981).

Table 2. Estimates of species composition and size of seabird colonies on Little Diomede Island, King Island, and Fairway Rock combined (Drury et al., 1981)

Abundance Ranking	Species	Number
1	Least Auklet	700,000
2	Crested Auklet *(Aethis cristatella)*	145,000
3	Murres (Thick-billed & common)	140,000
4	Parakeet Auklet *(Cyclorrhynchus psittacula)*	50,000
5	Black-legged Kittiwake	26,650
6	Horned Puffin	20,075
7	Tufted Puffin	3,000
8	Pigeon Guillemot	1,315
9	Glaucous Gull	385
10	Pelagic Cormorant	265

Few seabirds are seen in Norton Sound proper, especially in the turbid water which marks the outflow of the Yukon River west of Stuart Island. Murres are present within 10 km of Sledge Island, within 5 km of Stuart Island, and within 15 km of the shore between Cape Darby and Safety Sound. Flocks of foraging murres, puffins, and kittiwakes occur off Safety Sound and at the mouth of Golovin Bay. Otherwise, this area is relatively unimportant for seabirds, especially when compared with the western part of the basin.

From the standpoint of waterfowl, shorebirds, gulls, and terns, however, the shores of Norton Sound and its productive lagoons and estuaries are quite important (Fig. 13). Surf Scoter, Oldsquaws and others often gather together in large rafts. They and other shorebirds use Norton Sound in great densities as an area in which to molt on the sea or breed on the coastal tundra. Important areas include Agiapuk Delta in Imuruk Basin, Woolley Lagoon, Safety Sound, the mouth of the Fish River on Golovin Sound, Kwik River, Kwiniuk River north of Moses Point, Koyuk River Delta including the flats of the Inglutalik River, and the flats from Stebbins to Nokrot.

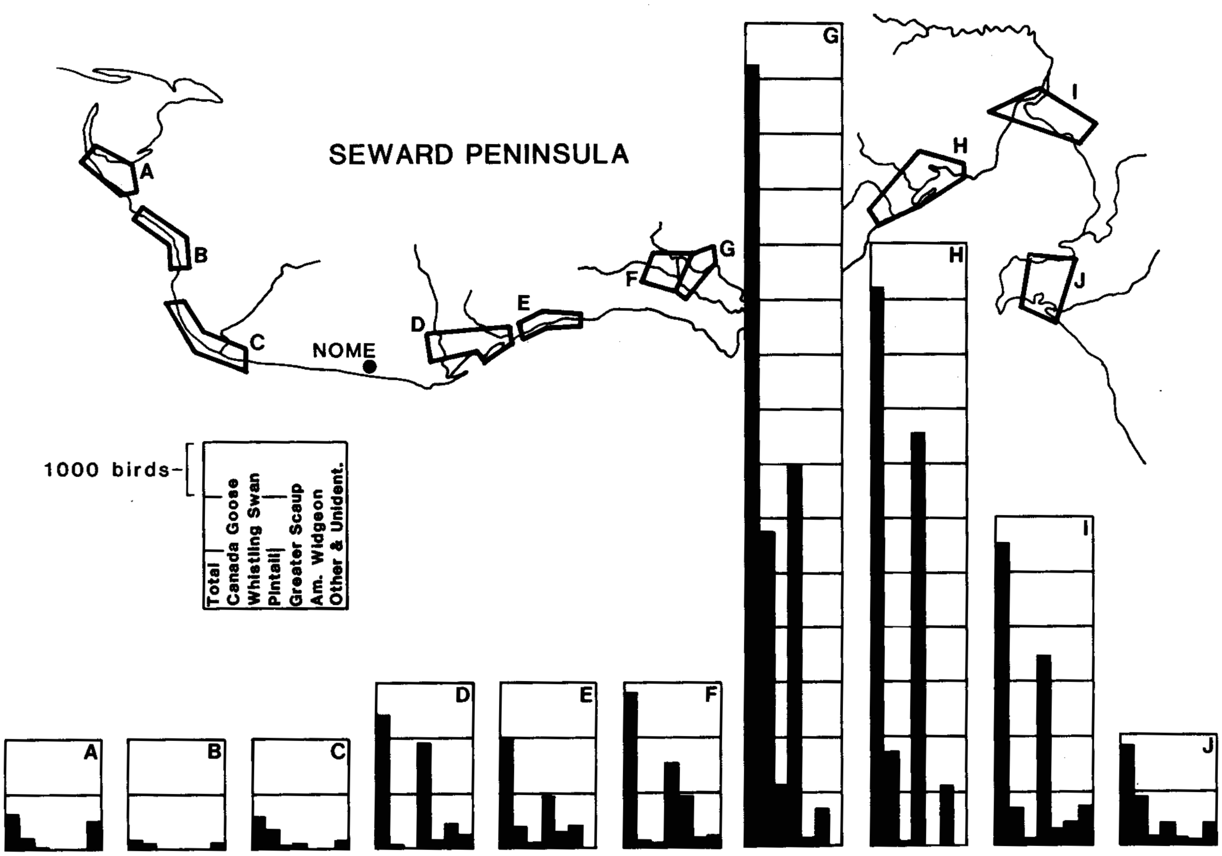


Figure 13. Numbers of waterfowl in major coastal habitats August 26-31, 1977 (Drury et al., 1981).

d. Summer to fall

In the period between mid-August and mid-October, flightless juveniles and molting adult murres from Norton Basin swim southward from nesting cliffs towards their wintering grounds at the ice front. Virtually all seabirds leave the western Norton Sound area by mid-October although some Pelagic Cormorants linger at the cliffs.

Along Norton Sound, shorebirds begin to gather together on coastal mudflats and scattered rocky shores, some coming from sites far inland before heading south. Populations of waterfowl from arctic areas gather with local breeders; populations peak in late August and early September when the Sandhill Cranes *(Grus canadensis)* which nest in eastern Siberia pass through. Shorebirds and waterfowl dwindle to small numbers by late September and early October, though gulls and Aleutian Terns may persist for several weeks. The gulls gather in large flocks beginning with the salmon runs and remain late into the fall along open shorelines until ice forces them out.

Although not as dramatic as spring arrival, autumn migration is a readily apparent phenomenon. Birds disappear from cliffs and feeding gounds; the shorebird flats are suddenly empty. Flocks of geese and cranes move east along the north shore of Norton Sound and a stream of gulls, often gliding on updrafts near steep slopes, moves eastward and eventually south.

Within Norton Sound the following comprise the major areas of coastal habitat use by birds (Bill Drury, pers. comm.):

Brevig Lagoon	Moderate use by migrating birds.
Grantley Harbor Imuruk Basin	Important area for migrating waterfowl.
Point Clarence "bicep"	Very important area for waterfowl.
Woolley Lagoon	Variable value for nesting, relatively important for migration.
Sledge Island	Moderately important seabird city.
Safety Sound	Important area for migratory waterfowl; major eelgrass beds; important feeding area for shorebirds.
Bluff Cliffs	Largest seabird city in Norton Sound.
Golovin Bay	Richest area for waterfowl and shorebirds in Norton Sound outside the Yukon Delta.
Moses Point	As important as Safety Sound; has more extensive tidal flats.
Upper Norton Bay-Koyuk River	Important waterfowl and shorebird area.
Reindeer Peninsula-Cape Denbigh	Moderately important seabird city; moderate use by waterfowl.
Unalakleet River	Small area of some value when considered together with small seabird cities along the shore to the south.
Saint Michael	Nesting of eiders, scoters and shorebirds; small seabird city.
Stuart Island	Moderate importance for migrating waterfowl.
Pastol Bay southwest of Stebbins	High importance for waterfowl.

It was noted by discussants that these areas coincided with the areas identified as shoreline segments of Norton Sound with the highest sensitivity to damage from oil spills.

5. Marine mammals

A recent review of the status of marine mammal stocks in Alaska is found in Brooks (1979). A major annotated review of published references on marine mammals of Alaska is found in Severinghaus (1979). Marine mammals can be classified as: (a) strongly associated with seasonal sea ice; (b) tolerant of limited ice cover; and (c) present during open water season only. Animals in each of these categories are:

- **Strongly associated with seasonal sea ice**

  Polar bear, *Ursus maritimus*
  Walrus, *Odobenus rosmarus*
  Ringed seal, *Phoca hispida*
  Bearded seal, *Erignathus baratus**
  Spotted seal, *Phoca vitulina largha**
  Ribbon seal, *Phoca fasciata**
  Belukha whale, *Delphinapterus leucas**
  Bowhead whale, *Balaena mysticetus**

- **Tolerant of limited ice cover**

  Gray whale, *Eschrichtius robustus*
  Killer whale, *Orcinus orca*
  Steller sea lion, *Eumetopias jubatus*
  Minke whale, *Balaenoptera acutorostrata*
  Harbor porpoise, *Phocoena phocoena*
  Humpback whale, *Megaptera novaeangliae*
  Fin whale, *Balaenoptera physalus*

- **Present during open water season only** (These species are generally rare in Norton Basin)

  Northern fur seal, *Callorhinus ursinus*
  Beaked whales, *Mesoplodon stejnegeri* and *Ziphius cavirostrus*
  North Pacific bottlenose whale, *Beradius bairdii*

  *All or a significant portion of the populations of these species occur in ice-free areas during summer. However, they are strongly associated with ice in other seasons.

The position of the ice front determines the species of marine mammals which will be found in Norton Sound. This front normally extends to the south of St. Lawrence Island. During occasional winters, however, it may reach only to the southern edge of the sound, west of the shore-fast ice.

a. Strongly associated with seasonal sea ice

i. Polar Bear

Polar bears can be found throughout the Arctic basin. Their extensive north-south movements and abundance in Norton Basin are related to the seasonal advance and retreat of the pack ice. Within the northern Bering Sea during the winter months, bears are normally found between St. Lawrence Island and the Bering Strait in association with the pack ice. Some animals have been known to summer on St. Lawrence Island, but they do not do so on a regular basis. The main prey species of the polar bear is the ringed seal. Bears feed less extensively on bearded seals, walrus, and carion.

Subsistence harvest of the polar bear within the Norton Basin ranges between 10 and 30 animals annually. Up to 77 bears have been taken in winters of very heavy ice. Most of the harvest occurs near the villages of Gambell, Savoonga, Wales, and Diomede (Bob Nelson, pers. comm.).

ii. Walrus

The Pacific walrus is one of the most abundant marine mammals utilizing the Norton Basin. Because the majority of the population winters in the Bering Sea and summers in the Chukchi Sea, a large portion of the walrus population passes through this area at least twice a year. As the air temperatures increase in late April and the pack ice begins to loosen, the walruses begin to move northward. By late June, most of these animals have passed through the Bering Strait. During recent years, however, numerous animals (primarily males) have been summering around St. Lawrence, Diomede, King, and Sledge islands as well as some locations along the Siberian Coast.

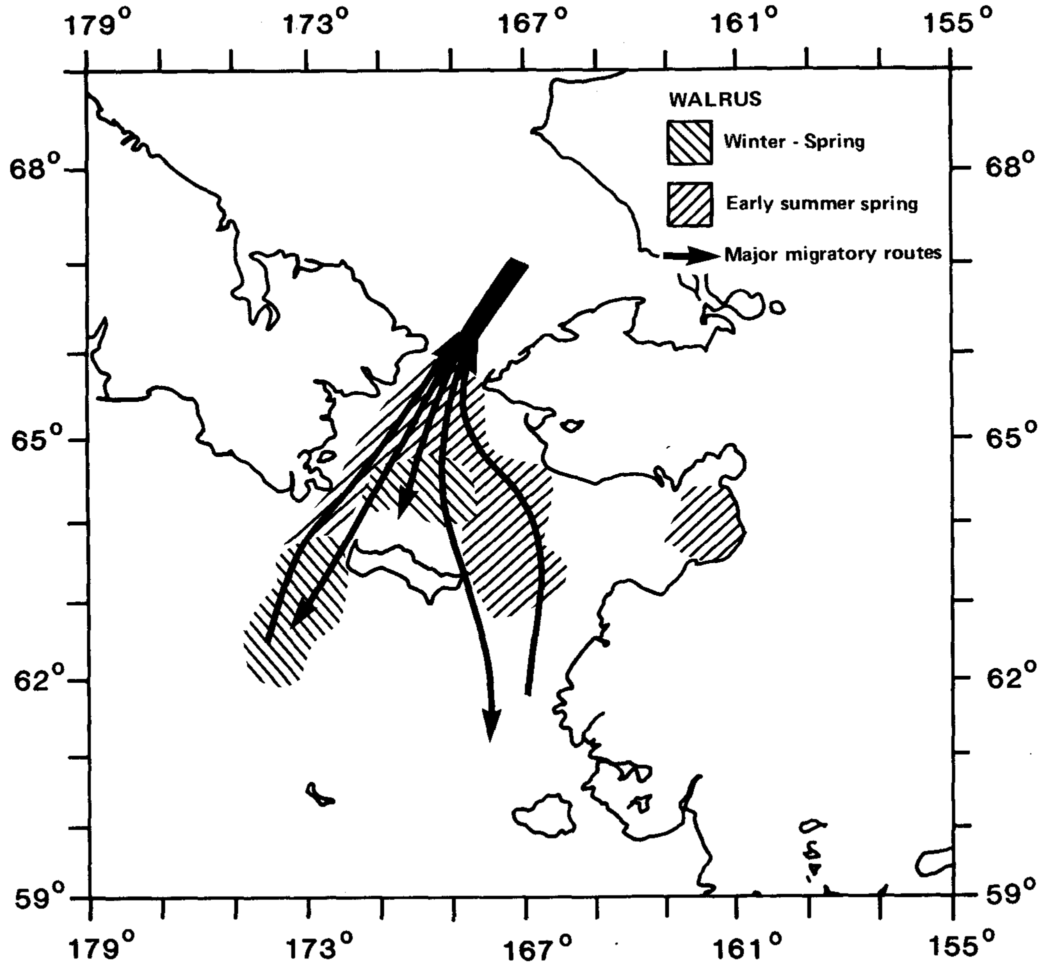


Figure 14. Seasonal distribution and migratory routes of walrus in the northern Bering Sea (Adapted from Krogman et al., 1979).

