Hydrocarbon Development In The Beaufort Sea - Mackenzie Delta Region

ENVIRONMENTAL IMPACT STATEMENT
1982

VOLUME 3A BEAUFORT-DELTA SETTING

ENVIRONMENTAL IMPACT STATEMENT

FOR

HYDROCARBON DEVELOPMENT

IN THE

BEAUFORT SEA - MACKENZIE DELTA REGION

VOLUME 3A
BEAUFORT SEA-DELTA SETTING

1982

BEAUFORT SEA-MACKENZIE DELTA ENVIRONMENTAL IMPACT STATEMENT

The Beaufort Sea Production Environmental Impact Statement
was prepared by
Dome Petroleum Limited,
Esso Resources Canada Limited
and
Gulf Canada Resources Inc.
on behalf of all land-holders in the
Beaufort Sea-Mackenzie Delta region.

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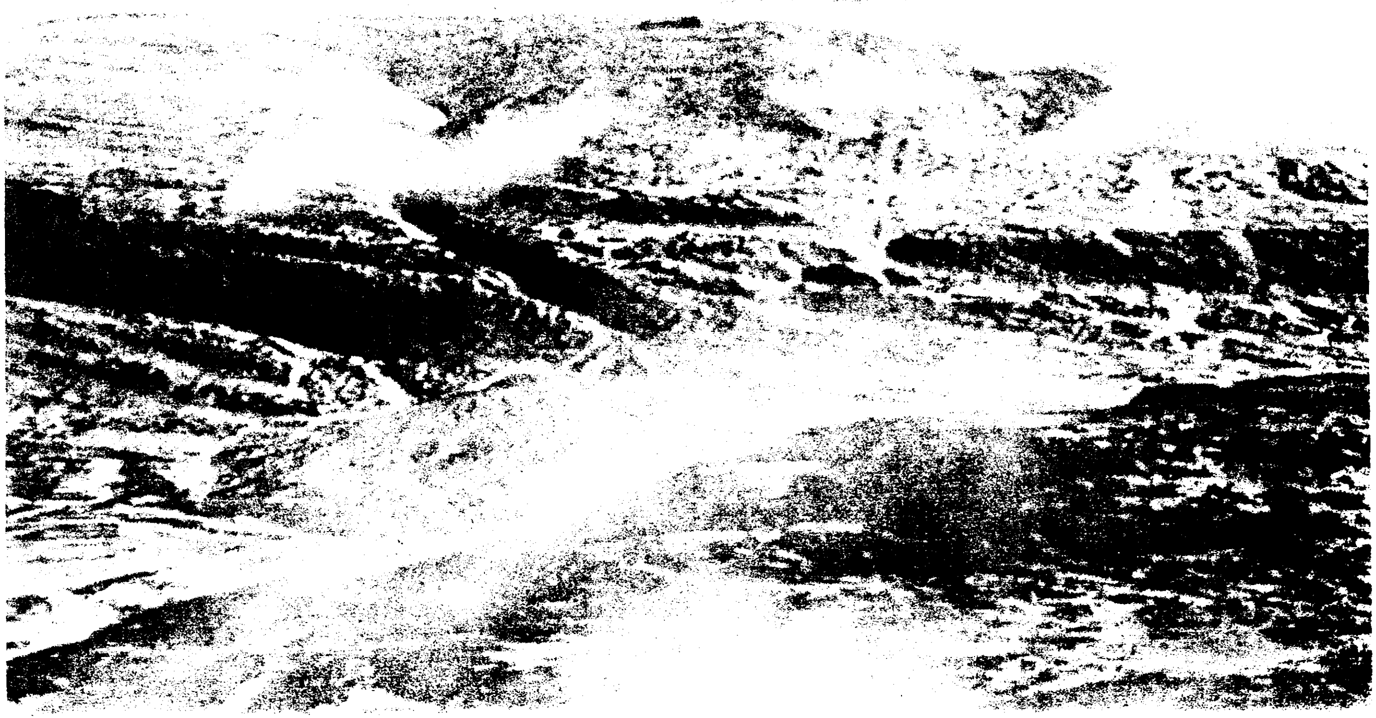

ENVIRONMENTAL IMPACT STATEMENT

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INTRODUCTION

Volume 3 of the Environmental Impact Statement provides the environmental setting for those parts of northern Canada which may be influenced by or which may impact upon the hydrocarbon production and transportation activities described in Volume 2. Emphasis has been placed on those subjects deemed to be most relevant for the purposes of assessing possible impacts on the environment (Volume 4) and for addressing socio-economic issues (Volume 5). The information has also been used to evaluate the potential impacts of hypothetical major oil spills (Volume 6), and to develop future research and monitoring proposals (Volume 7).

In accordance with the EARP guidelines, the information presented has been summarized as much as practical, while recognizing the importance of providing sufficient information to permit a satisfactory evaluation to be completed. Nevertheless the geographic area covered by the submission, and the available information are so extensive that it was necessary to divide the material into three subvolumes.

Volume 3A generally covers the marine region extending from the Bering Strait in the west, through the Beaufort Sea to Amundsen Gulf in the east, and the onshore coastal area from the Yukon-Alaska border, through the Mackenzie Delta to Cape Parry (Figure 1). Volume 3B describes the marine region of the Northwest Passage from Banks Island on the eastern side of the Beaufort Sea through Viscount Melville Sound, Lancaster Sound, Baffin Bay and Davis Strait, to 60° north latitude in the Labrador Sea. Volume 3C broadly describes the terrestrial environment along the Mackenzie Valley from the Delta in the north to the British Columbia-Alberta Border in the south. In all volumes, where it was appropriate to enlarge the region covered; e.g. to discuss weather patterns, or the migration habits of animal species, the region was extended.

For additional information the reader is referred to various supporting documents to the Environment Impact Statement as well as the literature cited in the text.

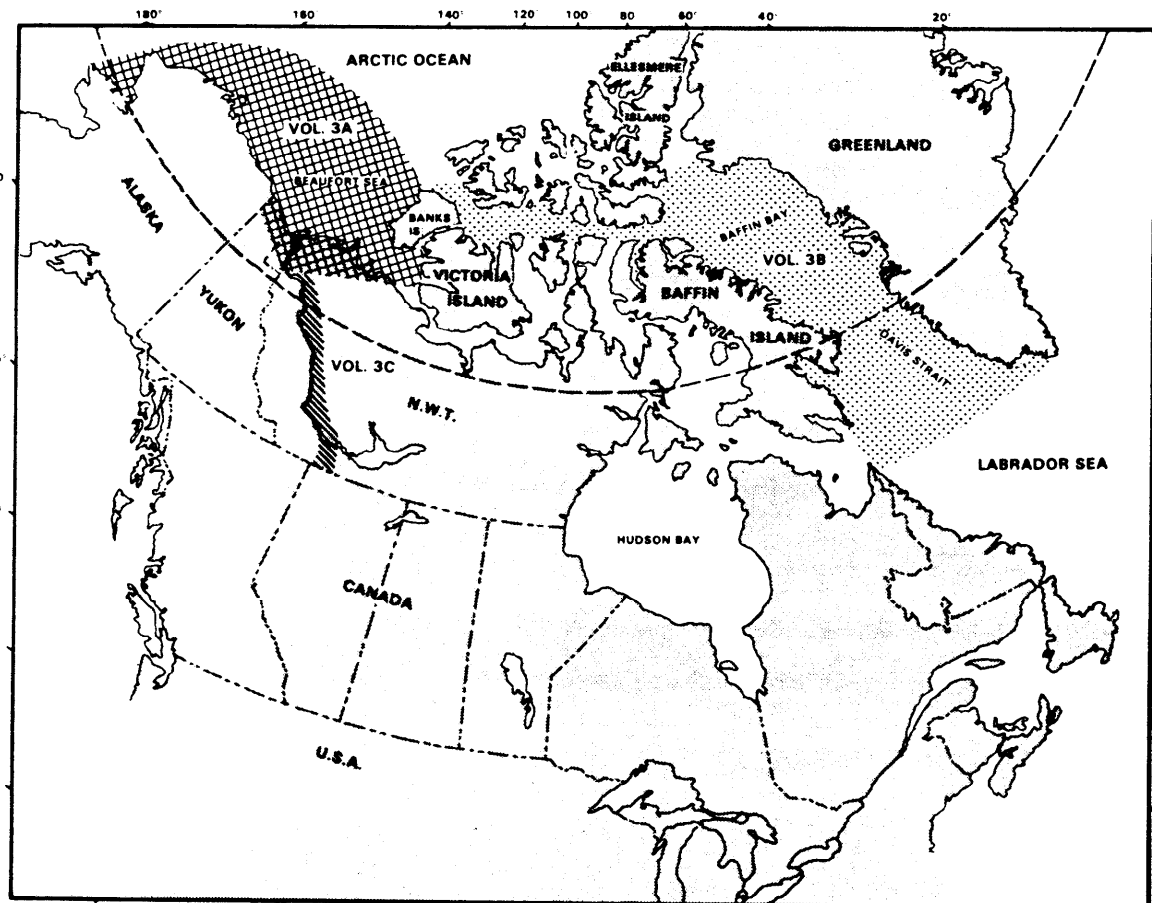


FIGURE 1 *Approximate boundaries of the three geographic regions described in the Environmental Setting, Volumes 3A, 3B and 3C.*

Volume 3A was prepared by the proponents with the assistance of several environmental consulting firms. Major external contributors included:

ESL Environmental Services Limited —
Atmospheric Environment
Arctic Marine Food Webs
Marine Mammals
Birds (marine)
Fish (marine)
Lower Trophic Levels (marine)
Resource Use (marine)
Special Areas (marine)
General Editing

R.M. Hardy and Associates Ltd. —
Geology
Soils
Hydrology
Vegetation

McCourt Management Ltd. —
Terrestrial Mammals
Resource Use (Terrestrial)

LGL Limited —
Birds (Terrestrial)
Marine Mammals

Aquatic Environments Limited —
Fish (fresh water)
Lower Trophic Levels (fresh water)

Arctic Sciences Limited —
Water Masses and Their Movements

Meteorological and Environmental Planning Ltd. —
Surface Weather and Wind Waves

Arctic Laboratories Limited —
Chemical Oceanography

Woodward-Clyde Consultants —
The Shores
The Sea Bottom

M.J. O'Connor and Associates Limited —
The Sea Bottom

In-house expertise and project co-ordination was provided by scientists and specialists from Dome Petroleum Limited, Esso Resources Canada Limited and Gulf Canada Resources Inc.

CHAPTER 1 MARINE PHYSICAL ENVIRONMENT

The following sections summarize existing information on the physical environment of the offshore marine region which extends from Amundsen Gulf in the east through to the Bering Sea in the west (Figure 1-1). Primary emphasis is placed on the area encompassed by the Canadian Beaufort Sea because of its particular relevance to proposed offshore hydrocarbon developments. This region also includes the Arctic portion of the western shipping corridor and the beginning of the transportation corridor to the east. Volume 3B describes the remainder of the eastern shipping corridor through the Northwest Passage.

Separate sections review ice conditions, surface weather and wind waves, water masses and their movements, the characteristics of the sea bottom, the chemical oceanography of the waters in the region, and finally the shoreline character of the coastal zone. Additional information is available in various supporting documents to the Environmental Impact Statement as well as the literature cited in the text.

1.1 ICE ENVIRONMENT

The primary environmental constraint affecting offshore operations in the Beaufort-Chukchi region is sea ice. For eight to nine months each year (October through July) ice of varying thickness covers most of the region. An ice-free corridor only develops along the coast during the summer months. Sea ice conditions in the southeastern Beaufort Sea production region are discussed in the greatest detail, while conditions in the Chukchi-Alaskan Beaufort Sea and Amundsen Gulf are discussed primarily in relation to their potential as shipping corridors.

1.1.1 ICE ZONES

The yearly winter ice cover of the southern Beaufort Sea can be subdivided into three zones, namely, the landfast zone, the seasonal ice or transition zone and

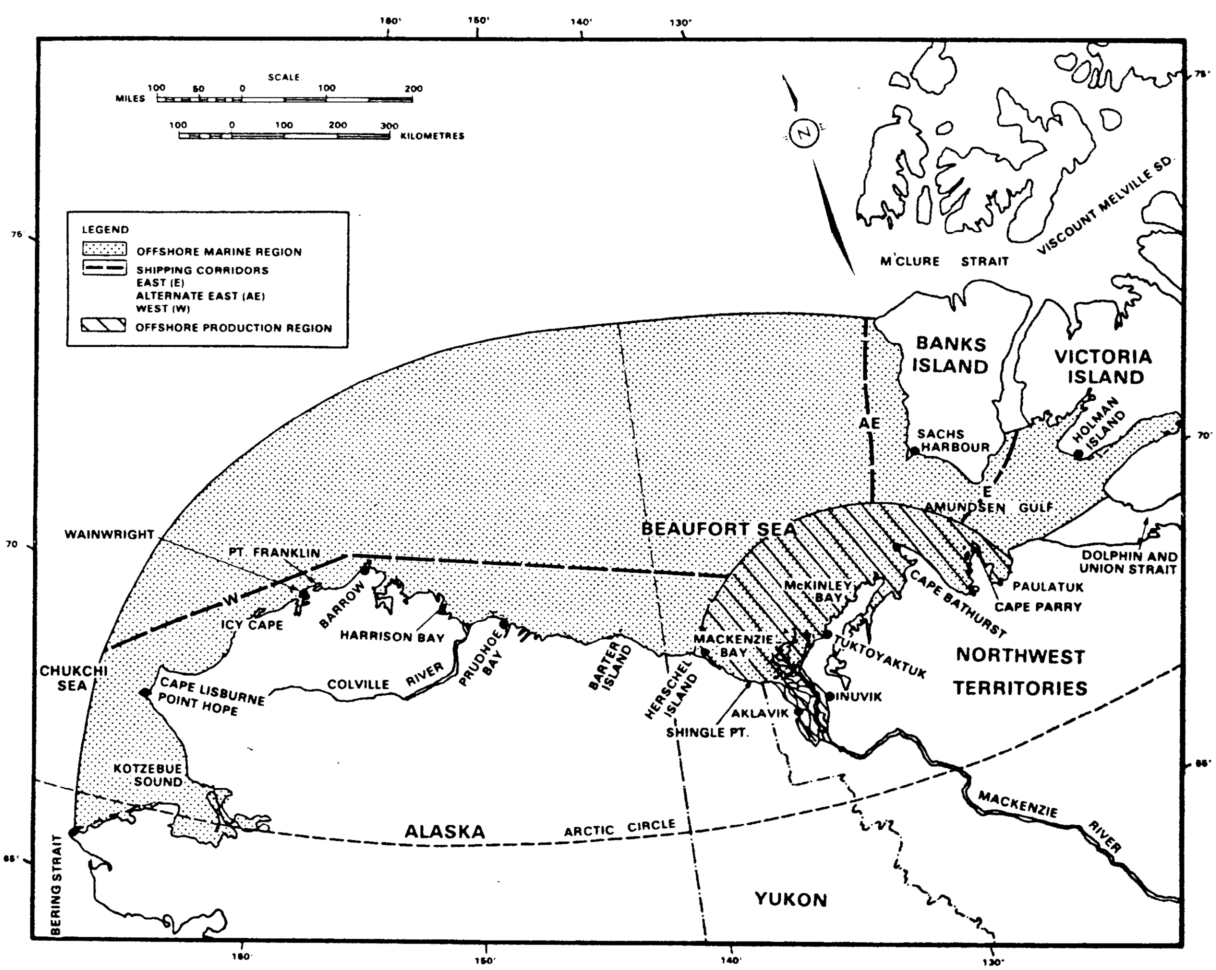


FIGURE 1-1 *Approximate boundary of the offshore marine region described in Volume 3A. Emphasis is placed on the offshore production region in the Canadian Beaufort Sea.*