In late autumn, decreasing temperatures and the advance of the Chukchi pack ice force most of the walrus out of the Chukchi Sea and into the Bering Strait (Fig. 14). Large herds of migrating walrus appear around Diomede, King, and St. Lawrence islands and normally remain until late December. Northerly storms and the advance of the ice push most of the population south of Norton Basin by late December or early January, depending on the severity of the winter. However, some walruses may remain in Bering Strait, along the south and west sides of St. Lawrence Island, and in Norton Sound all winter long (Fig. 14).

Walruses are bottom feeders, eating mostly invertebrates. Over 65 species of benthic prey have been identified from walrus stomachs (Lowry and Frost, 1981), but it is difficult to assess the dietary importance of many of these. The bulk of the walruses' food is clams.

Approximately 1,500 to 2,000 walruses are taken annually by native subsistence hunters. Most of these animals are harvested by villagers from Diomede, Nome-King Island, Savoonga, and Gambel. Walrus ivory provides a major part of the local economy at these villages (Bob Nelson, pers. comm.).

iii. Ringed Seal

Ringed seals are the most abundant and available seals in the Arctic. In winter, ringed seal populations are most dense close to shore in the shorefast ice (Fig. 15); however, they are found throughout the proposed lease sale area. Although ringed seals are generally associated with sea ice, some are seen in the Bering Sea during ice-free months. As with other ice-associated marine mammals which winter in the northern Bering Sea, ringed seals move northward with the retreating pack ice from April to June, and southward with the advance of the pack ice in late November to January. It should be noted, however, that only a small portion of the total Alaskan population actually winters in the proposed lease sale area. In both summer and winter, most of the ringed seal population is north of the Bering Strait.

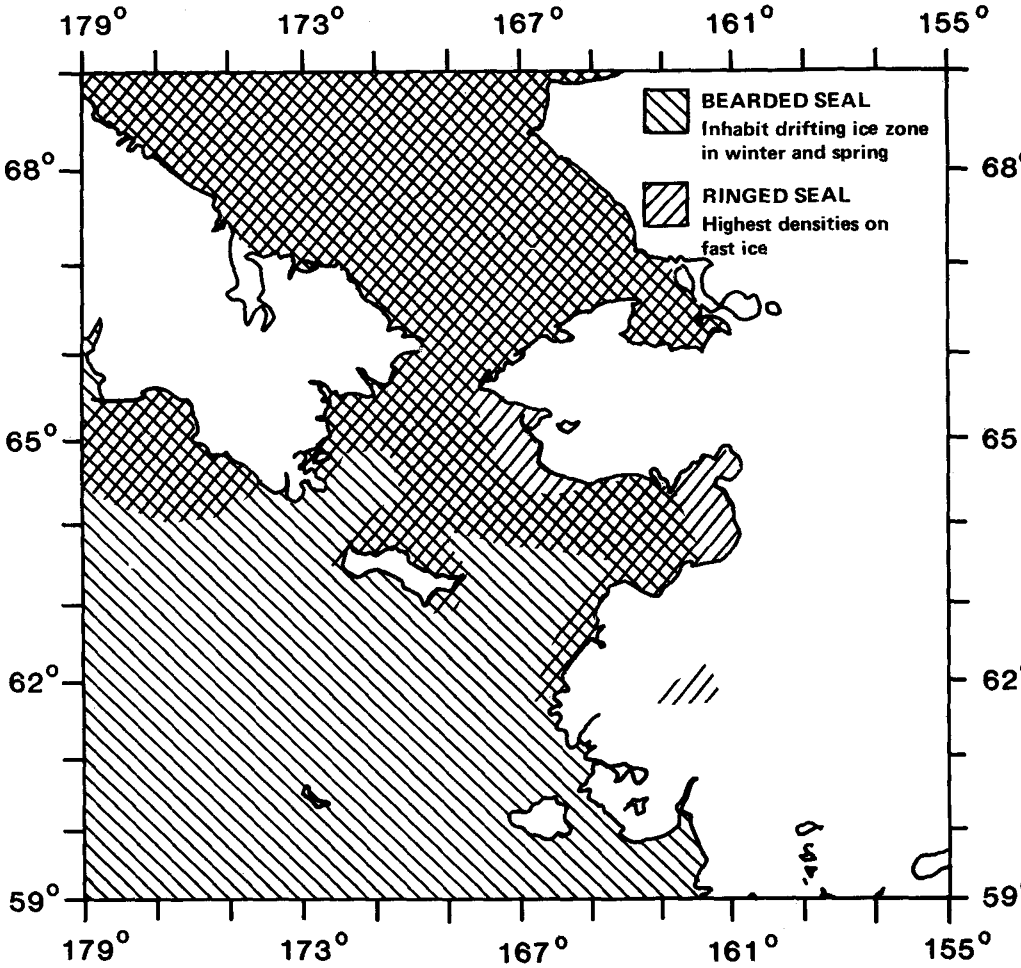


Figure 15. Winter distribution of bearded and ringed seals in the northern Bering Sea (Adapted from Braham et al., in press).

Ringed seals eat a wide variety of invertebrates and fish. The major prey utilized varies seasonally geographically. Studies conducted in the northern Bering Sea (Lowry and Frost, 1981) found that 80 percent of the stomach contents of ringed seals examined was made up of three or four of the following prey items: Arctic cod, saffron cod, sculpins, shrimps, mysids, and gammarid amphipods. Saffron cod appears to be the most important prey species during the fall and spring months. During winter months, Arctic cod was found to be the primary species eaten.

Because many ringed seals are found relatively close to shore they have long been important in the economy of the coastal Eskimos. The harvest from villages of the Norton Basin is between 1,000 and 1,500 ringed seals annually (Bob Nelson, pers. comm.).

iv. Bearded Seal

The bearded seal is the largest of the ice-associated seals. Although they can maintain breathing holes in the ice, they rarely do so in the Bering Sea and are thus largely excluded from the winter fast-ice zone (Fig. 15).

During winter and early spring bearded seals are distributed widely, though not uniformly, in drifting ice. Highest densities are found in the northern part of the Bering Sea. The northward spring migration of bearded seals through Norton Basin occurs from early April through June. Some bearded seals, mainly juveniles, inhabit the open sea during the summer months. They have also been known to enter bays and ascend some rivers. The southward migration of bearded seals through Bering Strait occurs during late fall and early winter.

Throughout the northern Bering Sea, crabs, shrimps, and clams compose the bulk of the bearded seals' diet. The most commonly eaten fish are sculpins and saffron cod; however, fish are generally of little importance in the berded seals' diet in the region (Lowry et al., 1980).

The number of bearded seals utilized by hunters within Norton Basin ranges from 700 to 1,000 annually. Occasionally, when other species are not available, the harvest is higher. Because of its large size and the quality of its meat, this seal is preferred over the other species by many villagers (Bob Nelson, pers. comm.).

v. Spotted Seal

During winter spotted seals are numerous in the leads south of the Seward Peninsula, but the largest populations are found at the ice front, usually south of the Norton Basin. As the ice recedes, spotted seals move with it eventually becoming abundant in the ice-free waters of Norton Sound. Many remain there as coastal residents during both transition seasons and the open water season. During the open water season this species is the most abundant pinniped in Norton Sound. Areas of highest abundance include: Stebbins to St. Michael, Besboro Island, Cape Denbigh, Golovin Bay, Safety Lagoon, Sledge Island, Sinuk River, Feather River, Woolley Lagoon, and sandbars in the Koyuk River.

Spotted seals eat a wide variety of foods, feeding mainly on fish such as capelin, pollock, herring, and saffron cod. During the summer and fall, they commonly congregate near the mouths of rivers, feeding primarily on anadromous and coastal spawning fishes (Lowry and Frost, 1981).

During an average year, 800 to 1,000 spotted seals are harvested by subsistence users within the area. Most of the recorded harvest is from villages within Norton Sound, and occurs in late summer and early fall (Bob Nelson, pers. comm.).

vi. Ribbon Seal

The ribbon seal is the least abundant of the seals commonly found in the northern Bering Sea. During the winter they congregate near the front; in the spring some migrate northward into Norton Basin, utilizing the diminishing ice remnants to haul out and molt. It is believed (Burns, pers. comm.) that the remainder of the year is spent in the ice-free waters of the northern Bering Sea where they adopt a pelagic existence, seldom coming to land.

Ribbon seals are pelagic feeders. Based on the limited data currently available, major prey species of this seal include shrimps, amphipods, mysids, and cephalopods. Several species of fish, particularly pollock, eelpout, Arctic cod, saffron cod, and herring, are also consumed (Frost and Lowry, 1980).

Average annual harvest of ribbon seals by Eskimo hunters within Norton Basin is small, totaling from 10 to 20 per year. The low harvest of this pelagic seal is attributed to their inaccessibility to coastal hunters. During occasional years of very limited ice, ribbon seals are abundant in Norton Basin. Relatively large havests have been recorded during those years (Bob Nelson, pers. comm.).

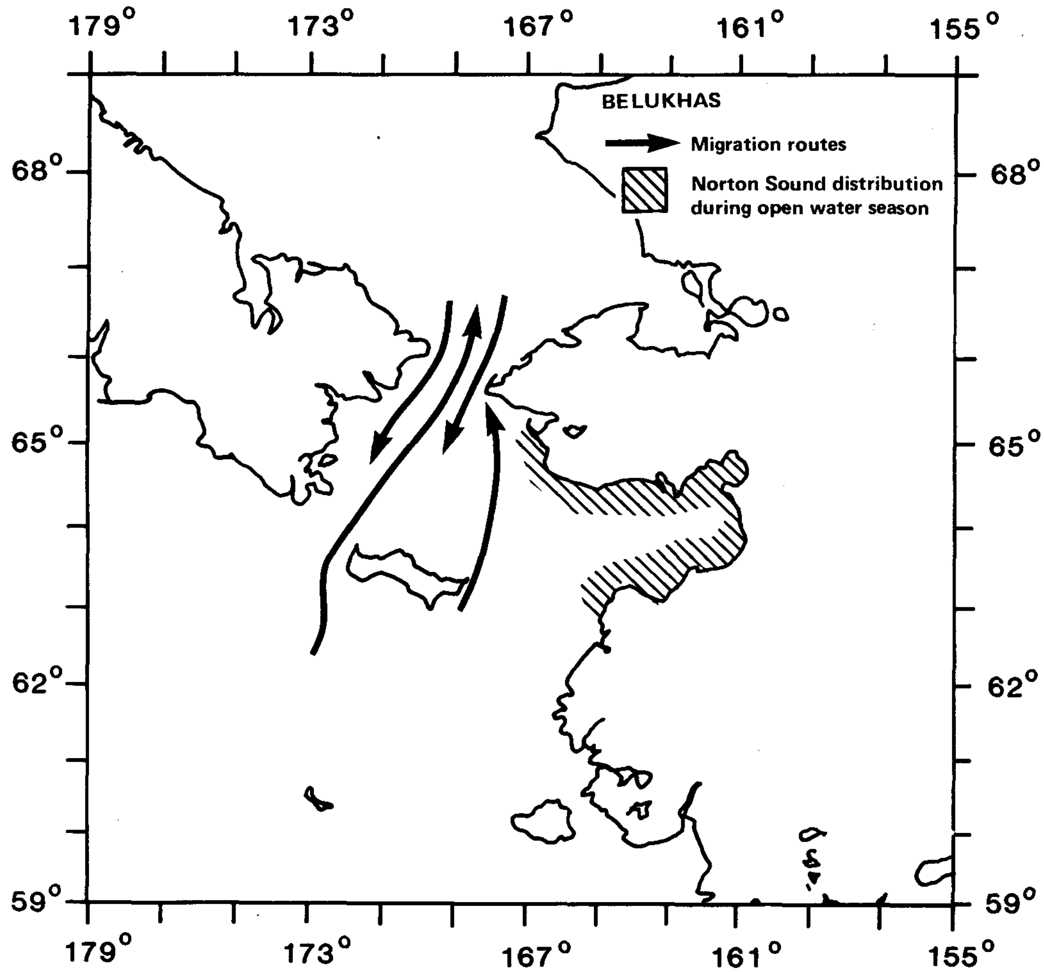


Figure 16. Distribution of belukhas in Norton Sound during the open water season and their major migratory routes.

vii. Belukha Whale

Belukha whales have a wide distribution throughout the Bering Sea. During winter they are associated with the more unstable parts of the pack ice (which provide easy access to air) and therefore most winter south of Norton Basin. During the transition season a large part of the belukha population migrates through Norton Basin, passing to and from summering areas farther north. Significant numbers, however, spend the ice-free months in the coastal zone of Norton Basin where they concentrate in bays, estuaries, river mouths, and lagoons which are relatively undisturbed by humans (Fig. 16). In this regard, eastern Norton Basin is of greater significance to belukha whales than the western sector.