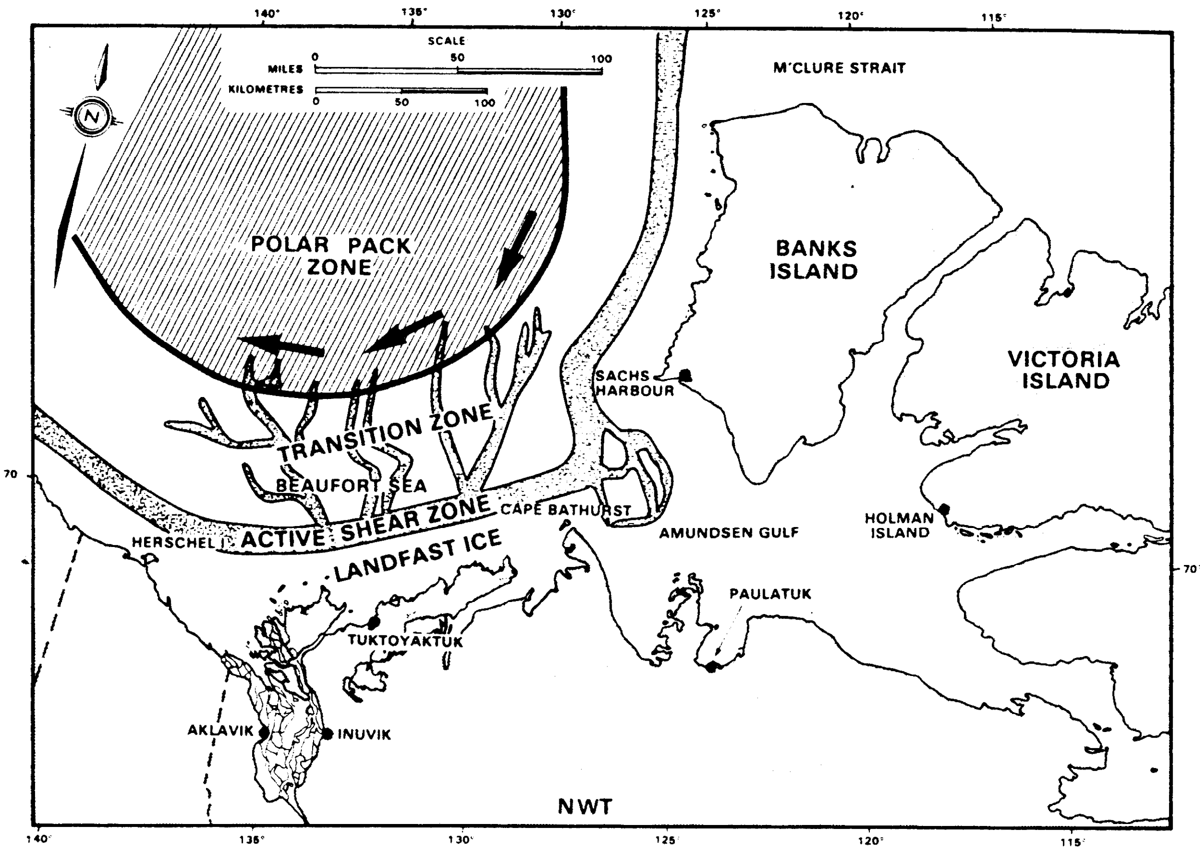


FIGURE 1.1-1 *Winter ice zones of the Southern Beaufort Sea. Most recent exploratory drilling is taking place seaward of the landfast ice zone. (Source: Kovacs and Mellor, 1974).*

the polar pack zone (Kovacs and Mellor, 1974) (Figure 1.1-1).

1.1.1.1 Landfast Ice Zone

The landfast ice zone lies adjacent to the coast where motion is inhibited by attachment to the shore.

Starting in late September or October, the ice advances out from shore to about the 20 m depth contour over the continental shelf. The maximum winter extent of the landfast ice zone is generally reached between mid November and early March. The ice grows throughout the winter, reaching a maximum thickness of approximately 2 m by late April (Figure 1.1-2). Break-up and clearance of ice from the shorefast zone usually begins in May. A generally ice-free open water corridor exists along the coast from July through to the formation of new ice at the beginning of October.

Although the ice cover of this zone is normally composed of first year ice, in some years, multi-year ice may become incorporated into the ice sheet. For example, in 1974, multi-year ice from the polar pack

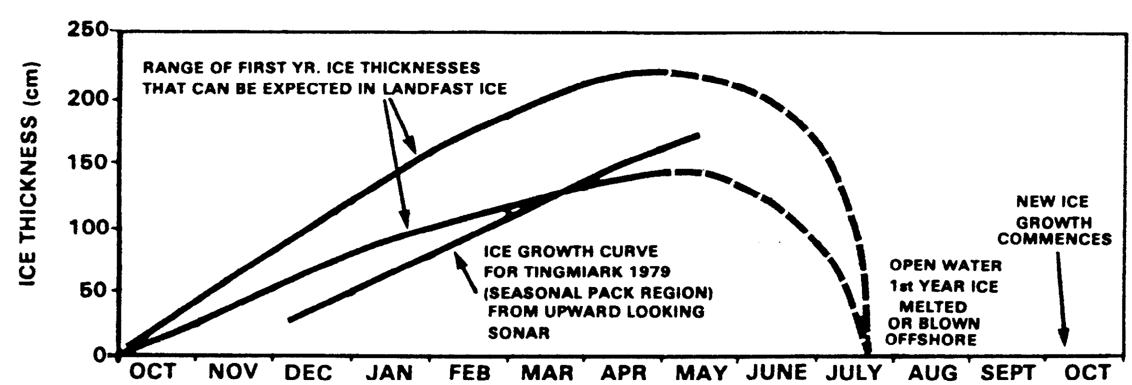


FIGURE 1.1-2 *First year ice thickness growth curves in the Southeastern Beaufort Sea. (Adapted from Hoare, 1981).*

was driven into coastal waters by predominantly onshore winds, and grounded floes became trapped in new ice for the winter (Ramseier et al., 1975). This is likely to occur once every five years (Spedding, 1978).

Landfast ice in the Mackenzie Delta region and off the coast of Alaska can be subdivided into three characteristic zones (Figure 1.1-3) (Spedding, 1974). The "bottom fast ice" grows outward from shore to around the 2 m water depth, where a tidal ridge marks its junction with the "floating ice sheet." The floating ice zone extends out to the 13 m water depth, beyond which is a zone of heavily ridged ice which has been termed the "grounded ice zone," since many of the ridges are grounded (Gladwell, 1976a).

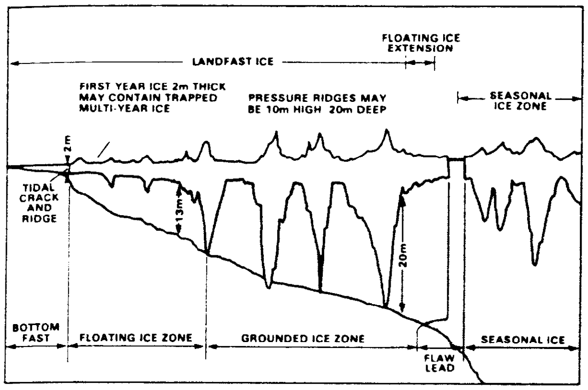


FIGURE 1.1-3 *Schematic cross-section of landfast ice showing zonation. Grounded ridge-keels minimize movement in winter. (Adapted from Gladwell, 1976a).*

Generally smooth, featureless ice is found up to the 5 m water depth, although tidal ridges may also be present. In the floating ice zone, piles of ice known as "pressure ridges" are encountered (Plate 1.1-1). These ridges are generated when ice sheets are crushed together under the influence of winds and currents. The frequency of these ridges increases with distance from shore, reaching frequencies greater than 12 ridges/km in the grounded zone (Spedding, 1979). A region of continuous ridging or hummock fields may often be present at the outer edge of the grounded zone (Plate 1.1-2). The term "hummock field" is used to describe a series of parallel ridges formed along the landfast edge by the crushing of thinner ice against the thicker landfast ice. The majority of pressure ridges in the landfast ice are between 0.75 and 1.5 m in height (Gladwell, 1976b), although along the extremities of the landfast zone, ridges with sail heights in excess of 10 m have been observed. While ridge heights generally increase with distance from shore, ridges with sail heights in the 3 to 4.5 m range can be present in water depths of 10 m

PLATE 1.1-1 *Typical first year pressure ridge encountered in the landfast and seasonal ice zones of the Southern Beaufort Sea.*

PLATE 1.1-2 *Typical ice conditions at the landfast ice edge. Heavy ridging, hummock fields and a flaw lead are often present along the landfast ice edge.*

and less (Spedding, 1979). With the exception of the extremities of the landfast edge, ridges in the landfast ice are formed during the growth and stabilization period in the early winter. In both the floating and grounded ice zones, the majority of the ridge systems tend to parallel the shore. As indicated in Figure 1.1-4, which shows a cross-section of a grounded ridge, the grounded ice provides anchor points that stabilize the ice sheet. Once the landfast ice reaches its maximum extent, it changes little until break-up commences, even though flaw leads may be present along the extremities throughout the winter. Changes at the extremities are usually due to the "calving" of the thinner ice extensions that are not anchored by grounded ridges. While the 20 m water depth contour tends to mark the seaward limit of the landfast ice variations in the location of the outer edge do occur from year to year (Figures 1.1-5a and 1.1-5b).

As a result of its attachment to the land and the presence of grounded pressure ridges within the ice sheet, movement of the landfast ice throughout the winter is only in the order of metres compared to the tens of kilometres by the polar and seasonal pack ice (Croasdale and Spedding, 1972; Spedding, 1975). Single displacement events of up to 100 m have been recorded, but the majority of the events are less than 1.5 m. Over the entire winter, net displacements of the landfast ice are generally less than 10 metres.

1.1.1.2 Seasonal Ice Zone

The seasonal ice zone extends from the landfast ice edge to the polar pack ice. It is a transition zone between the essentially non-moving landfast ice and the polar pack ice. Due to northerly and southerly movements of the pack edge, the width of the zone varies from a few kilometres up to 300 km both during a season and from year to year (Spedding, 1978). The width of this zone also varies with geographic location. For example, it is normally wider in the Canadian Beaufort than off Alaska where the polar ice boundary runs closer to shore. Although the seasonal (transition) ice zone is generally composed of first year ice, it may contain varying concentrations of multi-year ice.