Studies conducted on the food habits of belukha whales in Alaska waters indicate that relatively few species of prey comprise the bulk of their diet and that these vary with season and location. During the late spring and summer their primary prey in Norton Sound is saffron cod. A variety of other fish such as sculpins, herring, smelt, capelin, and salmon have been reported in belukha stomachs but are less important in their diet.

Although the present harvest of belukha in the proposed sale areas is relatively small, subsistence hunters have used this species for thousands of years. The annual harvest in this area is between 40 and 60 belukha, with most of these animals being taken by hunters from villages along the coast of Norton Sound (Bob Nelson, pers. comm.).

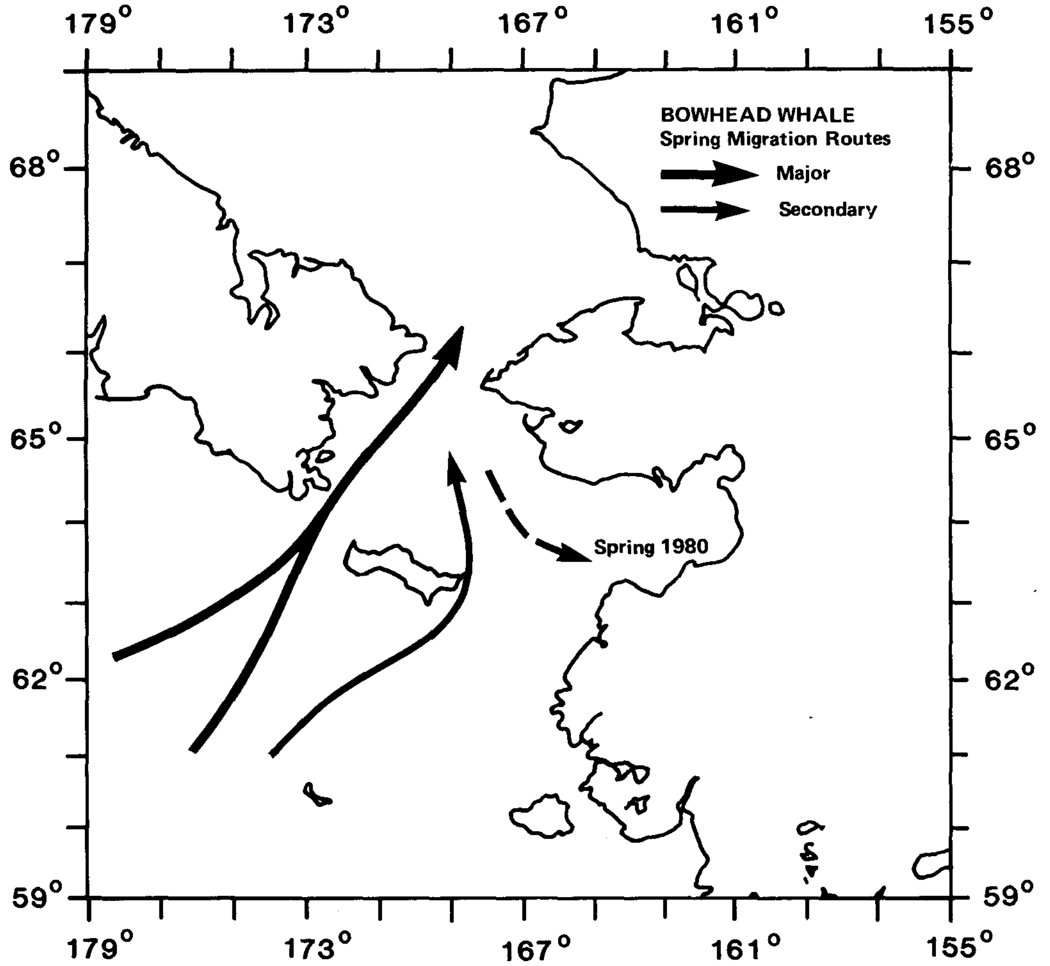


Figure 17. Spring migratory routes of the bowhead whale in the northern Bering Sea. The movement toward Norton Sound was observed only in Spring 1980 (Adapted from Braham et al., 1980).

viii. Bowhead Whale

Bowhead whales are endangered because their population has been drastically reduced. Prior to the period of extensive Yankee whaling, they could be found in western Norton Basin during the entire open water season. At present, the remaining population winters mainly south of St. Lawrence Island (the majority in the southwestern ice-covered portions of the Bering Sea) and seasonally migrates through the Bering Strait to and from summering areas farther north (Fig. 17). Thus, they are found mainly in the western and northern parts of Norton Basin and usually during spring and autumn.

Foods eaten by bowhead whales in the Bering Sea are presently unknown. Whales killed in the spring while they are migrating north have little or no food in their gastrointestinal tracts. Samples taken from stomachs of whales harvested in Arctic waters in autumn contained primarily copepods or euphausiids.

The annual harvest of bowhead whales within Norton Basin is normally between three and five animals. Bowheads are usually taken in the spring by hunters from the villages of Gambell and Savoonga (Bob Nelson, pers. comm.).

b. Tolerant of limited ice cover

Generally speaking, the marine mammals in this category are species which summer in Norton Basin, arriving while some ice persists in late spring and remaining until it reforms in autumn.

i. Gray Whale

The annual migration of gray whales, or "summer whales" as they are often called by Eskimos, is the longest undertaken by any northern marine mammal. These whales travel from wintering grounds along the coast of Baja California to summering grounds in the Bering and Chukchi seas (Fig. 18). The gray whale is one of the most abundant cetaceans utilizing Norton Basin and is found throughout the region during the months of May through November. Most gray whales spend the summer feeding in the shallow waters of the northern and western Bering Sea and in adjacent waters north of Bering Strait (Braham et al., 1979).

The feeding habits of gray whales are unique among cetaceans; unlike other baleen whales, they feed on epibenthic organisms. Gray whales also appear to be very selective feeders, utilizing amphipods as their major prey.

Although gray whales are quite common close to most of the villages bordering Norton Basin, they are seldom hunted. This bias against this species is believed to result from its more aggressive disposition when hunted, and the presence of barnacles and parasites in the skin and blubber which make the flesh less desirable (Bill Marquette, NMML, pers. comm.).

The annual harvest within the area is between one and three whales, and these are mainly taken close to the villages of Gambell, Savoonga, Wales, and Diomede (Nelson, pers. comm.; Marquette and Braham, in press).

ii. Killer Whale

Killer whales are normally observed in the northern Bering Sea during the months of June through October. They are commonly found around St. Lawrence Island and to a lesser extent in Norton Sound.

Little is known about the feeding habits of killer whales within the northern Bering Sea. It has been suggested that they utilize mainly large fish such as salmon, sea birds, pinnipeds, and other cetaceans. Judging by the number of stranded gray whales killed by killer whales, the northern Bering Sea must be a productive hunting area for this species.

The killer whale is one of the few species of marine mammals in the Norton Basin which is not normally hunted by local residents. The bias against hunting killer whales results from fear and from the legendary reverence in which this species is held (Bill Marquette, NMML, pers. comm.).

iii. Minke Whale

The minke whale is the smallest species of baleen whale. Their numbers in the Bering Sea are presently unknown. They summer throughout the north Pacific and are commonly seen around St. Lawrence Island during the months of June through October.

Little data are available concerning the food habits of minke whales in the Bering Sea, although they have been observed feeding on sandlance off Sledge Island (W. Drury, pers. comm.). In other areas they are primarily zooplankton feeders utilizing euphausiids. Otoliths from fish such as pollock have also been recorded in stomachs.

Utilization of minke whales by subsisitence hunters is minimal. On the average one or two of these whales are taken annually by hunters from Gambell or Savoonga (Bob Nelson, pers. comm.)

iv. Other species

Other species tolerant of limited ice conditions, which are found in small numbers, or which are uncommon in Norton Basin include: Steller sea lions, harbor porpoises, Dall porpoises *(Phocoenoides dalli)*, humpback whales, and fin whales. With the exception of sea lions, few, if any, are harvested by Native hunters.

c. Present during open water season only

Animals in this category include Northern fur seals, usually sub-adult males, and a few beaked or bottlenose whales. Little is known of their distribution in Norton Basin.

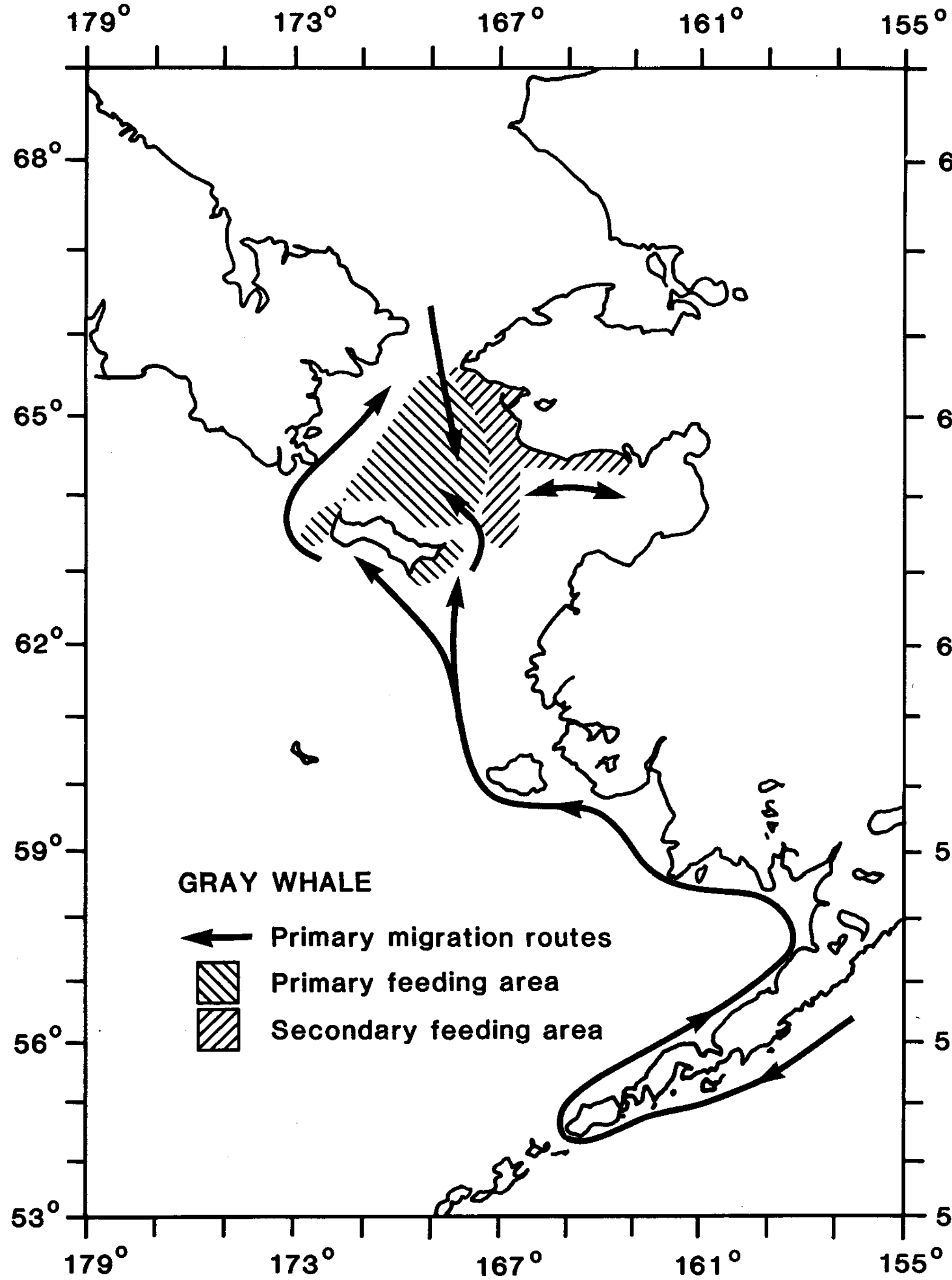


Figure 18. Migration routes and seasonal distributions of gray whales (Braham 1977; and Braham et al., 1977).

D. Effects of Oil on Coastal and Nearshore Habitats

The possible effects of oil on coastal habitats were considered by session participants. Discussion topics included the effects of oil on shoreline areas, the effects of oil on biota, and a consideration of specific oil spill scenarios.