The ice in this zone is highly dynamic and ice movement can be expected throughout the winter (Marko, 1975; Norcor Engineering, 1976; McGonigal and Wright, 1977; McGonigal, 1978). Studies conducted to date indicate that mean ice speeds in the seasonal ice zone range between 3.0 and 13.0 km/day through-

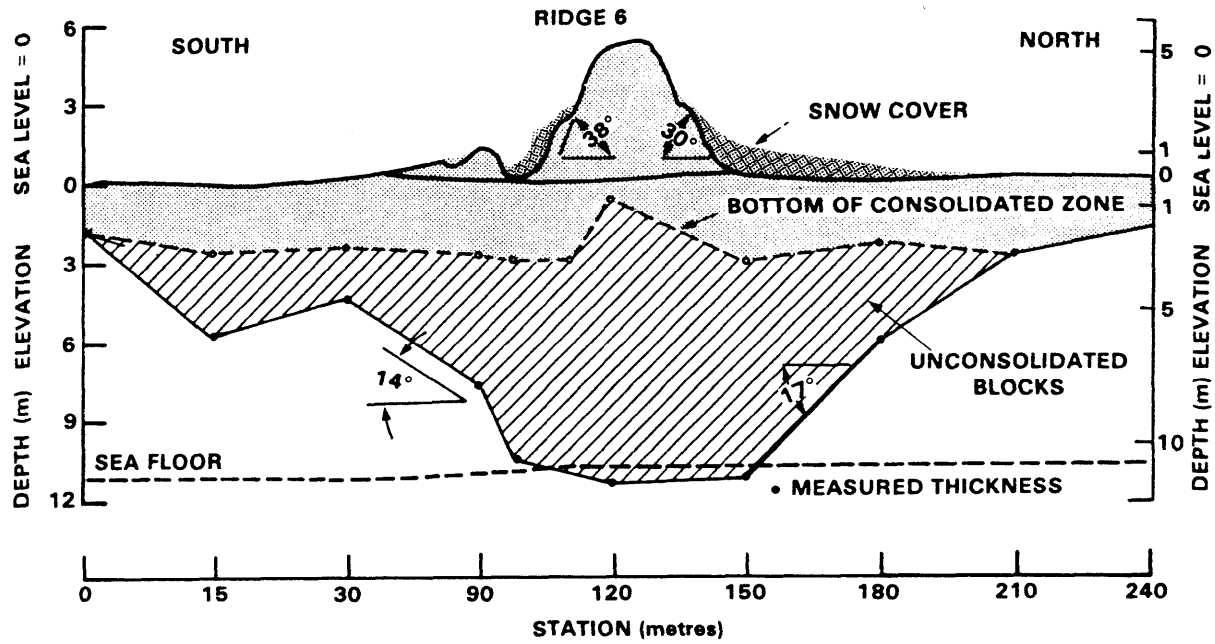


FIGURE 1.1-4 *Cross-section of a grounded first year ice ridge in the landfast ice zone. Grounded ridges within the landfast ice stabilize its seaward extent during the winter which is generally over the 20 m depth contour. (Source: Gladwell, 1976b).*

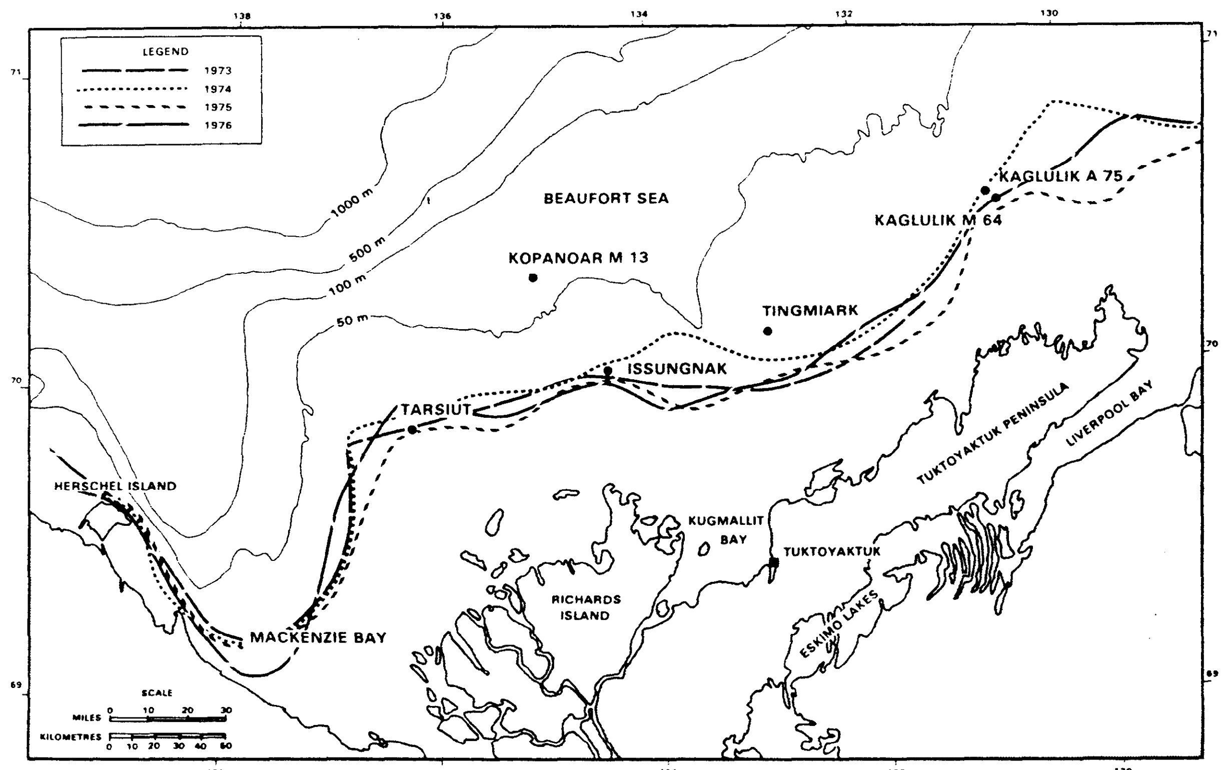


FIGURE 1.1-5a *Maximum extents of landfast ice in the southeastern Beaufort Sea in late winter (1973-1976). Landfast ice generally extends to over the 20 m depth contour. (Source: Spedding, 1979).*

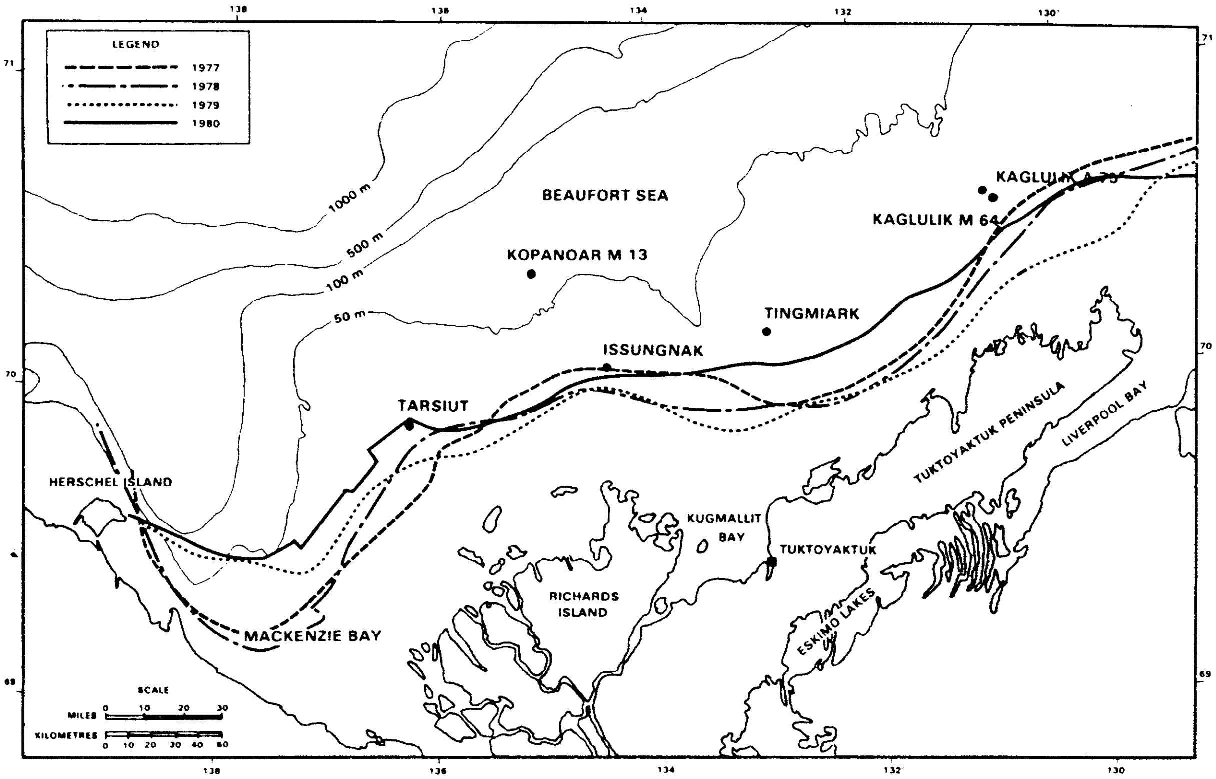


FIGURE 1.1-5b *Maximum extents of landfast ice in the Southeastern Beaufort Sea in late winter (1977-1980). (Source: Spedding, 1979).*

out the year (Figure 1.1-6). However, in the Mackenzie Delta region, movements can be in excess of 30 km/day. The least amount of daily motion generally occurs in March, while the maximum movement is found during the fall months. Net ice displacement in the seasonal (transition) zone is from east to west; however, the drift pattern tends to be random over short time intervals.

As a result of the dynamic conditions that prevail in the seasonal ice zone, deformation and ridge building processes continue throughout the winter (Spedding, 1979), and areas of thin ice may be present, particularly along the landfast ice edge. In this area, an active shear zone exists where flaw leads open and close under the influence of offshore and onshore winds, respectively. During some winters this zone of thin ice may be 50 km or greater in width. In the southeastern Beaufort Sea it may extend westwards from Cape Bathurst along the landfast ice extremities to Herschel Island.

The recurring flaw lead along the extremities can be expected with easterly winds. In the Cape Bathurst area this recurring flaw lead can be very large and is known as the Cape Bathurst Polynya. A polynya is an open water or thin ice area surrounded by thicker ice. In many winters such a region may be formed or persist at the entrance of Amundsen Gulf north of

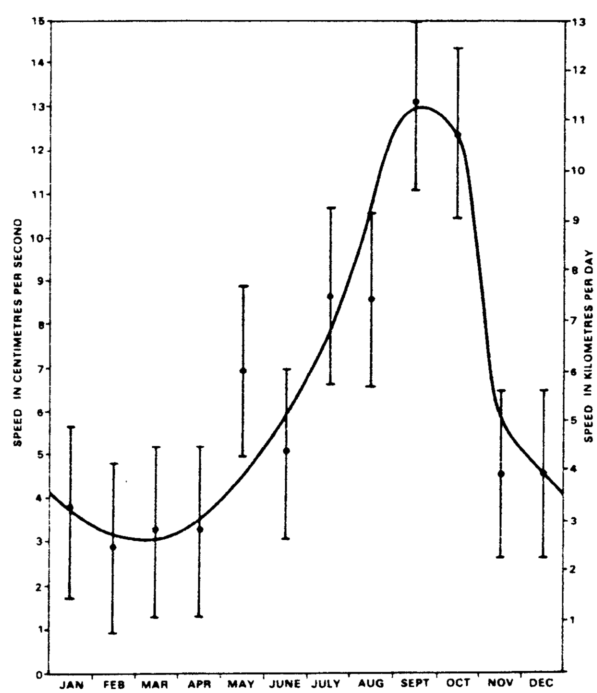


FIGURE 1.1.6 *Mean drift speeds of pack ice in the seasonal ice zone (from RAMS Buoy Data. 1975-1978). Drift speeds are least in February and March. (Sources: McGonigal, 1978; McGonigal and Wright, 1977).*

Cape Bathurst. Studies tend to support the observation that winds are the major cause of such features in the Beaufort (Marko, 1975).

The occurrence of the flaw leads and significant areas of thin ice have an important effect on operations. For instance vessels have thinner ice to travel through and forces exerted on structures by moving ice will be lower. Figure 1.1-2 shows that ice thicknesses in 1979 at the Tingmiark site which is located in the seasonal ice zone, are much less than those in the landfast ice.

Pressure ridges are masses of jumbled ice blocks, ranging in height from less than 1 m to over 10 m (Plate 1.1-1 and Figure 1.1-4). Like icebergs, the greatest proportion of a pressure ridge is underwater. For new or first year ridges, the sail height to keel depth ratio is about 1:4.2 (eg. a 1 m high ridge has a depth of 4.2 m). If the ridge survives the summer, it becomes smoother, its core consolidates, and it becomes a "multi-year ridge."

While first year ridges may be formidable, they are relatively weak when compared to multi-year ridges. A layer of reconsolidated ice generally occurs below the sail of a first year ridge, but the major portion of the keel below this layer consists of unconsolidated slushy blocks (Figure 1.1-4). Multi-year ridges are structurally stronger because voids between the blocks become filled with meltwater which freezes and cements the blocks together into a homogeneous mass of ice.

The number of ridges increases rapidly during the early part of November and December. After February the number of ridges seem to remain constant although local variations in ridging intensity occur with geographic location, season and year, depending on ice and meteorological conditions. This variability is particularly evident along the landfast ice extremities. Ridging can be extensive when onshore winds compress the seasonal (transition zone) ice against the thicker landfast ice, while light ridging occurs during periods of offshore winds. Under the latter circumstances, flaw leads are produced. During some winters, a zone of this ice 50 km wide or greater may exist along the outer edge of the landfast ice zone. Figure 1.1-7 shows the probability of encountering first year ice ridges during the winter, based on an analysis of aerial photographs by Wright and Schwab (1979). This figure indicates that only 1 ridge in 1,000 is likely to be higher than 5 metres.

1.1.1.3 Polar Ice Zone

The polar ice zone refers to the permanent multi-year ice covered regions of the Beaufort Sea and Central Arctic Basin. This central mass of multi-year ice which has survived numerous summers, slowly circulates in a clockwise direction throughout the year in the Beaufort Gyre. During the winter, this multi-year ice is surrounded by a matrix of first year ice. In the summer, melting along the pack edge allows the ice to loosen, and open water areas develop around the floes.

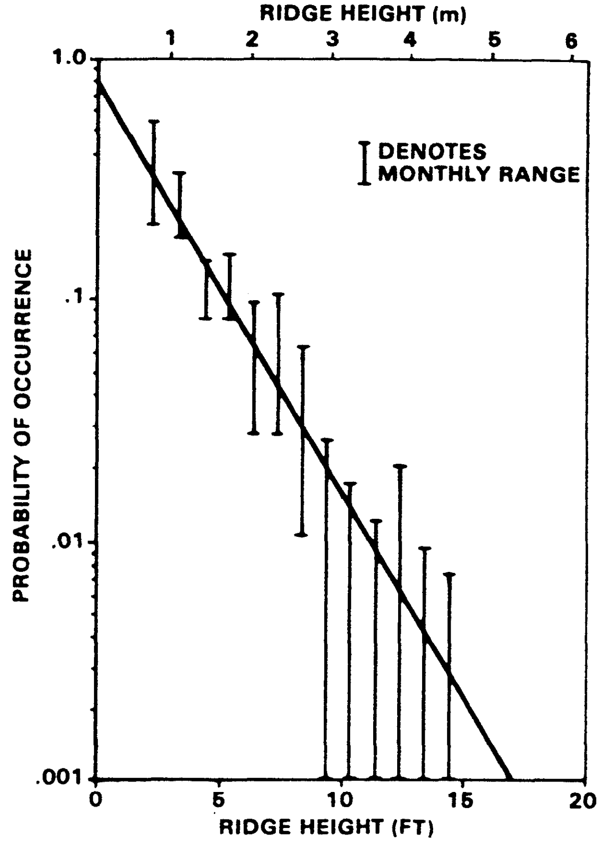


FIGURE 1.1-7 *Probability of finding first year ridges of a given height in the seasonal ice zone in winter (1973-1979) based on Wright and Schwab (1979). The seasonal ice zone can be 50 km wide or greater in some winters. This figure shows that only 1 ridge in 1,000 is likely to be higher than 5 m in the zone.*

The predominant driving force of the Gyre is the atmospheric high pressure system situated over the Beaufort Sea (Section 1.2). Investigations conducted to date indicate that the mean drift speed of ice near the edge of the Gyre is approximately 2 km/day, although this varies considerably in response to prevailing wind patterns (Markham, 1981; Thorndike and Cheung, 1977; Thorndike and Colony, 1977).