1. Effects of oil on shoreline areas

Shoreline areas of Norton Sound having the highest sensitivities to oil spill damage are shown in Fig. 19. Ice-related factors which might **intensify** the amount of damage caused by oil spills in such areas include: overriding by ice which could drive oil above the high tide line; trapping of oil under the ice which would be difficult to clean up; and trapping of oil inside the ice, thus insuring the release of fresh oil in the spring.

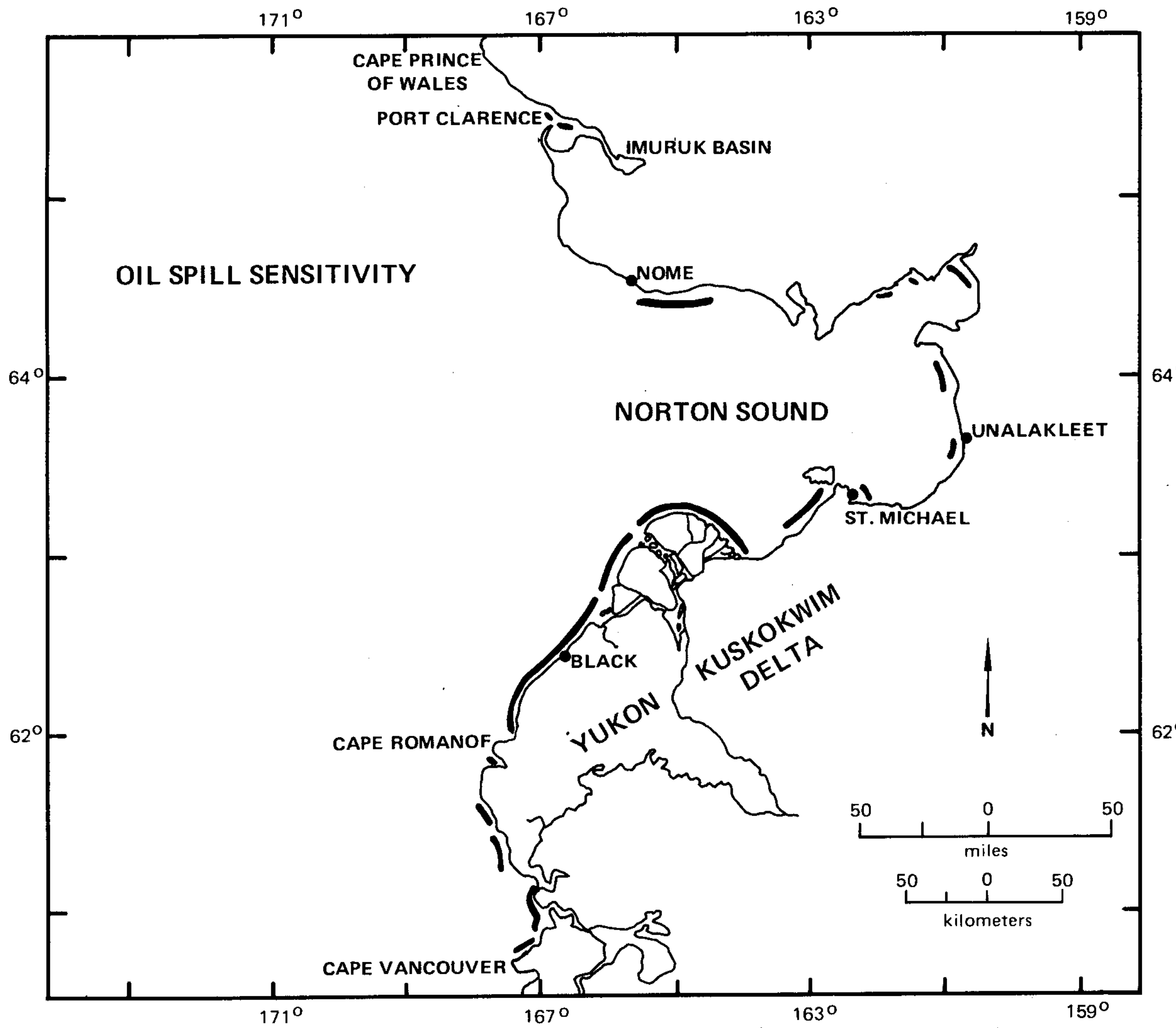


Figure 19. Areas of highest sensitivity to oil spill damage (ESI = 8, 9, 10). These environments tend to be associated with delta mouths and lagoons, with fine-grained sediments, abundant marsh vegetation, and are sheltered from wave attack. If these shorelines were oiled, natural cleansing processes would take several years (Hayes and Gundlach, 1980).

Additional problems caused by movement of ice include: the rocking of moving ice which could pump oil onto the surface (thereby increasing the potential for contamination of marine birds and mammals); the grinding of oil into small droplets by moving ice, making it more readily suspendable in the water column; and, the long distance transport of oil by currents, dispersing the oil for later release near the ice edge.

Ice-related factors which might serve to **ease** the amount of damage caused by oil spills include: reduction of turbulence which could reduce mixing through the water column; localization of spills behind ice barriers; incorporation of the oil into freshly freezing ice; and movement of ice containing oil away from vulnerable shoreline areas.

2. Effects of oil on biota

a. Bacterial base

Detritus feeders are vital to the productivity of Norton Sound. The basis of their food web in this area begins with bacteria.

Observations made by Griffiths and Morita (1981) on sediments collected in Cook Inlet and in the Beaufort Sea suggest that the presence of crude oil in marine sediments interferes with the flow of organic carbon. Griffiths and Morita measured the reduction of redox potentials (formation of anoxic sediments), the reduction in the rates of nitrogen fixation and denitrification, and the reduction in enzyme activity breaking down structural polysaccharides such as cellulose. They concluded that an oil spill would result in a reduction in available fixed nitrogen, and in a reduction in overall productivity due to decreased rates of nitrogen fixation.

b. Benthic invertebrates

Because they are found in depositional areas which are scoured by drifting ice, benthic systems in Norton Sound appear to have adaptations which might allow them to recover from heavy disturbance. The organic sediments upon which these benthic animals depend, however, facilitate the incorporation of oil into the substrate; therefore, the long-term detrimental effects of an oil spill on marine benthos would be increased.

Observations also suggest that the pelagic larval stages of benthic invertebrates are highly sensitive to oil. King crab and Tanner crab larvae have acute median tolerance limits (concentrations that kill 50 percent in 24-96 hours) of 300 to 500 parts per billion (ppb) total aromatics. The larvae are most sensitive at molting stages, which occur with greatest frequency in the first year of life. (Sid Korn, pers. comm.)

c. Fish

Herring and flatfish larvae are very sensitive to the aromatic fraction of crude oil; mortalities occur at concentrations less than one part per million (ppm). Sublethal effects of oil have been documented for herring and flatfish larvae at low levels in the range of ppb (Malins et al., 1980). These include abnormalities in development, inability to swim, decreased rate of growth, and reduced ability to avoid predation. In most cases these sublethal effects would result in death in a natural environment. Adult herring exposed to low levels in ppb of benzene (an important component of oil) had eggs and subsequent larvae with lower survival rates than the eggs and larvae of unexposed fish. Abnormalities and death of the eggs occurred at a higher rate when herring were exposed during spawning.

Spawning of pelagic species (herring, capelin, and smelt) frequently takes place in systems with low wave energy such as bays, lagoons, and estuaries in inner Norton Sound where flushing of the water is slow. In these areas, pollutants may persist much longer than where wave and current energy is higher. Several species (capelin, sandlance, saffron cod) have demersal eggs, which may be buried in beach sands until hatching. Oiling of these beaches and subsequent movement of the oil into the sediments could cause huge mortalities of hatching fish.

Salmon eggs are generally resistent to acute exposure, but are sensitive to long-term exposure because the oil accumulates in the yolk of the egg and kills the larva at hatching. Sublethal effects of oil (reduced growth) have been documented in laboratory studies at 300 ppb. (Sid Korn, pers. comm.)

Arctic cod, one of the major forage fish in the northern Bering Sea, appear to spawn under the ice in winter. Eggs and larvae are pelagic, remaining in surface waters under the ice for as long as six months. Thus, they live in the shallow band of water most likely to be exposed to an oil spill. Toxicity studies indicate that both eggs and larvae of Arctic cod are highly sensitive to hydrocarbons.

d. Birds and mammals

Seabird populations are presently so high that the lack of nesting habitat is excluding many potential breeders from the breeding population. However, the high sensitivity of seabirds to oil pollution, combined with their low reproductive rates, insure that seabird colonies would be slow to regain their numbers if a major pollution incident occurred. A large spill in the fall would be especially devastating if it intersected the large numbers of molting and flightless young murres which swim south ahead of ice. Physical disturbance by increased human populations working in the area would also take its toll. When frightened by passing aircraft or approaching motorboats, seabirds dive headlong off their narrow nesting ledges, kicking their eggs onto the rocks below as they leave.

Session participants concluded that adverse impacts on marine mammals due to oil development in Norton Basin would likely be of an indirect nature, resulting from lowered abundance of prey or sensitivity to increased marine traffic. Additional information concerning the susceptibility of individual marine mammal species to oil is contained in the following sections on oil spill scenarios.

3. Hypothetical spill scenarios

a. **Case 1.** Summer spill (10,000 bbl) in eastern block of lease tracts.

i. Effects on the western Norton Sound lease area.

Such a spill would likely remain inside Norton Sound and not be incorporated into surface waters west of the boundary zone.

ii. Effects on the eastern Norton Sound lease area

Central Waters. It was the general concensus that a spill of average magnitude (10,000 bbl) in the inner lease area would have a minor impact on the central waters of Norton Sound based on the following assumptions:

- The number of seabirds in Norton Sound would be small.
- Most of the seals would be gone: spotted seals would be present mainly in coastal areas, bearded seals (and walrus) would have moved north, and ribbon seals would be distributed at sea in the Bering Sea.
- Gray whales would probably not be present in the inner portion of the Sound.

Although the immediately obvious impacts of such a spill at this time would be minor, as compared to the effects at other times of the year, the impacts on some forms of life could occur based on the following assumption:

- Belukha whales would be present in inner Norton Sound.
- Benthic species would be releasing eggs.
- Fish larvae would be present at peak numbers (flounders, saffron cod, and Arctic cod).
- The seabirds which do feed in central Norton Sound would likely be seriously affected.

Coastal Areas. Were the oil to reach Norton Sound coastal areas, the resulting damage might be quite extreme because:

- The larvae of saffron cod, herring, capelin, and smelt would be present and especially vulnerable in the nearshore "wave zone."
- King crab and other crustaceans are especially abundant over an area of about 20 km of tidally-induced rough water just south of Cape Darby/Rocky Point.
- Waterfowl and shorebirds would be highly vulnerable if oil reached the heavily used tidal flats around Norton Sound.

b. **Case 2.** Summer spill (10,000 bbl) in western block of lease tracts.

In this scenario, the greatest portion of such a spill would be carried northward by the surface waters of the Bering Shelf water mass. The major volume of surface oil would probably become strung out along the boundary zone between the Norton Sound coastal waters and Bering Shelf waters. A large area of eastern Bering Strait could become affected within a few days of the initial release due to the relatively rapid rate of transport and the funneling effect of the Strait.

Large numbers of birds from King Island, Fairway Rock, and the Diomede Islands could be exposed to surface oil, although the amount of surface oil moving past these major breeding areas would depend entirely upon weather conditions which prevailed at the time of release and transport. Light or moderate winds would allow oil to remain on the surface, while strong winds would result in narrow bands of oil which, through turbulence, would become well mixed into the water column. The former conditions could have serious consequences for large numbers (tens of thousands) of seabirds. An unfortunate compounding consideration is the fact that some seabirds would be attracted to oil covered areas because of their sheen and the localized "calm" of oiled waters.

Water soluble fractions of crude oil would reach eggs and larvae of invertebrates and fish. Benthic invertebrates would be releasing their eggs at this season and larvae (of invertebrates and many of the fish) would be at their seasonal peak of abundance, coincident with the peaks of phytoplankton and small zooplankton abundance. Larvae of arctic cod, a major prey species for many animals, would be abundant in the Bering Shelf waters and would be highly susceptible to pollution involving the water soluble fractions of crude oil.

It was indicated that in addition to the probability of significant direct mortality to seabirds utilizing the islands of the Bering Strait region, an oil spill as indicated in Case 2 would cause depletion of available food sources. Thus, the carrying capacity of a much larger region (that region benefiting from high productivity in Bering Strait) would be lowered.

Although the impacts of a summer spill would probably not cause any significant direct mortality to marine mammals, several other consequences were discussed.It was suggested that cetaceans may be more susceptible to harm from spilled oil than pinnipeds because of the greater sensitivity of their skin (whale skin is more metabolically active). Several other problems concerning cetaceans were mentioned including:

- Matting of baleen straining plates could result in loss of filtering efficiencies (however, this would be hard to observe in the field, i.e., gray whales can fast for months though they feed intensively during summer).

- Minor irritation to the tissues of blowholes could result in labored inhalation and eventually the possibility of pneumonia.