The centre of rotation of the Gyre is situated at about 76°N, 145°W. In the southeastern Beaufort Sea, the southern boundary of the polar ice zone generally lies at about 72°N. This is seaward of the continental shelf, although fluctuations in the southern limit of the polar pack do occur from year to year, presumably due to annual variations in the mean summer winds. For example, in 1955, 1964, 1967, and 1974.

northerly winds pushed the polar ice into coastal waters causing multi-year floes to reach water depths as shallow as 5 m.

Multi-year ice is distinguished from first year ice by a number of physical characteristics (Kovacs and Mellor, 1971; Kovacs et al., 1975). First year level ice generally attains a maximum thickness of about 2 m by the end of the winter, whereas multi-year ice ranges from 2 m to nearly 4 m throughout the year. The surface topography of multi-year ice is also more undulating than first year ice. In addition, the salinity of multi-year ice is lower as a result of the ice undergoing a number of melting and refreezing cycles. Due to the melting and refreezing process, the voids in first year ridges become filled with ice as the ridges mature. As a result, multi-year ridges are essentially solid ice.

The deepest multi-year keel measured in the polar pack extended to 47 m below the sea level (Bercha, 1976). However, it is felt that such ridges are rare (Wadhams, 1979; C-CORE, 1981). Figure 1.1-8 shows the distribution of polar pack ice keel depths found during U.S. submarine cruises.

1.1.2 EXTREME ICE FEATURES

Icebergs such as those found off the east coast of

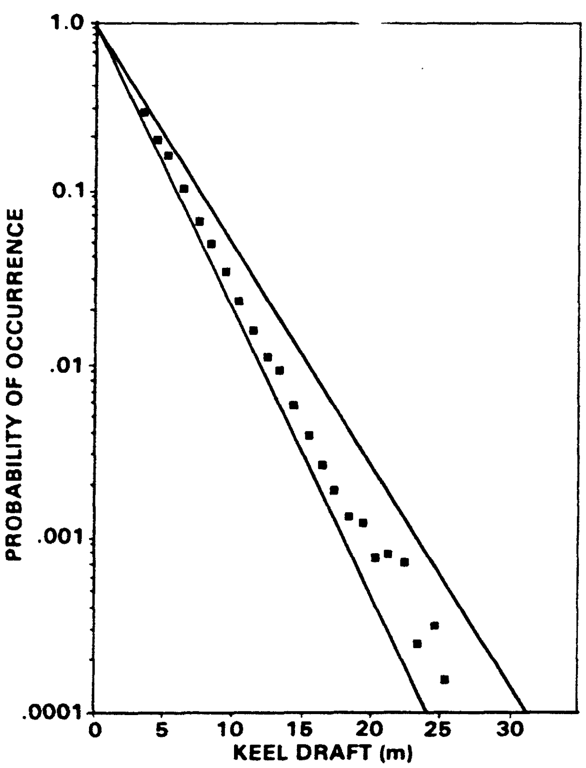


FIGURE 1.1-8 *Probability of finding pressure ridge keels of a given draft during submarine transects in the polar ice zone (based on Wadhams and Horne, 1978). This figure shows that the probability of finding a pressure-ridge keel with a draft of 20 m, along a transect in the polar ice zone, is about 1 in 1,000.*

Baffin Island and elsewhere in the eastern Arctic are not found in the Beaufort Sea, but two formidable multi-year ice features, ice islands and multi-year hummock fields, may be encountered (Plates 1.1-3 and 1.1-4). These features, although rare, could collide with a permanent structure in the Beaufort Sea during its life-time. Consequently, the maximum size and thickness of these features, and the probability of collision with an artificial structure are considered during the design of both temporary and permanent offshore facilities.

Ice islands are the only ice of glacial origin found in the Beaufort Sea (Plate 1.1-3). The presence of ice islands was first documented in the late forties, with the sighting of ice islands T1, T2 and T3 (for radar target 1, 2, and 3) during U.S. Airforce reconnaissance flights (Koenig et al., 1952). The discovery of these ice masses which had areas up to 697 km^2 and thicknesses up to 30 m initiated numerous scientific programs to determine their number and origin. It is now generally accepted that these features originate from the remnant ice shelves of northern Ellesmere Island (Crary, 1960)).

The presence of these large ice masses in the Beaufort Gyre is well documented. In the Mackenzie Delta region, all those tracked stayed north of the continental shelf. However, grounding and break-up of these ice masses off the coast of Alaska have produced large numbers of ice fragments. One such grounding in the fall of 1971 resulted in 433 ice island fragments, ranging from 15 to 300 m in diameter. These fragments were subsequently trapped in the landfast ice in water depths between 10 and 25 m throughout the winter (Barton et al., 1972). Although many of the grounded pieces drifted free the following summer, fragments remained in coastal waters for the following three years (Spedding, 1977).

Ice island T3 had dimensions of 5.5 km by 11 km when it passed through the southeastern Beaufort Sea in March, 1978. However, because of its draft, it is unlikely that it or similar features will be encountered in water depths less than 20 m. In fact, T3 is believed to have moved into Soviet waters and over the pole (De Paoli et al., 1982). If this is the case there is a possibility that it will enter the Atlantic Ocean east of Greenland and eventually break-up.

Ice islands are a potential threat to offshore structures in water depths greater than 20 m. Unfortunately, the number of these features drifting around in the polar pack is not known, although available literature indicates it is unlikely there are more than 11 islands remaining with diameters in excess of 1.5 km (Spedding, 1977). One hundred metre diameter islands are occasionally seen in the southern Beaufort, but these are unlikely to be a serious risk to a

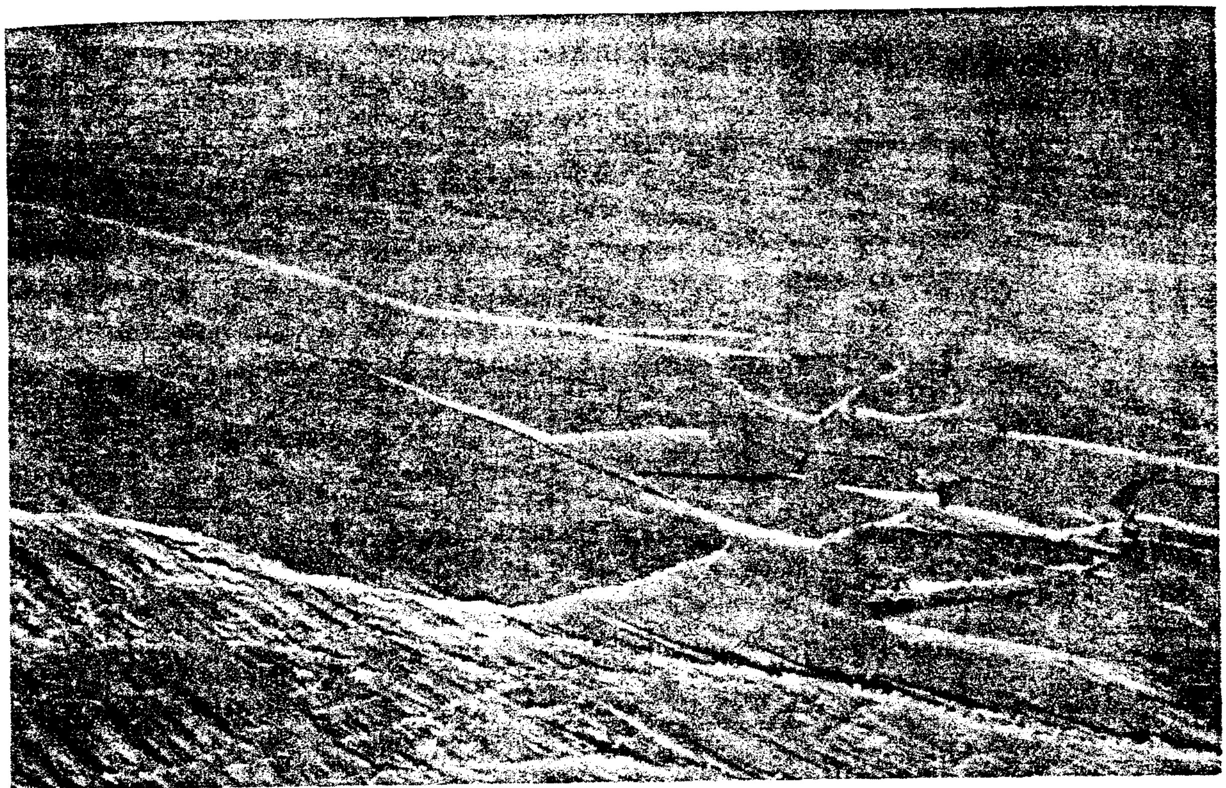


PLATE 1.1-3 *Ice island grounded in the Alaskan Beaufort Sea in the fall of 1971. Ice islands are the only ice of glacial origin found in the Beaufort Sea and originate from Ellesmere Island ice shelves.*

PLATE 1.1-4 *Multi-year hummock field fragment drifting in the Southeastern Beaufort Sea. Multi-year hummock fields are formed at the edge of the landfast ice along the western edge of the archipelago adjacent to the Beaufort Sea.*

permanent structure. It is also noteworthy that with the increase in the number of reconnaissance flights over the past few years, significant numbers of new ice islands have not been observed (Spedding, 1977). In fact, many observations in recent years seem to be of previously reported islands.

Calvings observed in 1962 and 1967 appear to be associated with a general retreat of the Ellesmere Island ice shelves. It is estimated that approximately 725 km^2 of ice shelf remains; the maximum size ice island that could be produced would be about 300 km^2 in area, (R. Pilkington, pers. comm.) and this is likely to break into three 100 km^2 islands due to its shape. The likelihood of these shelves calving in the near future is not known. Some of the shelves may be grounded, and the chance of these calving will be small. Further studies are underway to try to quantify the possibility of additional calving from the ice shelves and to determine the number of islands that may be drifting in the Beaufort Gyre. These investigations will improve structure collision probability assessments.

Along the westerly islands of the Arctic Archipelago adjacent to the Beaufort Sea, landfast ice is present along the shore as in the southeastern Beaufort Sea. However, unlike in the southeastern Beaufort Sea area, this ice does not break-up every year and multi-year landfast ice is formed. This multi-year landfast ice runs from Ellesmere Island to Prince Patrick Island. Within these ice sheets, thick level multi-year ice and multi-year hummock fields can be found (Hudson *et al.*, 1982).

These multi-year hummock fields are formidable. They are formed at the edge of the landfast ice along the western edge of the Archipelago adjacent to the Beaufort Sea. In this region, the crushing and overriding of multi-year ice sheets creates large fields of crushed ice and ridges parallel to the shore. These ridges exceed 20 m in height and have been observed to be grounded in water depths of 60 m. If hummock fields survive one or more summers, their sails and keels consolidate and when they subsequently ablate and calve, they could drift with the Gyre along the edge of the polar pack and eventually enter the proposed production region. There is limited information regarding the size distribution, frequency of calving, and probability of these features entering the production area. However, hummock fields with dimensions up to several kilometres have been observed adjacent to Prince Patrick Island and others up to 600 m in diameter have been seen along the pack edge in the southeast Beaufort Sea. In order to assess the collision probability of these features with structures, reconnaissance flights are being flown to monitor the presence, formation, and calving of hummock fields. Recent calculations indicate that hummock fields less than 15 m thick will be broken up by waves into pieces having a maximum dimension of 500 m or less (Wadhams, 1981).

Little is known about the thickness of the level multi-year landfast ice sheets adjacent to the hummock fields. But in Nansen Sound and Sverdrup Channel, multi-year fast ice over 40 years old, with a thickness of 10 metres, has been reported (Serson, 1972, 1974). In other areas it is not expected to be as old and thick, for exposure to the pressures of the moving ice of the Beaufort Gyre causes the ice shelf to break off more frequently.

1.1.3 ANNUAL ICE CYCLE

1.1.3.1 Break-up

The patterns of ice break-up in the seasonal (transition) and landfast ice zones are similar each year (Atmospheric Environment Service, 1978, 1979, 1980). However, there are annual differences in rates of break-up and the date of final clearance, due to annual differences in winds and temperature. In the southern Beaufort Sea, break-up in the spring commences in the seasonal ice zone. Flaw leads develop at the entrance to Amundsen Gulf and expand westward along the landfast ice edge during periods of sustained winds from the east. These flaw leads tend to be an extension and development of the Cape Bathurst Polynya as described in Section 1.1.1.2. The typical manner in which these leads develop is shown in Figure 1.1-9, where the development in 1975 is illustrated.

The creation of these open water areas allows the ice in Amundsen Gulf to fracture and drift to the west. The flaw leads tend to develop rapidly as far west as Herschel Island, but along the Alaskan coast they tend to become more intermittent and filled with ice displaced from the southeastern Beaufort. The extensive open water allows the disintegrating landfast ice to move seaward and to act as centres for increased input of solar radiation. In some years (eg. 1974), these flaw leads do not develop, and this results in a delayed break-up and clearance of ice. Although flaw leads may be present along the landfast ice edge from mid April, disintegration of the landfast ice does not begin until June.

In Mackenzie and Kugmallit bays, flooding over the bottom-fast ice occurs in early May with the commencement of the Mackenzie River spring runoff. Melt lagoons are formed at the river channel mouth, and these expand through melting at the ice-water interface (Figure 1.1-15). When these meltwater lagoons extend out to a water depth of approximately 6 m, the remaining ice barriers across the bays fracture. Beyond the major influence of the Mackenzie River, solar radiation causes structural weakening

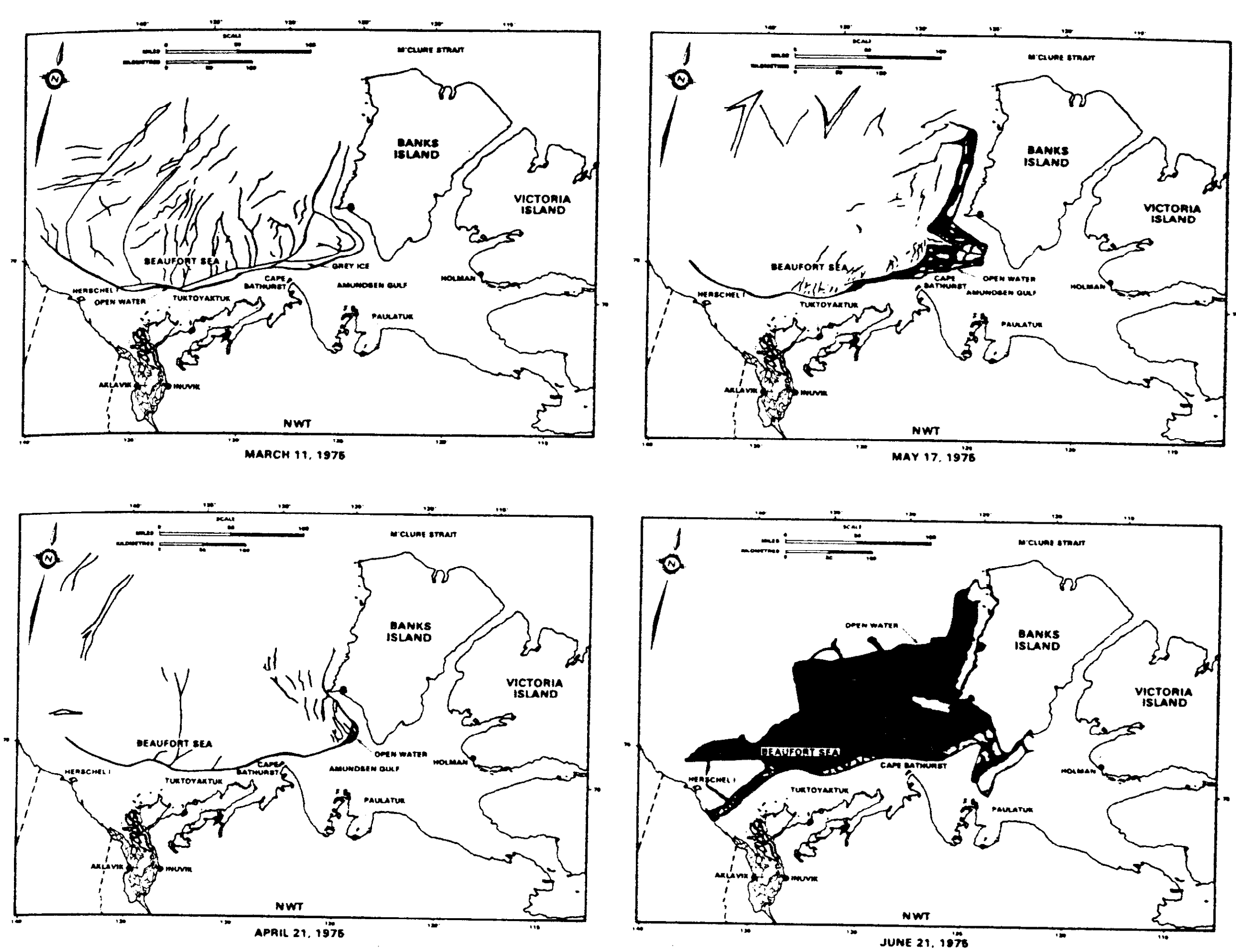


FIGURE 1.1.9 *Springtime break-up patterns in the Southeastern Beaufort Sea in 1975. Flaw leads develop at the entrance to Amundsen Gulf and expand westward along the landfast ice edge during sustained easterly winds.*

of the ice which destroys bonds with the shore and ablates grounded ridges, eventually allowing the ice sheet to drift seaward, weaken and break up.

The dates of break-up and for ice to clear from coastal waters varies from year to year, and depends on the presence of an offshore wind. Under favourable winds and temperatures, the landfast ice zone may be ice-free as early as the fourth week of June (Spedding, 1978). In a year such as 1974, when offshore winds did not prevail, break-up was delayed and ice remained throughout the summer in areas with water depths greater than 30 m. The median clearing dates when ice concentrations are less than 2/10ths are shown in Figure 1.1-10. Due to the influx of drift-ice from the Canadian Beaufort, the clearance of ice off the Alaskan coast is slower. It may be mid August before median pack concentrations fall to open pack values of less than 6/10ths ice concentration.

1.1.3.2 Summer Ice Conditions

Once the landfast ice has disintegrated and the remnant ice moves seaward, a gradual expansion of the coastal open water corridor generally occurs throughout the summer. The maximum summer open water extent is usually attained in early September.

In the seasonal (transition) ice zone, a breakdown and melting of the first year ice accompanies the gradual northerly retreat of the ice edge throughout the summer. Typical summer floe size distributions determined in a 114 km^2 area over a four year period are illustrated in Figure 1.1-11, which indicates a predominance of smaller floes. Other investigations indicate that the floe sizes within the seasonal ice zone decrease throughout the summer (Markham, 1975; Spedding et al, 1978). The total number of floes reaches a maximum in early summer as the large floes break up, but subsequent melting decreases the number of ice remnants. By the time that new ice formation begins in early October, most of the seasonal ice has melted together with any remnants lying along the polar ice edge.

In summer, ice may drift back into coastal waters during storms and affect offshore operations. Multi-

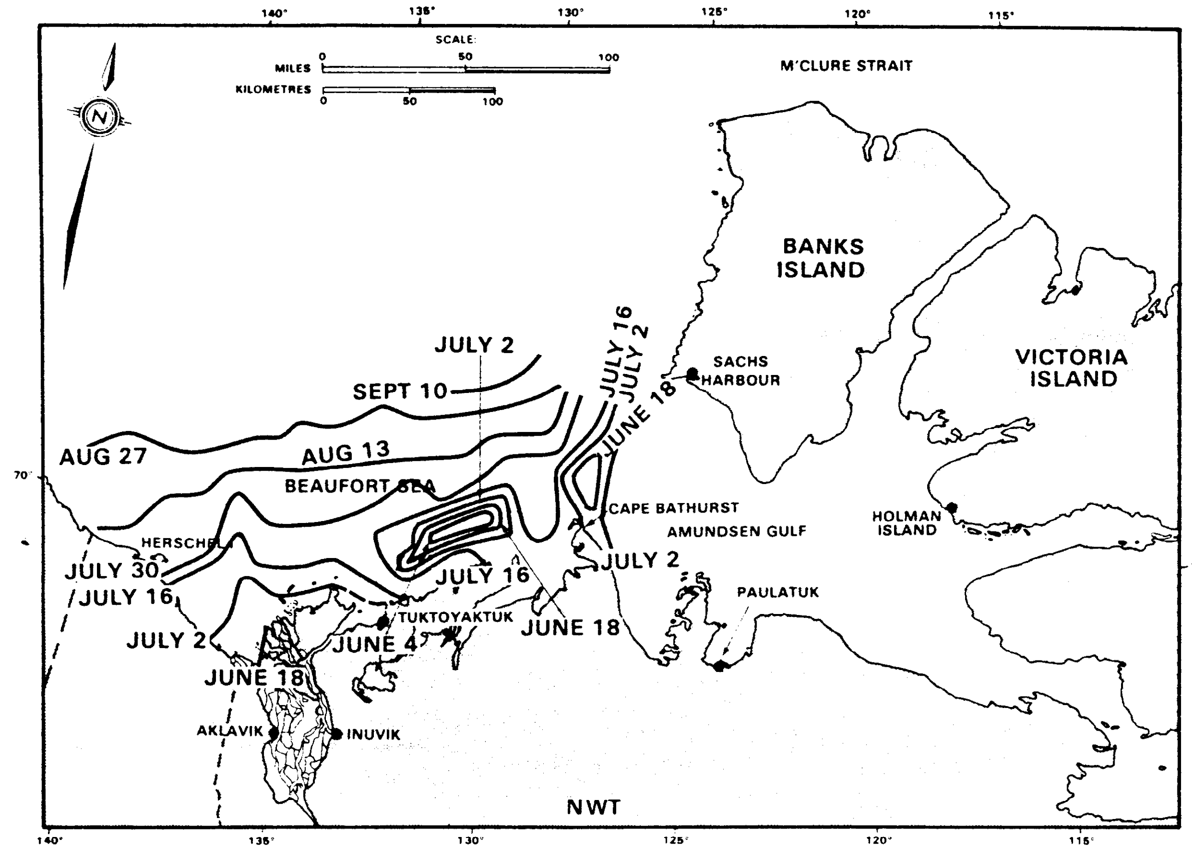


FIGURE 1.1-10 *Mediam clearing dates when 2/10th or less ice cover occurs in the Southeastern Beaufort Sea. Earliest median clearing occurs at the Mackenzie River outlets and north of Cape Bathurst where the Cape Bathurst polynya develops. (Source: Marko, 1975).*

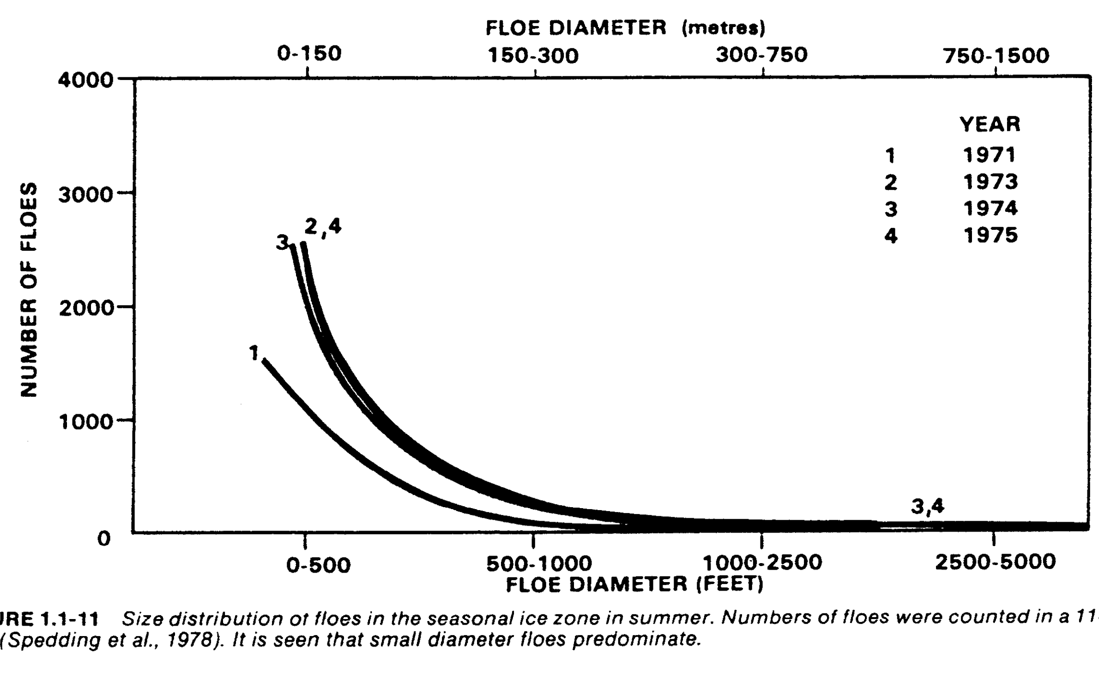


FIGURE 1.1-11 *Size distribution of floes in the seasonal ice zone in summer. Numbers of floes were counted in a 114 km² area (Spedding et al., 1978). It is seen that small diameter floes predominate.*

year floes pose the greatest problem because of their greater mean thickness, stronger physical properties and larger mean diameters. Observations by Arsenault (1980) (Figure 1.1-12) indicate that the sizes of multi-year floes along the edge of the polar pack are larger than seasonal ice floes (Figure 1.1-11). Gener-

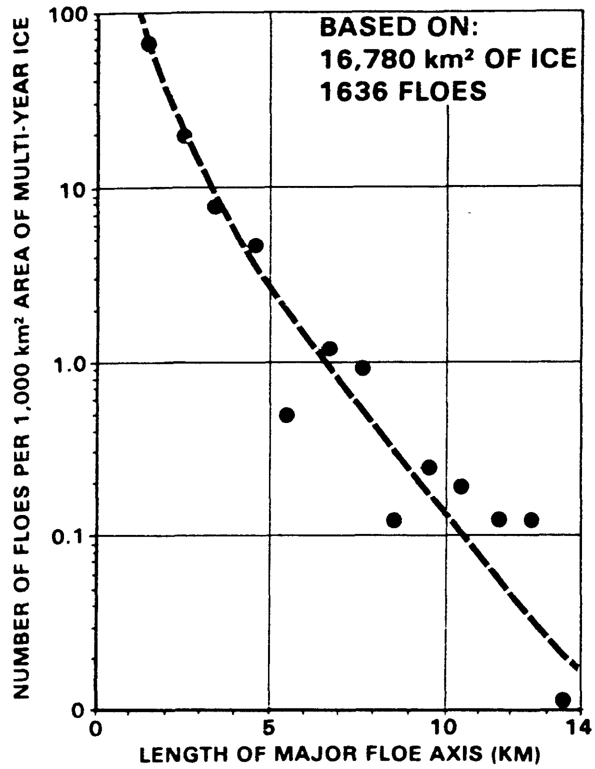


FIGURE 1.1-12 *Mean number of multi-year ice floes in pack ice between 70°-72° N, 127°-138° W in Sept. and Oct. 1980 (after Arsenault, 1980). The sizes of multi-year floes along the edge of the polar pack are larger than seasonal ice floes.*

ally large multi-year floes are comprised of a number of smaller floes which have become frozen together during their circulation in the Beaufort Gyre (Wright and Schwab, 1980). These large multi-year floes drift down the coast of Banks Island into the southeastern Beaufort Sea. These floes are larger than the seasonal ice floes because they have not been exposed to wave action.