- Loss of forage items, such as the large populations of ampeliscid amphipods fed upon by gray whales, could cause subsequent displacement or reduction in the amount of energy which could be stored prior to annual migration out of the area.

Waters around St. Lawrence Island and immediately north of it would probably not be contaminated because of the northerly currents. Similarly, the Yukon Delta would have a low probabilty of impact at this time of year.

c. **Case 3.** Transitional seasons

As indicated previously, trajectories and target areas of oil spilled during the transition seasons would be highly variable because of the "unsettled" and less predictable weather conditions in spring and autumn. The frequency of significant storms, particularly in autumn, could intensify mixing of oil in the water column, thus increasing the chances of toxic hydrocarbon derivatives reaching the benthos.

i. Fall transition

Rapid formation and transport of sea ice during the fall would reduce the likelihood of mixing as the ice season progresses. Oil spilled anywhere in the proposed lease area would eventually end up west of the boundary zone between eastern and western Norton Basin. Oil originating from tracts east of the boundary zone would have a much longer time of residence in Norton Sound because of gyres and slower surface currents before beng flushed into Bering Sea. Oil from the more westerly tracts would be carried directly into western Norton Basin and then southward.

A large proportion of spilled oil would become incorporated into the rapidly forming ice sheet. It would remain there throughout autumn and winter, eventually being transported over a huge area. Some of the trapped oil would eventually reach the ice margin where it would be released by the continuous melting of ice in close proximity to the shelf break. Oil reaching this area of ice disintegration would rapidly become incorporated into the water column.

During the fall transitional period many seabird and waterfowl species will have migrated out of Norton Basin. Late migrants, especially molting seabirds, could be quite vulnerable in the vicinity of the ice front. Among the marine mammals, gray and humpback whales will have migrated south, but walrus and several species of seals will have moved back into the areas with the advancing ice edge. Walrus, seals, and belukha whale will be most vulnerable to the effects of oiling during the fall and spring transition periods.

ii. Spring transition

During the spring transitional period (March-June) ice leads open up, creating open water areas where large numbers of birds congregate. Migrant birds enroute to regions over most of northern Alaska and northwest Canada are found here at these times. It is during this critical period when spilled oil in the leads and polynyas could cause the greatest direct mortality to birds.

During the spring transitional season pupping of seals, walrus and possibly bowhead whales occurs within the Norton Basin area along open leads and the ice front. Walrus, ribbon seals, and ringed seals give birth to young between April and June. Bearded seals pup a little earlier, between March and May.

If oil were to reach ice habitats and subsequently to be pumped onto ice, spotted and ribbon seals would be more vulnerable than the other pinniped species because their young are dependent on drifting ice. Bearded seals and walrus, whose young swim at birth, would not be as susceptible to harm as spotted and ribbon seals, although they might be affected by ingestion of oil or oiled foods.

In years of relatively warm winter weather, as in 1976-1979, predatory flatfish, i.e., starry flounders and yellowfin sole, have been known to migrate into Norton Basin in search of prey. These fish might be impacted and their populations reduced in numbers if their benthic food items were affected by a spill in the late spring-early summer period.

d. **Case 4.** Spill during the season of maximum ice cover.

In general the northern Bering Sea, particularly Norton Sound, is a source of new ice which forms rapidly in the persistent polynyas.

Observations on the rates of movement of ice in Norton Basin indicate significant differences between the eastern and western portions of the sale area. Although trajectories in both cases are southerly, velocities of ice in the western portion are up to four times greater than those from the inner Sound (40-45 km/d vs. 12 km/d – Ray and Dupré, 1981). This suggests a flushing rate of about 75 days for the eastern portion of the sale area. Ice oiled in inner Norton Sound during March is likely to remain there until May. Eventually, it will be (1) transported to the ice front if the spill occurs in early to mid-winter, (2) moved northward with retreating ice if the spill is in late winter, or (3) deposited on the beaches in late spring-early summer.

Oil originating from a spill in tracts west of the boundary zone could be incorporated directly into the surface waters and ice of the Bering Sea. Since ice continues to form during this period, oil would occur in the small openings until it became incorporated into the ice cover. Weathering would be very slow. Eventually, the oil resulting from a spill in the western tracts would either be carried to the southern ice margin or would be released when the ice melts. Oil released by the melting of the ice pack in late spring would cover a wide area.

During the winter months, the polynyas in Norton Basin do not support as many animals (birds and marine mammals) as those south of St. Lawrence Island. However, they are still important and even their small populations may represent a significant proportion of the breeding stock for some species. The peripheral portions of the open waters within the polynyas are used by Oldsquaws, murres, eiders, and walrus and bearded seal. In the central part of the basin, where ice thickness is greatest, walrus, ringed seals, and bearded seals tend to be clumped. In the eastern part of the lease area, where ice is weaker, larger numbers of bearded and ringed seals are likely to be found. Bearded and ringed seals in this region would be more vulnerable to an oil spill during the winter than the other mammals.

Polar bears are occasional migrants into Norton Basin during the winter, and Canadian studies have shown them to be highly vulnerable to direct contact with oil due to renal failure resulting from grooming of even a small portion of oiled body pelage (Dan Costa, pers. comm.).

Winter spawning fish, such as Arctic and saffron cod, sculpins, and eelpouts, would also be affected by a winter spill. The pelagic eggs and larvae of Arctic cod could suffer heavy mortality wherever contact with oil occurred. Tainting of the flesh of either of the cod species could present a severe subsistence problem.

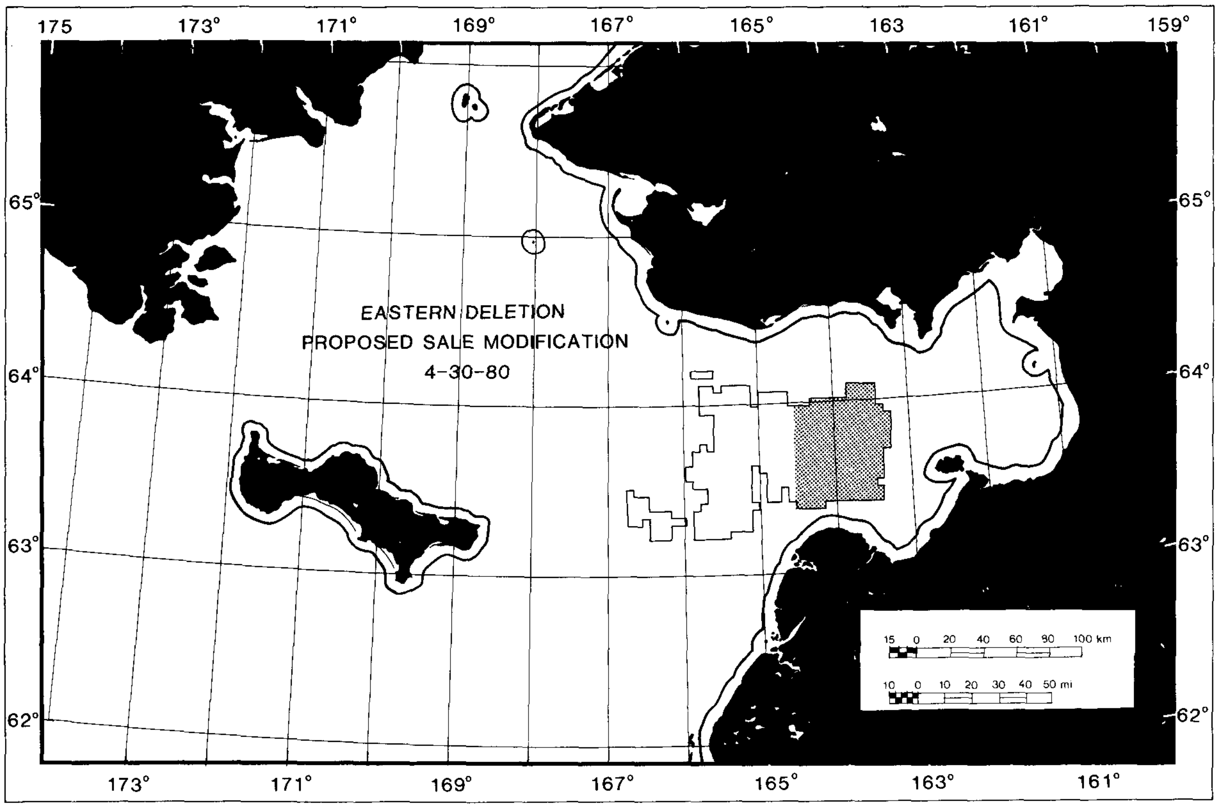


Figure 20. Proposed deletion of eastern tracts.

4. Proposed alternatives to offshore oil and gas development
   a. Delete eastern tracts (Fig. 20)

      It was suggested that deletion of these tracts would reduce the potential impact on eastern Norton Sound in summer. Deletion of these tracts would not, however, have an important effect on Norton Sound in winter because the surface transport of oil together with ice would be out of Norton Sound.

   b. Delete southern tracts (Fig. 21)

      This deletion might reduce the hazard of oil being pumped back and forth under the shorefast ice for part of the year. It was felt that deletion of these tracts would protect major waterfowl habitats and the subsistence use of waterfowl on the northern perimeter of the Yukon Delta.

   c. Delete northern tracts (Fig. 22)

      Deletion of the northern tracts could lessen the possibility that spilled oil might get into the gyres observed in central Norton Sound, where they might remain for long periods during the season of open water.

      No consensus was sought, but it appeared that the options for deletion of eastern tracts might be most significant for protection of wildlife resources in the different parts of Norton Basin.

E. Needs for Further Study by OCSEAP

The number and seriousness of the research gaps is not surprising when one compares the effort invested in the Norton Basin with that put into studies in the Beaufort Sea and south eastern Bering Sea. The following list of research needs was compiled by session participants.

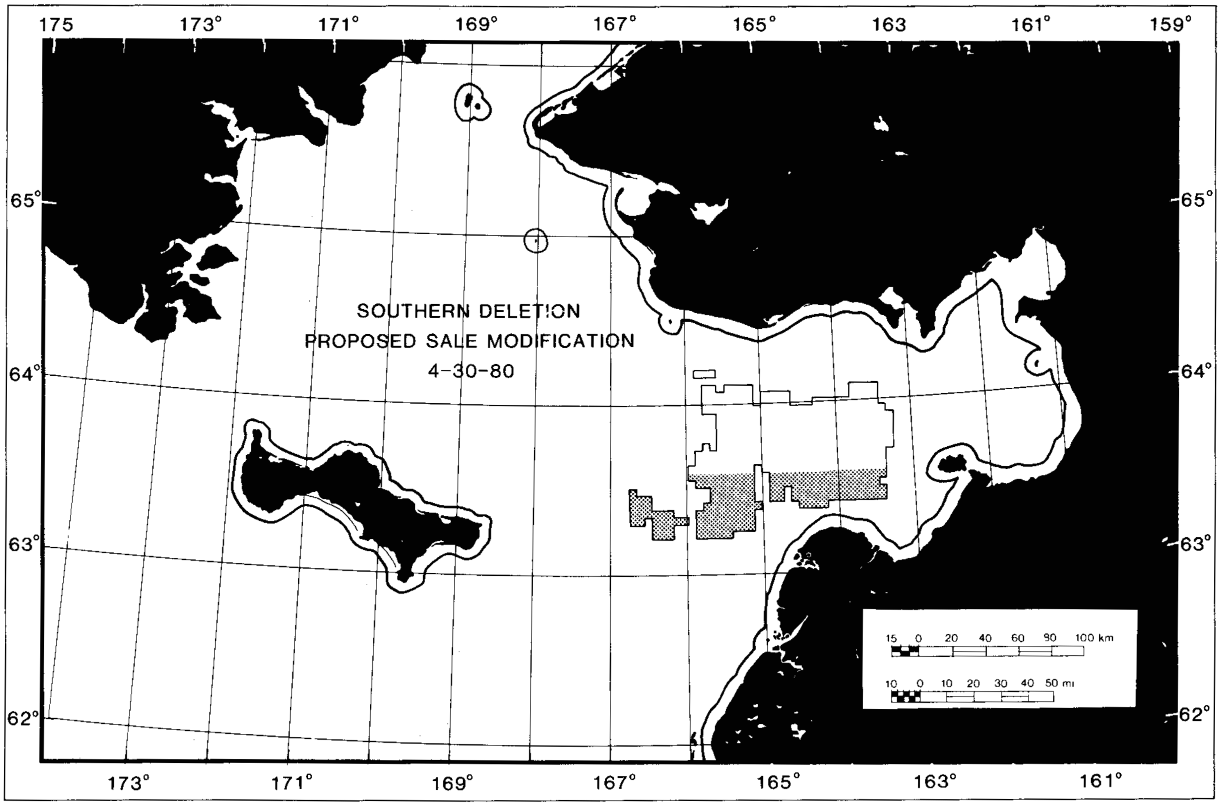


Figure 21. Proposed deletion of southern tracts.