1.1.3.3 Freeze-Up

Annual ice growth in the coastal areas commences between late September and late October, with the actual date being dependent on late summer ice conditions. For instance, in a poor summer such as 1974 when polar ice intruded into coastal waters, new ice formation commenced on September 24 (Spedding, 1978). In a summer such as 1977 when maximum clearance of ice and open water occurred, new ice formation did not begin until October 11. New ice initially forms along the edge of the pack, and is followed by growth in sheltered coastal waters. Simultaneous growth continues until the gap between the two advancing ice edges is bridged.

In coastal waters, new ice first forms around Richards Island where surface salinities are low due to the Mackenzie River discharge. Once new ice growth commences, it takes about two weeks for the entire Beaufort Sea to be ice covered, although open water conditions persist much longer in Amundsen Gulf (Markham, 1975). Initial consolidation takes place in more sheltered bays. However, it is usually mid November before landfast ice has formed out to the 5 m isobath, at which time the level ice is 30 to 60 cm thick (Figure 1.1-2). The landfast ice grows seaward in a series of steps with the progression of winter.

In years such as 1974 and 1975, grounded multi-year ice along the 20 m isobath provided a protected environment for new ice growth, allowing the landfast ice edge to stabilize at its maximum extent by mid November (Spedding, 1974, 1975). Advancement of the landfast ice edge occurs during periods of onshore winds when shear zone ice is compacted against the landfast ice edge. As indicated earlier, ridges are formed during these periods, and many of these become grounded. However, under the influence of offshore winds, shear zone ice is moved away from the edge of the landfast zone and advancement of the latter does not occur.

Some southerly movement of the polar ice occurs in the fall until the seasonal ice is sufficiently established to halt its progress. Normally, unless a late summer storm pushes the polar ice into continental shelf water, it tends to remain around the position of maximum summer retreat throughout the winter. The seasonal (transition) ice zone continues to move and grow throughout the winter.

1.1.3.4 Variability in Summer Ice Conditions

The aerial extent of open water conditions in the southern Beaufort Sea varies greatly from year to year (Figure 1.1-13). Both the rate and extent of clearing depend on the yearly meteorological conditions. In years such as 1976 and 1977, when winds were predominantly offshore, a gradual retreat of the ice edge took place throughout the summer. In other years such as 1974 and 1975, onshore winds pushed multi-year ice into coastal waters. This variability in the rate and extent of yearly ice clearance is evident from studies conducted at Tingmiark where the length of the open water season ranged from 0 to 160 days during the period from 1953 to 1980, (Figure 1.1-14).

As in seas elsewhere, life in the Beaufort Sea ultimately depends on sunlight and nutrients. When these are abundant, marine productivity is increased; conversely, when they are scarce, productivity is reduced. At 70° N there are over 12 hours of sunlight per day from mid March until mid September, with 24 hours per day from mid May to mid July. The extent to which the solar energy can be used for photosynthesis depends on its ability to penetrate into the water. This, in turn, is influenced by how

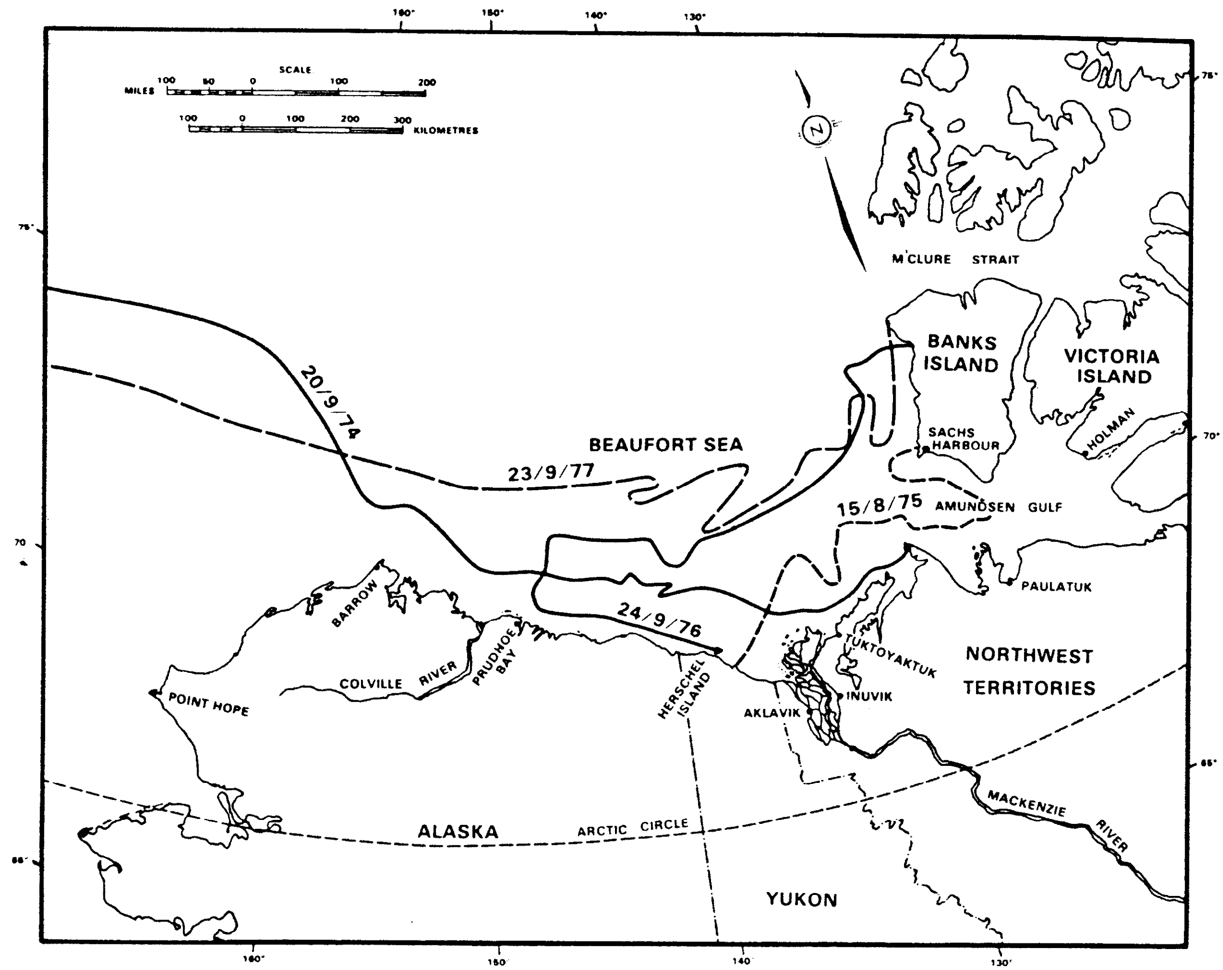


FIGURE 1.1-13 *Maximum extent of open water in the Beaufort Sea in 1974-1977. In 1976 and 1977, winds were mostly offshore so that a gradual retreat of the ice edge took place throughout the summer. In 1974 and 1975 onshore winds pushed mult-year ice into coastal waters. (Source: Spedding, 1978).*

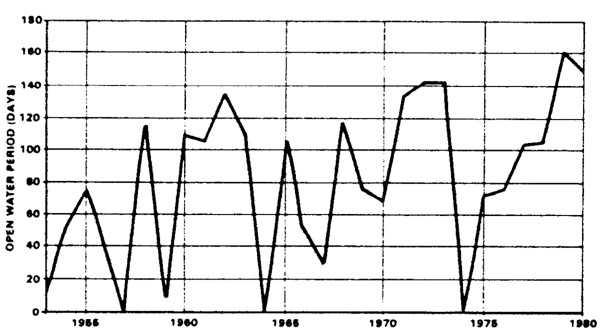


FIGURE 1.1-14 *Open water days per year at Tingmiark, 70° 10' N, 133° 0' W. The open water season ranged from 0 to 165 days from 1953 to 1980.*

much of the sea's surface is free of ice during the sunlit part of the year. Although sea ice does not completely shade the sea below, it reduces light penetration and prevents the sea from warming. Compared to sea ice, the water surface reflects little sunlight. Thus the absence of ice allows the water surface to warm more rapidly and winds to mix the heat downward and nutrients upward. The presence of nutrients in the spring causes plankton blooms, which fuel the marine food chain (see Section 3.1 for more detail).

The implication is that during years with more ice in spring, biological productivity may be lower and the base of the food chain may not be as well established. Conversely, in years with little ice, biological productivity could be increased. The links between the extent of open water and biological productivity in the southeastern Beaufort Sea are complex and remain descriptive rather than analytical. Some of these links are implied in the following descriptions of the annual variability of the southeastern Beaufort Sea spring and summer ice cover.

Springtime ice variability relates to the annual fluctuations in open water areas observed in the transition zone polynya and in coastal lagoons near the mouth of the Mackenzie River as shown in Figure 1.1-15.

(a) February through June transition zone polynya area.

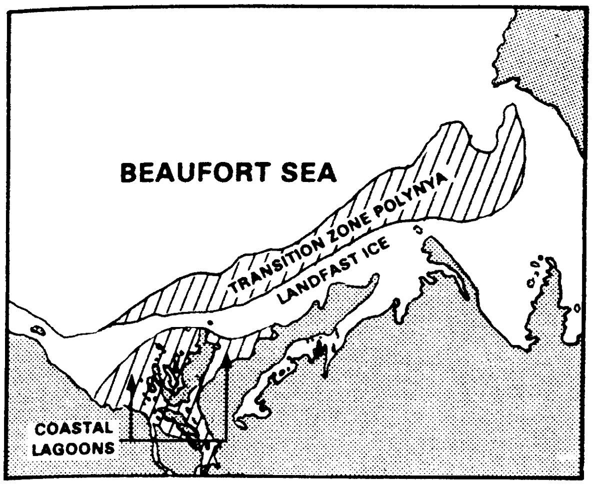
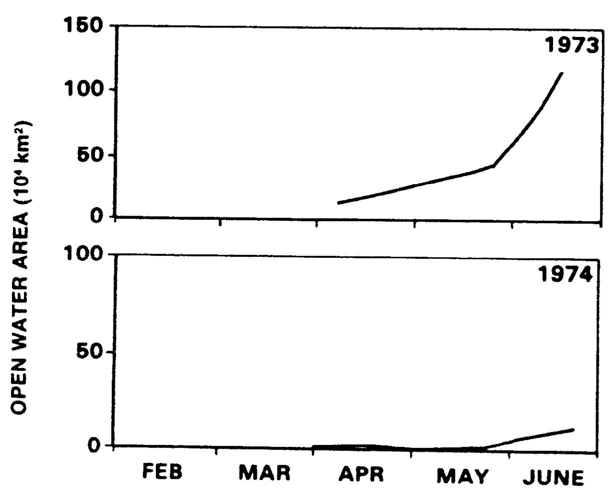


FIGURE 1.1-15 *Typical springtime open water areas in the Canadian Beaufort Sea. (Source: Marko, pers. comm.)*

Figure 1.1-9 shows lead and polynya patterns, north of the landfast ice, for the spring of 1975. For any year, however, the area of open water on a particular day depends on wind fields and their easing and reversals. As the 24 hours of winter darkness ends in February, open water areas begin to absorb solar energy and are subject to wind-mixing. The resultant warming and stirring stimulates early season phytoplankton growth. These open water areas and their positions are enormously variable in any one year, as shown in Figure 1.1-16. For this figure, satellite imagery was used to estimate the area of open water in the transition zone polynya seaward of the landfast ice between the longitudes of Herschel Island and Sachs Harbour for the years 1973 to 1980 and for days in February through June in each year. (J. Marko, pers. comm.). It can be seen that, on May 20th, for example, the open water area ranged from about zero km^2 in 1980 to 35,000 km^2 in 1979. In this figure the latest date at which measurements were made was before the landfast ice broke up in a particular year.



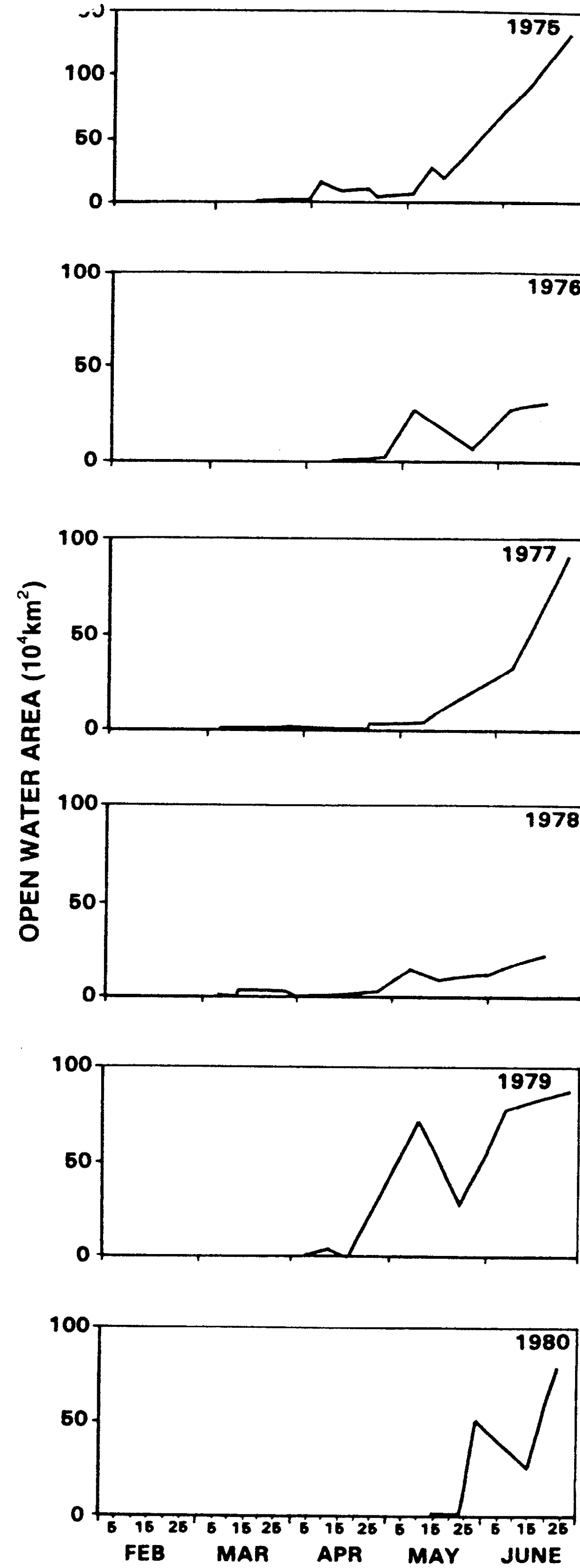


FIGURE 1.1-16 *Open water area in the transition zone polynya for the years 1973 through 1980. (The area includes open water between the longitudes of Herschel Island and Sachs Harbour). This polynya varies enormously in area from year to year and within any one year. (Source: Marko, pers. comm.).*

b) May through June coastal lagoon area.