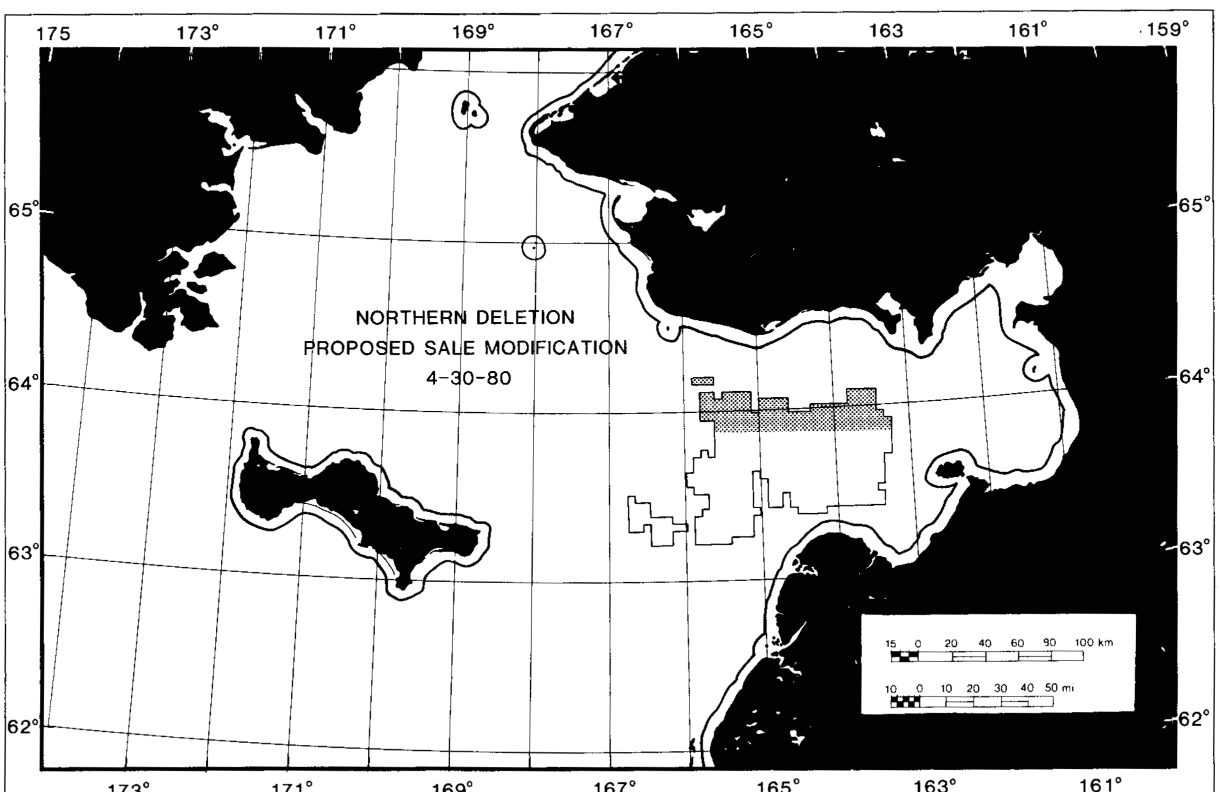


Figure 22. Proposed deletion of northern tracts.

1. Physical and geological oceanography

   a. Transport of sediments

      Geological information on how local beaches are built is needed to understand the potential effects which contaminants might have in the case of a spill. Observations that beaches at Moses Point and part of the beach at Safety Lagoon have been built toward the east, in contrast to the described westerly flow of water along the northern shore of Norton Sound, suggest that more work is needed to be confident of the directions in which storm-generated currents move sediments.

   b. Oil and ice

      Additional transport-related research is needed to determine if oil traveling with ice in winter could reach the St. Lawrence area. If so, what are the associated risks?

2. Biological oceanography

   a. Productivity

      Little is known about the primary productivity and the important species of phytoplankton which occur in the St. Lawrence and Norton Sound regions. Areas of high water column productivity need to be delineated, and the manner in which this productivity is distributed to pelagic or benthic food chains needs to be determined.

      More studies are needed to confirm that major carbon inputs to the Norton Sound benthic system originate as detritus from the Yukon and other rivers, from sea grass beds, or from intertidal algae. These studies should incorporate knowledge of bathymetry and sediments in the several parts of the Norton Basin.

      The intertidal and shallow subtidal zone of Norton Sound (O'Clair et al., 1979) and the Yukon Delta region (Zimmerman and Merrell, 1976) have received little attention. Information on tidal mud flats and the species present is scanty. What will be the effect of oil deposited in eelgrass beds and sandflats? Eelgrass beds are located in the back areas of Woolley Lagoon, Safety Lagoon, and Golovin Bay; many key "bait forage fish" species spawn in these places.

   b. Invertebrates

      It is not known why Norton Sound is important to so many species of benthic invertebrates, especially echinoderms. The competitive interactions of predatory invertebrates with demersal fishes in years when the latter group is abundant are important to understand the system.

      Local villagers catch king crab through the ice in winter and spring, and out of the shallows in mid-June. The locations of nursery and feeding areas for these crabs in the inshore waters or for the commercial populations in the western part of the basin are unknown.

   c. Fish — demersal

      Little is known about demersal fish reproduction in Norton Sound; most information is inferred from literature sources, mostly from other regions. How important are lagoons as rearing areas for young fish of different species?

      Nothing is known about the winter distributions of bottomfish. Indirect evidence suggests that there are major changes in the availability of some species; most notably, Arctic cod populations appear to increase during the winter.

      We still know essentially nothing about the biology, spawning times, and distribution by season for Arctic cod and saffron cod. Is Arctic cod used as a food item by other species of fish, birds, and mammals in Norton Sound? How extensively is saffron cod utilized by other species?

      Little is known about the life history, movements, and distribution of Pacific sandlance in both Norton Sound and elsewhere in their range. This species is a preferred food item for spotted seals and many seabirds (particularly kittiwakes and puffins) in Norton Sound during July and August.

      If oil were layered on the seabottom or incorporated into the sediments, what would be the effect on predatory flatfish (i.e., starry flounder, yellowfin sole)? Would there be a great reduction in numbers or reduced reproductive potential if their benthic food items were "impacted" by a spill in the late spring-early summer period?

Information on reproduction of starry flounder in Norton Sound is not known. During the 1976 demersal fish survey, no fish younger than five years old were taken. Five and six year olds were found only in inner Norton Sound, inside a line from Cape Darby to Stuart Island. What is the distribution of larvae and young starry flounder?

d. Fish — pelagic

Little information is available on life histories of the pelagic fish of the region. Temporal distributions are poorly understood.

Although life history information is available for capelin in the Atlantic, there is little information available for the Bering Sea (especially northern Bering Sea-Norton Sound) population. Areas used for spawning by capelin vary from year to year. Locations of spawning sites in Norton Sound need to be determined.

The distribution of toothed smelt in the northern Bering Sea-Norton Sound region is poorly known. Spawning sites have not been delineated. The phenology of this species is not understood and little distributional information is available although the species is known to be abundant locally in the fall.

While utilization of various fish species by predators such as other fish, birds, and mammals is assumed, the degree of dependence on specific forage fish is not well understood. Decreased availability of "critical prey species" may have major ramifications despite the presence of apparently suitable alternative prey.

e. Birds

Insufficient information is available on the distribution and abundance of seabirds by season in the western part of the basin. Preliminary work using overwater transects indicates that murres feed primarily in water under 20 fathoms, that auklets are especially abundant in the westernmost waters, and that all species fly farther to feed than reported in other regions. These distributions should be studied and related to shelf depth, and physical and biological features of the water column.

We have little information on the fall migration through the Norton Sound region. Some birds persist into November, but the locations of areas of concentration are unknown.

Distributional and seasonal data on waterfowl species are lacking, especially near St. Lawrence Island. What areas are used when by which species? More information on the overwintering of ducks in the open leads south of St. Lawrence Island is needed (see Fay and Cade, 1959).

Site intensive studies of feeding are needed at selected seabird colonies in the major oceanographic regimes. The purpose of these studies would be to confirm what prey species are utilized by seabirds at different locations and in different seasons. For example, we do not know what kittiwakes feed on in June before sandlance are available. Kittiwakes appear to catch crustacea and some small cod among the ice pans, and often they follow gray whales southwest of King Island and south of St. Lawrence Island, apparently feeding on debris brought up by the whales. They depend heavily on sandlance to feed their young, but essentially nothing is known about the other prey species on which they feed.

f. Marine mammals

Insufficient information is available on the seasonal distributions and abundance of fin, minke, humpback, and killer whales. These cetaceans are known to migrate into and feed in the Norton Basin lease area during summer months. Killer whales have been seen at several places along the edges of drifting ice pans. Little other information is available. Use of Norton Sound by harbor porpoises is also poorly documented.

III. Interdisciplinary Session D: Environmental Hazards to OCS Exploration and Development in Norton Sound, and the Status of Technologies to Cope With These Hazards

G. Keller (Chairman)
R. Combellick (Rapporteur)

With contributions from A. Allen, G. Atlas, N. Biswas, L. Brooks, P. Burbank, J. Dygas, L. Gefvert, M. Hayes, H. Jahns, J. Kravitz, J. Leendertse, R. Muench, H. Nelson, J. Overland, W. Sackinger, J. Shantz, W. Spring, W. Stringer, and R. Wright.

A. Introduction

To identify those environmental hazards most likely to impact various facilities and activities associated with OCS exploration and development, four topics were addressed as this part of the Norton Sound data synthesis: (1) identification of potential environmental hazards to facilities and/or activities necessary for petroleum exploration and development, (2) status of current technologies to cope with the potential hazards, (3) additional data needs to better define and understand hazards of the area, and (4) assessment of environmental hazards as related to different leasing scenarios. By means of comparing the potential hazards to specific facilities or activities, while at the same time assessing the technology available to cope with a particular hazard, an overall assessment was derived that pinpointed which hazards presented the greatest threat to what particular facilities or activities. Assessments were also made of the current level of knowledge pertaining to a particular hazard and whether further study of it was necessary to allow for sound management decisions. In light of leasing alternatives suggested for Norton Sound, the various environmental hazards were considered for each of the proposed scenarios in order to determine the degree of impact these hazards would have with respect to the various Norton Sound leasing options.

B. Hazards, Facilities, and Activities

As a result of the review conducted, 16 potential environmental hazards were identified which could impact OCS exploration and development in Norton Sound to varying degrees. As noted from the following list, these hazards are quite diverse:

Ice Forces (ice not reaching the bottom)
Ice Gouging (bottom-reaching ice)
Icing
Faulting
Seismicity (earthquakes)
Liquefaction
Wind and Waves
Storm Surge
Current Scour
Sediment Sheet Flow
Sand Waves
Biogenic Gas Charging
Thermogenic Gas Charging
Coastal Erosion
Permafrost
Sediment Sensitivity

Eleven man-made facilities and/or activities commonly associated with OCS exploration and development were identified as being potentially impacted by some or most of the above hazards. The following list also indicates the activity commonly associated with the respective item (E — exploration, D — development, P — production):

Jack-up Rigs (summer use only, E)
Floating Drilling Vessels (E)
Gravel Islands (E, D, P)
Logistics (work boats, barges, helicopters, etc. E, D, P)
Gravity Platforms (D, P)
Pile-Supporting Platforms (D, P)
Drilling (E, D)
Pipelines (P)
Tankers (P)
Onshore Processing Facilities (P)
Sea Terminals (P)

In order to identify the degree of impact the various hazards would have on specific facilities and/or activities, a matrix table (Table 3) was developed in which the hazards were classified according to the following criteria:

N — The phenonmenon is **not a hazard** to the facility.

L (low) — The phenomenon could result in **minor damage** if not adequately considered in the design and emplacement of a facility or the application of some activity.

M (moderate) — The phenomenon could cause **moderate damage** if not adequately considered in the design and deployment of a facility or the application of some activity. Requires moderate effort to counter the hazard.

H (high) — The phenomenon could cause **major damage** if not adequately considered in the design and deployment of a facility or the application of some activity. Requires a great degree of effort to counter the hazard.

UNK — It is **not known** to what degree the phenomenon is likely to be a hazard to a facility or activity owing to a lack of information.

1. Ice forces

   As used here, ice forces refers to shorefast ice or to floating ice which does not encounter the seafloor. Norton Sound is primarily impacted by pack ice and to a lesser extent by shorefast ice during the late fall, winter, and spring months. Ice thicknesses of one meter and flow rates of 15 to 25 km per day are commonly encountered in the area. In some areas the ice undergoes compression in response to southerly winds, which results in ridging. A major ice zone extends through the proposed lease tracts.

   - **Jack-up Rigs** — Since these rigs are to be used only during ice-free summer months, ice forces are not a problem.
   - **Gravity Platforms** — A moderate hazard level exists; ice thickness, flow velocity, and ridge keel strength should be taken into account for the design criteria.
   - **Pile-supported Platforms** — A moderate hazard level exists; the platform must be properly designed to counter the ice forces.
   - **Floating Drilling Vessel** — A moderate hazard level exists. Consideration must be given to ice thickness and flow velocity in the positioning of these vessels.
   - **Gravel Islands** — Low to moderate hazard.
   - **Pipelines** — Not a hazard, unless they are not adequately buried at and near the shoreline.
   - **Tankers** — Moderate to high hazard owing to ice thickness and flow velocity.
   - **Onshore Facilities** — Low hazard. Could be a high hazard if facilities were placed close to the shoreline where ice override onto the beach would become a hazard.
   - **Sea Terminals** — Moderate hazard.
   - **Logistics** — Moderate hazard, in that considerable concern must be given to ice conditions and flow rates.
   - **Drilling** — Ice forces are not considered to be a hazard because drilling itself would not be attempted if the drilling platform were threatened by ice forces.