Later in the spring the Mackenzie River freshet floods its deltas and the adjacent sea ice. Lagoons form at the river outlets as the warm river waters and solar radiation melt the coastal landfast ice. Small melt areas expand outward into the landfast ice, eventually merging to form a single shallow body of fresh, warm, sediment and nutrient-laden water. This waterbody remains separated from the transition zone polynya by a progressively narrowing strip of landfast ice which is eventually breached between mid June and mid July. Figure 1.1-17 shows estimates of the inshore lagoon areas for May 25, June 10 and June 20 in the years 1973 to 1981. Most variability, in a relative sense, occurs early in the expansion of open water in lagoons, as seen from May 25th data, where some years had no open water at all.

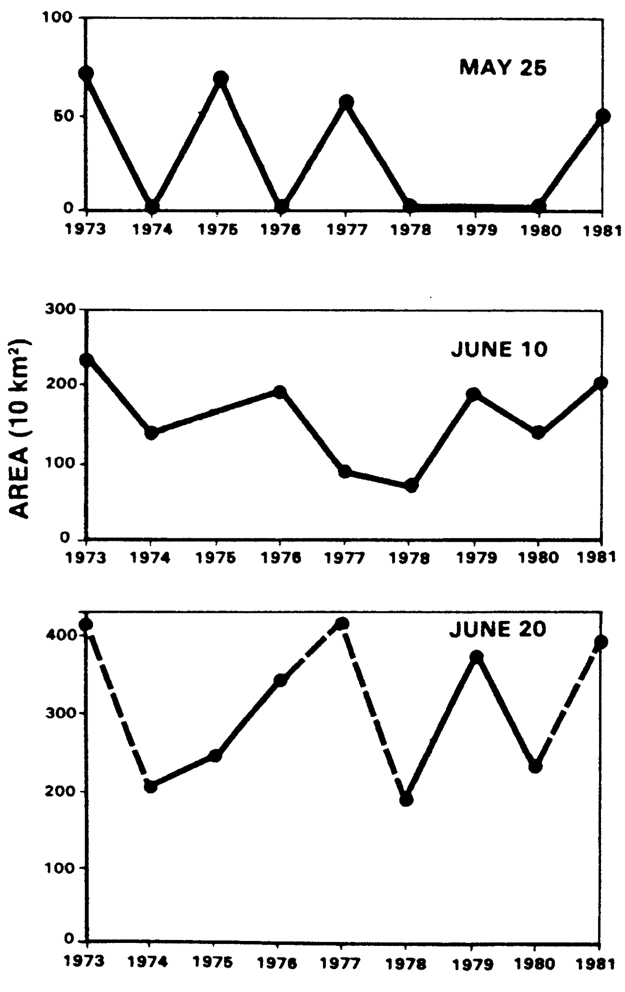


FIGURE 1.1-17 *Coastal lagoon open water areas on May 25, June 10 and June 20 for the years 1973 through 1981. Breeching of the coastal lagoon occurred just prior to June 20 in 1973, 1978 and 1981 as indicated by the dashed lines. (Source: Marko, pers. comm.).*

The summer year to year variability concerns the open water observed in the months of July, August and September, after the break-up of landfast ice and before freeze-up begins in October. The annual variability in open water areas is shown on Figure 1.1-18 for mid July, mid August and mid September of the years 1974 to 1977. Ice edges were defined as the location of 7/10ths ice concentrations. There was considerable ice during the summer of 1974 and relatively little ice in 1977, with intermediate conditions existing in 1975 and 1976. The open water area varied by a factor of about five between mid August 1974 (55,000 km^2) and mid August 1977 (250,000 km^2) between the longitudes of Herschel Island and Sachs Harbour.

The expanse of open water in a particular summer has a major effect in determining how the plume of turbid water from the Mackenzie River spreads into the Beaufort Sea. In 1974, a poor ice year, the river plume was confined within a relatively small open water area in Mackenzie Bay and off the Tuktoyaktuk Peninsula. The result was a plume with a deep layer of fresh, warm water that was exceptionally turbid. In contrast, during the good ice year of 1977, the river plume was often well dispersed over a very large area.

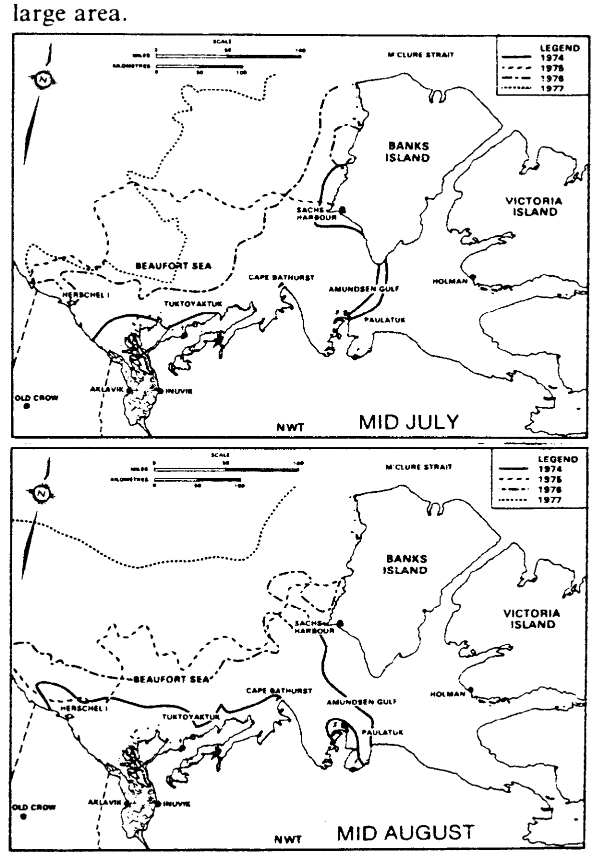


FIGURE 1.1-18 *Extents of open water in the Southeastern Beaufort Sea in the months of July, August and September for the years 1974 through 1977. Ice edges are defined as the location of 7/10ths ice concentrations. (Source: Marko pers comm.)*

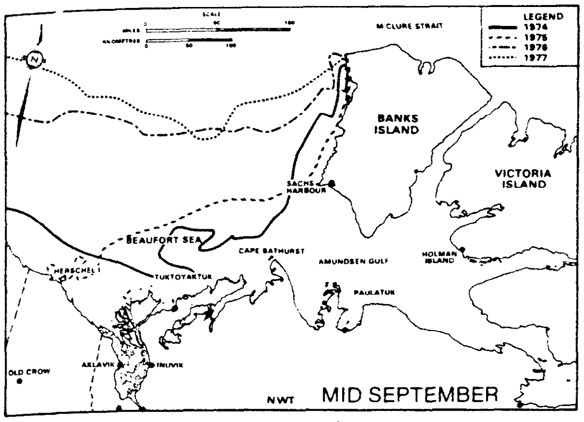


FIGURE 1.1-18 *(cont'd).*

Winds are a key factor in determining the expanse of summer open water. For example, winds from the northwest sector can move ice into previously open water and shift the river plume toward the southeast shores of the Beaufort Sea. On the other hand, winds from the southeast sector increase the expanse of summer open water and expand the river plume seaward, causing the upwelling of nutrient-rich water near the coast (Section 1.3.2.2).

Evidence to verify wide swings in year to year biological production is generally limited. However, a good example is the major ring seal population reduction observed in 1975 that was attributed largely to the poor ice year of 1974. More detailed information on the variability of biological populations in the Beaufort region resulting from this and other physical factors can be found in Chapter 3 of this Volume. .

1.1.4 ICE CONDITIONS AND SHIPPING

1.1.4.1 Southern Beaufort Sea

Generally, ice conditions for shipping in the Canadian Beaufort Sea are less severe than off the Alaskan coast. The Canadian Beaufort Sea is characterized by up to a month longer open water season, less multi-year ice, and reduced opportunity for serious ice pressure situations. In addition, vessels operating in the eastern Beaufort are not constrained to the often narrow corridor of first year ice between the 30 m isobath and the polar pack.

Multi-year ice concentrations in the seasonal ice zone are generally less than 2/10ths, with a concentration of 8/10ths having occurred in only one year out of the last 13 years (Dickins, 1979). In most years, a 30 m draft vessel would be able to move through the Canadian Beaufort Sea in predominantly first year ice with moderate to heavy ridging, depending on how close the vessel route is to the landfast ice edge.

An extensive shore lead may be present throughout the winter between Cape Bathurst and Herschel Island and between the 20 and 30 m isobaths. The width of this open water lead can vary from 100's of metres to tens of kilometres in less than 24 hours (Marko, 1975; Spedding, 1979). Even in mid winter, there are cracks and leads every few kilometres which roughly parallel the landfast ice edge.

1.1.4.2 Amundsen Gulf

The winter ice cover in Amundsen Gulf is composed of first year ice of a variety of ages due to the dynamic ice movements that occur throughout the winter. Generally, only traces of multi-year fragments which have drifted from Viscount Melville Sound, or blown in from the Beaufort Sea by late season northwesterlies, are present in these waters (Dickins, 1979). First year ridging and rafting is common throughout the Gulf, but since extensive areas of young ice are present at any time during the winter, block sizes are small and ridge consolidation is much less prevalent than in the Beaufort Sea transition zone. There are no quantitative data describing ice surface roughness in Amundsen Gulf (Markham, 1981). Local polynyas and new ice can cover over 20% of the area between Cape Parry and Banks Island by as early as mid January (Dickins, 1978).

During "favourable" years, a clear east-west division in ice conditions takes place in Amundsen Gulf by March, with distinct shear fractures and open water patches occurring in the western half of the Gulf between Cape Bathurst and the south end of Banks Island. Figure 1.1-9 shows conditions leading to a sharply defined and stable first year ice edge by late April. Very large first year floes up to 60 km across often break into smaller floes after several days (Markham, 1975). In June, prevailing easterlies remove this loose ice, leaving a large area of open water south of Banks Island. Due to wave action and melting, the eastern half of the Gulf usually breaks up within two weeks of any extensive spring ice clearance in the western sections. Ice concentrations in Amundsen Gulf remain below 5/10ths between mid July and early November (Markham, 1975, 1981).

Freeze-up in Amundsen Gulf is a slow south to north process, with frequent false starts before a relatively stable new ice cover is formed by mid November. In two winters during the period from 1973 to 1979, a fast ice cover was not formed in deep water west of Dolphin and Union Strait (Markham, 1981).

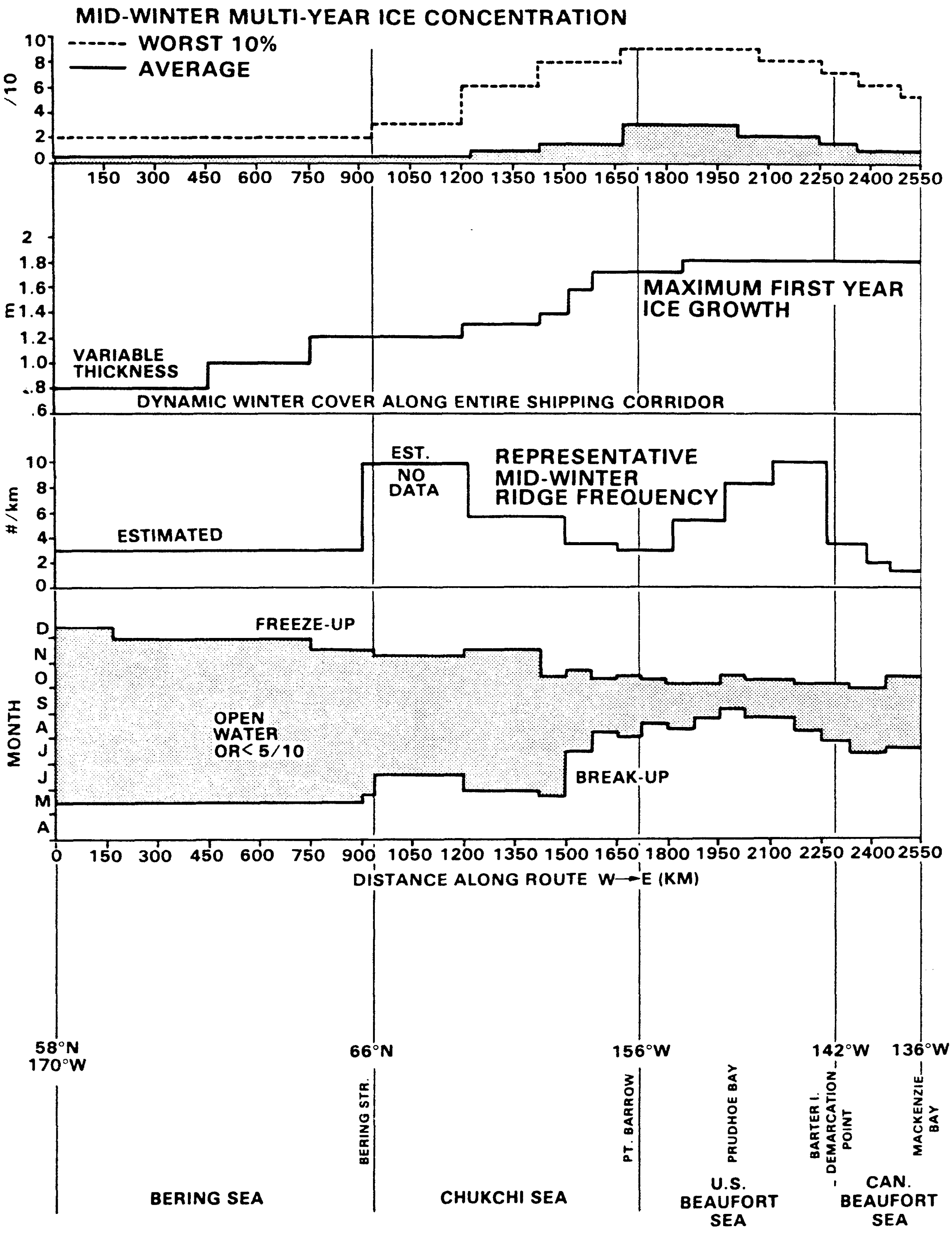


FIGURE 1.1-19 *Ice conditions along the western shipping corridor. (Source: Dickins, 1979).*

1.1.4.3 Alaskan Beaufort Sea

Ice conditions along the western approach to the Beaufort Sea are shown in Figure 1.1-19. Year round navigation along the Alaskan Beaufort coast largely depends on the degree to which the dominant, recurring east-west lead systems near the 30 m isobath can be safely used. Compared to the Bering and Chukchi seas, there is a much higher probability of encountering significant old ice concentrations in these waters. Mean concentrations of old ice are highest (about 3/10ths) between Point Barrow and Harrison Bay (Dickins, 1979), while during one in ten years, multi-year ice concentrations have reached 8/10ths in certain waters between Point Franklin and Prudhoe Bay (place names are shown in Figure 1-1). With few exceptions, the minimum old ice concentrations are encountered close to shore.