2. Ice gouging

   Ice gouging is common to varying degrees in water depths of 10 to 20 m, and is particularly pronounced in the central and southwestern parts of Norton Sound. Of the 11 facilities and activities considered here, ice gouging is a hazard only to pipelines. One example of the synergistic effects of ice gouging is the removal of riprap from the base of structures, which may expose such installations to current scour.

3. Icing

   Icing conditions present a moderate hazard primarily to work boats and service vehicles. They could also present some degree of hazard to the work performed from the floating drilling vessel.

4. Faulting

   Numerous faults transect Norton Sound, many of which are exposed as scarps on the seafloor, indicating that faulting is relatively recent. At this time, little is known about the fault activity in this area.

   A very high hazard exists to any land or seafloor mounted installation placed on a fault along which movement might take place. For this reason, faulting is considered a high hazard for most of the bottom-mounted facilities because of possible disruption to the integrity of the well and displacement of the drilling string.

   For facilities such as floating drilling vessels, tankers, and work boats, which are not mounted to the seafloor, faulting is not considered to be a hazard.

5. Seismicity (earthquakes)

Based on available data, seismicity in Norton Sound is moderate, with a maximum 4.2 magnitude shock occurring in the area in the past two years. Magnitudes of 6.0 and 6.5 have been reported near the northern shoreline within the past 30 years, indicating that earthquake activity could be a significant hazard over longer periods.

For all the land or seafloor mounted installations, seismic activity is considered to be a moderate hazard. In all other cases, it is not rated as a hazard. If seismic activity is centered at an active drilling site, a severe hazard would exist as noted in regard to faulting.

6. Liquefaction

Excess pore pressure may be created in a submarine deposit causing a loss of sediment cohesion and a liquefying of the material down to depths of 10 m below the seafloor. Such a loss of strength creates a hazard in Norton Sound to varying degrees.

- **Jack-up Rigs** — Moderate hazard; however, legs of most rigs can be jetted into the sediment to a depth below that at which liquefaction appears to occur.
- **Gravity Platforms** — Moderate hazard; although the liquefiable sediments can be excavated from the site prior to installation of the platform.
- **Pile-supported Platform** — Low hazard because piles would penetrate through the liquefiable layer. The liquefied sediments could, however, lend themselves to ready erosion and thus present potential footing problems.
- **Gravel Island** — Low hazard because loading would be slow and drainage to relieve excess pore pressure would be allowed through the overlying gravel.
- **Pipelines** — High hazard owing to the loss of foundational support as a result of liquefaction.
- **Sea Terminals** — Moderate hazard since such a terminal would most likely be bottom mounted.
- **Other non-bottom mounted facilities** — Other facilities such as floating drilling vessels, tankers, and work boats would not be affected by liquefaction. Since drilling would be at much greater depths than the liquefaction zone, it would not be hampered by liquefaction.

7. Wind and waves

Available data indicate that wind and wave conditions present a moderate hazard to a majority of the facilities and activities associated with OCS development in Norton Sound.

- **Jack-up Rigs.** Low hazard due to the low wave loading characteristics of these rigs.
- **Tankers and Onshore Facilities.** Low hazard.
- **Pipelines and Drilling.** No hazard.

8. Storm surge

In Norton Sound, storm surge has been known to raise the water level up to five meters. Ice is associated with such surges during winter months. At such times the movement of ice across the shore zone may present a severe hazard to various installations located in this area. Ice associated with such surges presents a greater hazard than the movement of the water itself. Storm surge is considered a moderate hazard for all but three of the facilities and/or activities (pipelines, drilling, and logistics). In the case of work boat moorings, storm surge could present a considerable hazard if personnel are not alert.

9. Current scour

Erosion of the seafloor by bottom currents causes serious foundation problems for all bottom-mounted installations and thus is considered a high hazard for gravity platforms and pipelines, and a moderate hazard for other bottom-founded facilities such as jack-up rigs, pile-supported platforms, gravel islands, and sea terminals. Current scour is not a hazard for those facilities which are not dependent upon the seafloor for support.

10. Sediment sheet flow

Mass movement of sediment from the nearshore out into deeper water by means of a sheet flow along the bottom commonly occurs in Norton Sound, generally as a result of storm surge. The rapid downslope movement of sediment along the bottom is primarily a high hazard to pipelines because of the lateral load that would be placed on a pipeline exposed at the seafloor. Such sheet flows could be a moderate hazard to facilities near the shore owing to the rapid erosion of sediment from the nearshore area. Sheet flows do not present a hazard to any of the other facilities or activities considered here.

11. Sand waves

Migration of sizeable quantities of sand along the seafloor in the form of large waves or dunes, (up to several meters high off Port Clarence), could create foundation problems for certain bottom-mounted installations. In the immediate area of Norton Sound, sand waves thus far observed are only about 50 cm high. Such waves would present only a moderately low hazard to pipelines and no hazard to any of the other facilities or activities considered here.

12. Biogenic gas

Peats and organic-rich sediments blanketed by recent sediments underlie portions of Norton Sound, particularly off the Yukon Delta in the central part of the Sound. Decomposition of the organic materials results in high concentrations of methane gas at rather shallow depths below the seafloor. The major hazard here is that these gas-charged sediments display distinctly lower shear strength than deposits without gas. Escape of the gas often casues craters to form at the seafloor which contribute to bottom roughness and the potential for current scour.

The reduced shear strength of gas-charged sediments presents potential foundation problems for any bottom dependent facility. The hazard level is high for installations such as gravity platforms and sea terminals which depend upon the upper few meters of the seafloor for their bearing capacity. A moderate hazard level is expected in conjunction with jack-up rigs, gravel islands, and pipelines, which may in some cases gain the required bearing capacity from deposits underlying the gas-charged sediments. Gas-charged sediments are considered to be a relatively minor hazard to pile-supported platforms because the piles commonly penetrate to depths below the weakened deposits.

13. Thermogenic gas

Migration of CO_2 derived from a hydrocarbon source has resulted in the presence of highly charged gaseous sediments over a zone 9 km in diameter south of Nome. These gas-charged sediments reach to depths considerably greater than those affected by biogenic gas and also possess much greater pressures. The hazard here is similar to that found with biogenic gas but more so. The higher gas pressures and the possiblility of releasing these gases quickly presents a very serious foundation problem as well as the possibility of blow out and explosion. For this reason, such a gas-charged area presents a very high hazard to any bottom dependent facility or activity. Thermogenic gas charging is a localized problem which, when defined, can be avoided.

14. Coastal erosion

If onshore facilities are located at the interface between the land and the sea, there may be a high hazard due to coastal erosion. The hazard level is low for pipelines which must cross this zone because they are commonly trenched.

15. Permafrost

Although permafrost is found onshore, studies to date indicate a low likelihood for its existence offshore in Norton Sound. Permafrost is a minor potential hazard to buried pipelines that cross the shore zone where permafrost may exist, and is a moderate hazard to onshore facilities. It does not present a hazard to offshore facilities.

16. Sediment sensitivity

The ratio between the natural (undisturbed) sediment shear strength and the remolded (disturbed) shear strength provides an indication of the susceptibility of a deposit to lose its strength due to a disturbing force, such as a sediment shock, and is referred to as sensitivity. In an area of seismic activity, sediment sensitivity could be a major factor in defining the stability characteristics of the seafloor deposits. Although some geotechnical data are available concerning sediment sensitivity in the northern Bering Sea (Olsen et al., 1979), session participants agreed that the degree to which sediment sensitivity may present a hazard to OCS exploration and development in Norton Sound is unknown.

TABLE 3
ENVIRONMENTAL HAZARDS IN NORTON SOUND
PROPOSED OCS SALE NO. 57

HAZARD	FACILITY: JACK-UP RIGS SUMMER	GRAVITY PLATFORM	PILE SUPP PLATFORM	FLOATING DRILLING VESSEL	GRAVEL ISLAND	PIPE LINE	TANKER	ONSHORE PROC FAC.	SEA TERMINAL	LOGISTICS	DRILLING
ICE FORCES	0 N 0	1 M 1	0 M 0	0 M 1	0 L-M 0	0 N 0	0 M-H 1	1 L 0	1 M 2	0 M 0	0 N 0
ICE GOUGING	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	0 H 0	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0
STRUCTURAL ICING	0 N 0	0 N 0	0 N 0	0 L 0	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	0 M 0	0 N 0
FAULTING	1 H 0	1 H 0	1 H 0	0 N 0	1 H 0	1 H 1	0 N 0	1 H 0	1 H 0	0 N 0	0 H 0
SEISMICITY (EARTHQUAKES)	1 M 0	1 M 0	1 M 0	0 N 0	1 M 0	1 M 0	0 N 0	1 M 0	1 M 0	0 N 0	0 N 0
LIQUEFACTION OF SEDIMENT	1 M 0	1 M 1	1 L 0	0 N 0	1 L 0	1 H 1	0 N 0	0 N 0	1 M 1	0 N 0	0 N 0
WIND AND WAVES	1 L 0	1 M 0	1 M 0	1 M 0	1 M 0	0 N 0	0 L 0	0 L 0	1 M 0	1 M 0	0 N 0
STORM SURGE	1 M 0	1 M 0	1 M 0	1 M 0	1 M 0	0 N 0	1 M 0	1 M 0	1 M 0	1 N 0	0 N 0
CURRENT SCOUR	0 M 0	0 H 0	0 M 0	0 N 0	0 M 0	0 H 1	0 N 0	0 N 0	0 M 0	0 N 0	0 N 0
SHEET FLOW	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	0 H 0	0 N 0	0 M 0	0 N 0	0 N 0	0 N 0
SAND WAVES	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	0 L 0	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0
BIOGENIC GAS	1 M 0	1 H 1	1 L 0	0 N 0	1 M 1	1 M 1	0 N 0	0 N 0	1 H 1	0 N 0	0 N 0
THERMOGENIC GAS	0 H 0	0 H 0	0 H 0	0 N 0	0 H 0	0 H 0	0 N 0	0 N 0	0 H 0	0 N 0	0 H 1
COASTAL EROSION	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	0 L 0	0 N 0	0 H 0	0 N 0	0 N 0	0 N 0
PERMAFROST	0 N 0	0 N 0	0 N 0	0 N 0	0 N 0	1 L 0	0 N 0	1 M 0	0 N 0	0 N 0	0 N 0
SEDIMENT SENSITIVITY	1 UNK	1 UNK	1 UNK	1 UNK	1 UNK	1 UNK	0 N	1 UNK	1 UNK	0 N	0 N

KEY

SEVERITY OF HAZARD

N - NOT A HAZARD
L - LOW
M - MODERATE
H - HIGH
UNK - UNKNOWN

TECHNOLOGY (LOWER RIGHT)

0 - EXISTS NOW
1 - WILL BE AVAILABLE WITHIN 5 YEARS
2 - WILL BE AVAILABLE IN 5 to 10 YEARS

NEED FOR ADDITIONAL DATA (UPPER LEFT)

0 - NO FURTHER FIELD DATA NEEDED
1 - ADDITIONAL FIELD DATA NEEDED BUT NOT CRITICAL PRIOR TO LEASE SALE
2 - ADDITIONAL FIELD DATA NEEDED AND CRITICAL TO LEASE SALE

Table 3. Environmental hazards in Norton Sound, proposed OCS sale No. 57.

C. Status of Technologies to Cope with Environmental Hazards

Session members assessed the status of technologies available to cope with the hazards defined in the previous section. This assessment is noted in the lower right-hand corner for each item in the hazards-facilities matrix (Table 3) and is based on the following criteria:

- 0 Technology is presently available to cope with the hazard and has been successfully used elsewhere.
- 1 Technology is not presently available but is expected in less than five years. (short term)
- 2 Technology is not available but is expected in the next five to ten years. (long term)

1. Ice forces

   Designs for coping with ice forces are available for gravity platforms, floating drilling vessels, and tankers, but further advancement is required to address this hazard in Norton Sound. Appropriate technology is expected to be available in the short term.

   Suitable technology for sea terminals in ice is not now available. The most difficult problems are concerned with the approaching and loading of tankers. Adequate technology is expected in the next 5 to 10 years.

2. Ice gouging

   Pipelines are the only facility for which ice gouging is identified as a hazard. Technologies are available to trench pipelines below the one to two meter depth commonly gouged by ice in Norton Sound.

3. Icing

   Technologies and common operational procedures are available for coping with icing conditions.

4. Faulting

   Faulting hazards can be eliminated from consideration by locating a facility far from any known locations of active faults. Since pipelines will have to cross faults in Norton Sound to reach any shore facility, this hazard cannot be totally avoided. Technologies capable of addressing the problem of placing pipelines across active faults are expected in less than five years.

5. Seismicity

   Technologies are available, and in use, for coping with the moderate levels of earthquake-caused ground motion equivalent to that expected in Norton Sound.

6. Liquefaction

   The technology and procedures for placement of most installations on the seafloor are such that the hazard from liquefaction is largely eliminated. In those cases where bottom installations are dependent on the upper few meters of the seafloor for the required bearing capacity, technologies to cope with liquefaction are not adequately developed but are expected to be available in the near future.

7. Wind and waves

   Technologies are availabe and in use for coping with most of the wind and wave conditions expected in Norton Sound. Under the very few severe conditions that cannot be handled by existing technology, the operation would normally be shut down until conditions improve.

8. Storm surge

   Although sufficient information on storm surges does not presently exist for adequate documentation of the severity of this hazard in Norton Sound, session participants agreed that current technology is availabe to cope with whatever surge levels may occur in the area.

9. Current scour

   Present technology is capable of coping with potential current scour problems for the various facilities and activities being considered for Norton Sound. Technologies to counter the impact of current scour on pipelines may be lacking at this time; needed technology cannot be ascertained until more is known about the ability of currents to scour deeper where trenching has taken place. The assumption is that, should there be a lack of appropriate technology, it would be available in a relatively short time.

10. Sediment sheet flow

    Current technology is available to address this problem.

11. Sand waves

    Present technology can deal with sand waves of the scale reported in Norton Sound.

12. Biogenic gas

    Available technologies for exploration and development of Norton Sound can handle the potential hazards attributed to shallow methane gas occurrences. In those cases (gravity platform, gravel island, pipelines, and sea terminals) where an installation is dependent to some degree on the foundational characteristics of the upper few meters of the seafloor (gas-charged zone) for its stability, there is a need for improved technology. Advanced technology may also be needed for jack-up rigs in close proximity to the Yukon Delta; here gas-charged sediments may occur at depths greater than jack-up rigs are capable of jetting. In all these cases, technologies are expected to be available in less than five years.

13. Thermogenic gas

    Drilling operations can be placed a safe distance away from the localized occurrence of thermogenic gas. However, the possibility of a blow-out during drilling does exist, and although technologies are available to address such a problem, there is a need for improvement. This is anticipated in less than five years.

14. Coastal erosion

    Available technologies can cope with this potential problem.

15. Permafrost

    Present technologies are capable of countering potential problems in this area.

16. Sediment sensitivity

    Sufficient data are not presently available to evaluate the severity of this problem; therefore, the ability of current technologies to cope with potential sensitivity problems cannot be assessed.

D. Additional Data Needs to Address Environmental Hazards in Norton Sound

Participants considered the present state of knowledge upon which documentation of the possible severity of environmental hazards in Norton Sound is based. A rating scale of 0 to 2 was used (upper left-hand corner in hazard-facilities matrix) based on the following criteria: (a) sufficient data are available to define the hazard — 0, (b) additional data are needed to better define the hazards, but they are not critical to the lease scale — 1, (c) additional data are critical to define the hazards prior to the lease sale — 2.

1. Ice forces

    Additional information is needed regarding the velocity of ice movement, ice thickness distribution, and the movement of ice up onto shore. Although not critical to the lease sale, these additional data are needed to address potential ice hazards in respect to gravity platforms, sea terminals, and onshore facilities.

2. Ice gouging

    Sufficient data are available.

3. Icing

    Adequate data are available.

4. Faulting

    Although considerable data exist on the location of faults, additional definition of the fault system(s) in Norton Sound is necessary. This can probably be attained from further study of existing data. Of greater need is the documentation of fault activity bacause little or no information is available about how active the faults are. Data are required to determine whether there has been recent movement along the faults or if they are inactive. This need for information is important but not critical to the lease sale because the potential hazard can be defined and coped with prior to drilling.

5. Seismicity

    The data base for defining the magnitude and frequency of seismic events is not sufficiently developed to adequately document the potential earthquake hazard. Although ground acceleration associated with seismic events does not appear to be a particular problem for seafloor-mounted facilities, seismic data are needed to assess the severity and frequency with which sediment sensitivity and liquefaction may be impacted by seismic events. Seismicity studies are also particularly relevant to the evaluation of fault activity.

6. Liquefaction

   The availabe geotechnical data appear inadequate to evaluate the liquefaction problem in Norton Sound. Additional geotechnical studies on high grade sediment cores should be undertaken as should in-place pore pressure measurements.

7. Wind and waves

   Adequate information is not available for Norton Sound to predict the various limits expected from this hazard. Better weather forecasting will be required in the Norton Sound area.

8. Storm surge

   Sufficient information on storm surge does not exist for the adequate documentation of the severity of this potential hazard in Norton Sound.

9. Current scour, sediment sheet flow, and sand waves

   Sufficient data exist to define the extent, distribution, and frequency of these processes which impact various facilities placed on the seafloor.

10. Biogenic gas

    Additional data are needed to better define the depth and occurrence of gas-charged sediments. The gas-charged zone may be considerably deeper in the vicinity of the Yukon Delta relative to other parts of Norton Sound. This in turn may create hazards not evident from the shallow occurrences of gas-charged sediments reported thus far. A much better understanding of the effects which gas-charging has on the substrate's geotechnical properties is critical to defining the foundational characteristics of these deposits.

11. Thermogenic gas

    Adequate data are available to define the location and extent of thermogenic gas accumulation.

12. Coastal erosion

    Sufficient data are available to document this potential hazard.

13. Permafrost

    Additional data are required to define the distribution of onshore permafrost relative to possible pipeline crossings of the shore zone and for the design of onshore facilities.

14. Soil sensitivity

    The geotechnical data base for Norton Sound is inadequate to determine the potential hazards due to the sensitivity (degree of strength loss due to shock or disturbance) of the seafloor deposits. Additional study is needed, but it is not critical to the lease sale.

E. Hazard Impact Relative to Proposed Lease Tract Options

The widespread distribution of the identified environmental hazards throughout Norton Sound indicates that relatively few can be totally eliminated by merely deleting various groups of tracts from the sale. (See Fig. 23)

Alternative 1 (Northern tracts). Thermogenic gas problems as related to offshore platforms and drilling activity would be totally eliminated by removal of northern tracts. This hazard would still need to be considered insofar as future pipeline routes to Nome. The biogenic gas hazard, based on the known distribution of gas-charging, would be largely removed if this portion were dropped from the sale.

Alternative 2 (Eastern tracts). Deletion of the eastern portion of the lease tract would eliminate the biogenic gas hazard based on the present understanding of the distribution of gas-charged sediments.

Alternative 3 (Southern tract). Elimination of the southern tract does not eliminate any one of the environmental hazards from consideration; however, deletion of this portion of the tract would eliminate most of the severe problems due to ice gouging, current scouring, and intense storm surge activity.

In general, the most severe combination of hazards exists in the southern and southwestern sectors of the lease area; whereas, the hazards in the northern half are less severe or can be dealt with more easily.

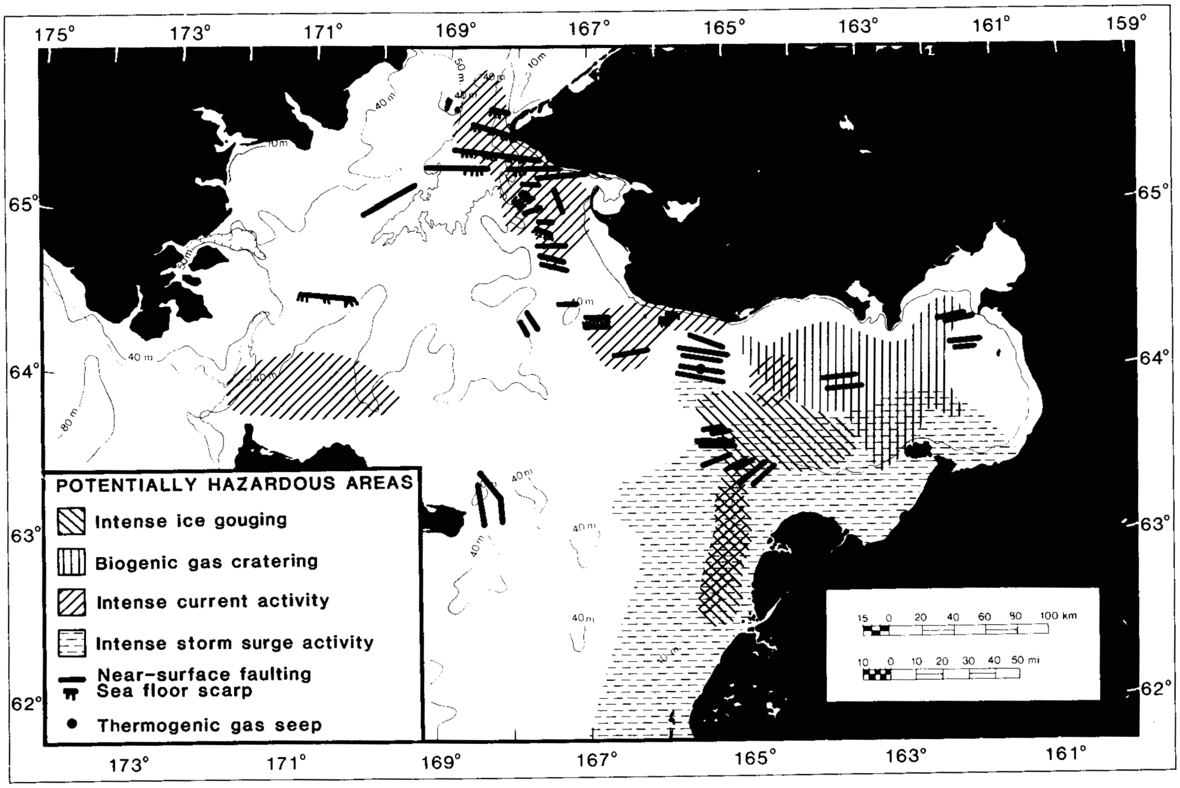


Figure 23. Potentially hazardous areas of the northern Bering Sea (Thor and Nelson, 1981).

F. Summary of Hazard Impact on Norton Sound Exploration and Development

Based on the material presented here and that summarized in Table 3, the following generalizations appear to reflect the severity of various hazards in relation to facilities and/or activities necessary for petroleum exploration and development in Norton Sound.

- Hazards which present the greatest problem areas due to inadequate technologies or data, in order of severity:
  1. Ice forces
  2. Biogenic gas charging
  3. Liquefaction
- Hazards that least impact OCS development and/or can be handled with existing technology, in order of decreasing impact:
  1. Permafrost
  2. Coastal erosion
  3. Icing
  4. Ice gouging
  5. Sediment sheet flow
  6. Sand waves
- Facilities and/or activities most severely impacted by environmental hazards:
  1. Pipelines
- Facilities and/or activities least impacted by hazards, in order of decreasing impact:
  1. Jack-up rigs
  2. Onshore processing facilities
  3. Floating drilling vessel
  4. Tankers
  5. Logistics (work boats, helicopters)
  6. Drilling

G. Conclusions

An analysis of environmental hazards to petroleum exploration and development activities in Norton Sound reveals that 16 such hazards may constitute potential problems for a number of the facilities and activities needed for such an effort in Norton Sound. Of the 16, faulting activity and thermogenic gas-charged sediments present the greatest hazards. Fortunately, once both are located and the degree of activity defined, procedures can be developed to mitigate these hazards. In light of the capabilities of presently available technologies, three environmental hazards exist that could present severe problems to facilities and activities associated with the Norton Sound development: ice forces, biogenic gas-charged sediments, and liquefaction of seafloor deposits. Indications are that technologies will be forthcoming in the next five years to render these as non-hazards. Until then, however, these hazards must receive serious consideration.

Of the facilities and/or activities proposed for Norton Sound, pipelines are most vulnerable to impact from the greatest number of hazards. In most cases, the hazard can be overcome by available technologies and the remainder are expected to be addressed by technologies which would be developed in less than five years.

In considering the 16 hazards versus the 11 facilities and/or activities necessary for exploration and development in Norton Sound, it was found that in the majority of the cases (92 percent) present technologies are available to cope with the respective hazard and in 7 percent of the cases adequate technologies should be available in less than five years. In only one case, ice forces on sea terminals, will the technologies needed to address this problem require more than five years to develop.

Although extensive studies have been made to identify and document the environmental hazards, this review clearly reveals that inadequacies exist in the available data to provide sufficient information to effectively delimit a number of the environmental hazards relevant to Norton Sound.

Data are particularly lacking in regard to the following hazards:

Faulting (activity)
Seismicity
Liquefaction
Wind and waves
Storm surge
Biogenic gas charging
Sediment sensitivity

Although a number of studies have dealt with the geotechnical properties of the bottom sediments, efforts designed specifically to address their liquefaction and sensitivity properties are needed to define the stability characteristics of the seafloor.

Owing to the large number and distribution of environmental hazards identified in Norton Sound, it is not possible to eliminate all the hazards by deletion of any particular portion of the proposed lease area. Exclusion of the southern half of the area would, however, probably eliminate the greatest number of hazards from consideration.

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