Level first year ice in the Alaskan Beaufort Sea reached a maximum thickness of 1.8 m (Dickins, 1979). Ridging is most severe between 20 and 80 km from the coast, and generally increases from west to east from an average frequency of 3/km at Point Barrow to over 7/km at Barter Island. Mean ridge heights range from 1.2 m in December to 1.7 m between February and April (Tucker et al., 1979). Open water duration in the Alaskan Beaufort Sea ranges from a minimum of 35 days off Prudhoe Bay to about 50 days elsewhere, and is generally limited to the period from mid August to early October. There is a large annual variability in the open water season in this region, depending on proximity of the polar pack to shore and prevailing winds. Even in mid winter, there is a high probability of encountering leads or thin ice zones paralleling the coast. The chance of encountering leads generally ranges from 40% in February to over 60% in May (Dickins, 1979).

The presence of cycles in ice severity off Alaska has been well documented (Barnett, 1977; McLeod and Hadden, 1977). Generally, these studies have shown unfavourable summer conditions (minimum open water with the ice pack closest to shore) in one of five years with the most favourable years being followed immediately by a winter of high multi-year ice concentrations.

1.1.4.4 Chukchi Sea

The Chukchi Sea is normally characterized by greater than 8/10ths first year ice during the winter, with a maximum thickness ranging from 120 cm in Kotzebue Sound to over 160 cm off Wainwright (Tucker et al., 1979). Multi-year ice concentrations increase from south to north, although winter means remain less than 2/10ths. Maximum old ice cover ranges from less than 4/10ths in the south to over 8/10ths north of Wainwright (one year in ten). There is a predominant winter flaw lead at the landfast ice edge between Cape Lisburne and Point Barrow.

As indicated in Figure 1.1-19, the normal open water season varies from 140 days (mid June to early November) in the south to 75 days at Point Barrow (early August to mid October in the north). However, recurring winter polynyas off Point Hope leads to an anomaly in the Cape Lisburne to Icy Cape area, with an average of 167 days of open water occurring between late May and early November. Extensive shear ice ridge fields are also common along the landfast ice edge in the Alaskan Beaufort.

The Chukchi Sea is a less dynamic but more highly pressured ice region than the Bering Sea. Laser profiles completed in the Icy Cape and Wainwright areas show mid winter ridge frequencies of 3 to 10/km, with mean ridge heights up to 1.6 m, peaking in the vicinity of the 30 m isobath (Tucker et al., 1979). Ridge frequencies are considered highest in the southern Chukchi Sea, although there are no publicly available quantitative data to confirm this.

1.1.4.5 Long Term Climate Change

The annual variability in the area of open water in the southeastern Beaufort Sea has been described in Section 1.1.3.4; measurements and observations of ice variables for shipping corridors are covered in Section 1.1.4. From these descriptions, it is not possible to determine future trends; the time series of observations is too short. Long time series, as far back as 10,000 years, have been obtained from cores extracted from the Devon Island Ice Cap and from Agassiz Ice Cap of Northern Ellesmere Island. These have been analyzed by Koerner and Fisher (1981) of the Polar Continental Shelf Project.

Koerner and Fisher predict a "High Arctic" annual "natural" temperature cooling of between 0.5 and 1.0°C between now and the year 2010. A similar short term natural cooling trend is supported by other investigators based on Camp Century cores from Greenland. Although the cores reflect past climate in locations within 500 km of each other, it is likely that predictions encompass the High Arctic Islands, the Northwest Passage and possibly the southeastern Beaufort Sea. The annual cooling trend prediction is based only on expected natural changes and excludes possible man-caused changes such as the effects of increasing carbon dioxide (CO_2) concentrations in the atmosphere. Indications are that man-caused atmospheric heating and atmospheric dust do not result in significant climate change; however, more serious are possible CO_2 effects.

So far, no evidence of CO_2 caused climate change is apparent in any climate record. However, recent numerical models dealing with possible CO_2 effects on the long term world's climate have reached a level of sophistication that their predictions cannot be dismissed (for a review see Hare, 1981). Most of these models predict climatic warming based on a constant natural climate. World average atmospheric temperatures are predicted to rise as much as 2.5°C over the next 50 to 70 years. These CO_2 caused temperature rises could emerge from the "noise level" of climate records by the year 2000. If such predictions on possible CO_2 effects prove to be true, then they would likely compensate for part of or more than the natural cooling in the High Arctic predicted by Koerner and Fisher (1981).

On the other hand, if man-caused CO_2 warming does not occur, a natural cooling prediction of 0.5 to 1.0°C over the next 30 years would produce increasing concentrations of multi-year ice in the summer, resulting from the increased survival of summer ice into winter. Koerner and Fisher (1981) have verified this effect because of the good relationship between the thickness of core melt-layers and observed amounts of open water in the Archipelago.

It is not certain that the natural cooling prediction applies necessarily to Arctic regions external to the Arctic Islands. Maxwell (1981) has used Arctic weather station records to classify climatic regions in the Canadian Arctic. Unfortunately his records from Cape Parry and Sachs Harbour are not long enough to show recent cooling or warming trends. Other stations, such as Alert Bay, Eureka, Resolute, Mould Bay and Isachsen, all in the High Arctic Islands, do, however, show a cooling of about 1°C since 1956, based on 10 year averages. These observations tend to support Koerner and Fishers cooling prediction for the High Arctic.

The conclusions are: that a high probability exists of a 0.5 to 1.0°C annual cooling taking place over the next 30 years in the High Arctic due to natural causes; that the predicted natural cooling does not necessarily apply to the Beaufort Sea region; that man-caused CO_2 atmospheric warming is predicted which could be detectable by the year 2000; and that the CO_2 warming, if real, could compensate for part of or more than the predicted natural cooling.

1.2 SURFACE WEATHER AND WIND WAVES

The following section briefly summarizes available climatological information describing temperature, Arctic temperature inversions, precipitation, visibility, winds, wind waves and synoptic storm tracks in the Beaufort-Chukchi region. Since accumulation of ice on marine vessels and offshore installations can be hazardous in this region, structural icing is also discussed. More details on the regional climate are provided in a supporting document (MEP, 1981b), while the climatology and atmospheric environment of coastal areas of the Beaufort Sea are discussed in Section 2.1.

1.2.1 WEATHER AND WEATHER FORECASTS

Weather is the term used to describe current atmospheric conditions. Climate, on the other hand, describes average weather conditions to be expected based on a long history of weather observations. In the Beaufort region, weather information and weather forecasts are provided by the Beaufort Weather Office (BWO) situated at Dome Petroleums Tuktoyaktuk basecamp. The BWO is operated by the Atmospheric Environment Service and funded by both Dome Petroleum Ltd. and Esso Resources Canada Ltd.

The forecast support network comprises the Canadian Meteorological Centre (CMC) in Montreal, Quebec, the Arctic Weather Centre (ARWC) in Edmonton, Alberta, and Ice Forecasting Central (IFC) in Ottawa, Ontario. CMC provides wide-area and long-range forecasts as source data to IFC and the BWO. ARWC has two main functions. It provides an overview of factors affecting weather over northern Canada, and it provides the BWO forecaster with routine aviation, marine and public forecasts overlapping the BWO area of interest. Between approximately May and December, the BWO is staffed by a team of meteorologists. The Atmospheric Environment Services Ice Branch ice observers, who report on daily ice conditions throughout the open water drilling period, comprise additional seasonal staff.

The principal function of the BWO is to provide site-specific forecasts of winds, waves and ice during the drilling season. Forecasts are issued daily at 6:00 am and 6:00 pm with updates at noon and midnight supplemented by updates reflecting changing weather. During 1980, for example, up to eight site-specific forecasts were issued. Wind, ice and gale advisories are also issued.

Meteorological teletype circuits transmit data from most of northern and western Canada, as well as from parts of northern and eastern Alaska. A data link to the Atmospheric Environment Service (AES) computer centre in Edmonton introduces additional data from Alaska, Siberia, the High Arctic and the Pacific.

During 1980, air pressure data from over the ice pack became available from up to nine POLEX buoys during the latter part of the drilling season. These data were routinely available through the Edmonton data link (AES, 1980). Data are also provided by the four nearby DEW-line stations at Komakuk, Shingle Point, Tuktoyaktuk and Nicholson Peninsula which issue short hourly reports in addition to their regular six hourly reports. These, combined with routine observations from the four Canmar drillships, one or two Esso Resources sites, and intermittent data from other ships and land-based sites, provide a close-knit supplemental data network.

1.2.2 CLIMATOLOGICAL DATA SOURCES AND LIMITATIONS

Historical weather data sources for the Beaufort-Chukchi region are primarily from coastal weather stations. Offshore data are from ships operating exclusively in the summer. There is a particular lack of wind data over the Chukchi Sea and comparatively, more historical data are available for the Beaufort Sea except over the pack ice.

The two major information sources for this region are reports by Burns (1973) and Brower et al. (1977). Both sources use historical data to the years 1973 and 1974 only. Twenty-five years of coastal and Canadian mean data were analyzed along with U.S. marine data spanning the years 1972 to 1974. An additional source of summer meteorological data for the Beaufort Sea is information collected yearly (since 1976) from Dome Petroleum's drillships during the period July to October.

1.2.3 TEMPERATURE

Extremely low temperatures can reduce human health and activity, and make equipment difficult to operate. Wind chill results from the combined effect of low temperatures and wind. Human heat loss increases dramatically as either the wind speed increases or the temperature decreases beyond a critical threshold. The combined effect of wind speed and air temperature on exposed flesh, which is known as wind chill, is illustrated in Figure 1.2-1.

Figures 1.2-2 and 1.2-3 show the mean air temperatures for the Beaufort-Chukchi region during February and August, respectively (Brower et al., 1977; Maxwell, 1980). Greater detail on seasonal differences in mean and extreme temperatures recorded at various coastal locations is provided in Section 2.1. The long Arctic winter is characterized by the Arctic Inversion (Section 1.2.4) and is often described as a season of "persistent" cold rather than "extreme" cold (Maxwell, 1980). Mean temperatures in the winter are -20°C for the southern Chukchi Sea and -30°C for the Beaufort Sea. Extreme minimum temperatures recorded in these two areas are -50.6°C at Barter Island and -50°C at Tuktoyaktuk, respectively. During the summer, mean temperatures increase to about 6°C on the coast and to about 2°C, 500 km offshore (Figure 1.2-3). Summer temperatures over open water are moderated by the heat exchange from the ocean to the air, resulting in strong horizontal temperature gradients perpendicular to the shore. Extreme maximum temperatures recorded were 30°C in the Beaufort at Tuktoyaktuk and 29.4°C in the Chukchi at Kotzebue (Burns, 1973; Brower et al., 1977).

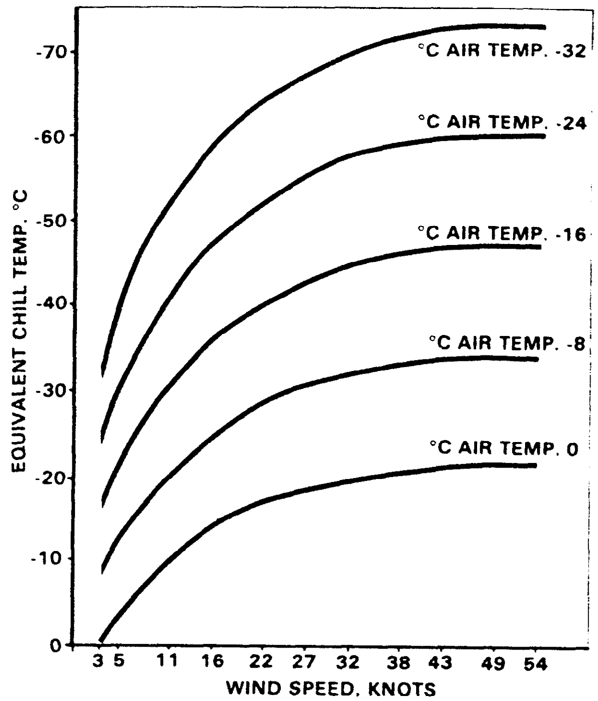


FIGURE 1.2-1 *Wind chill factors. Wind chill results from the combined effect of low temperatures and wind.*

During the autumn, before freeze-up, the sea is a source of heat so that temperatures over the water are often warmer than those over nearby land (Burns, 1973). This seasonal difference causes land-sea breezes. Also, "steaming" of the relatively warm ocean water adds moisture to the air. Ice begins to form on the sea in autumn as the air temperature decreases below freezing. Once the ice thickness exceeds 0.3 m there is little heat exchange between the water and air, and air temperatures over the ice pack drop rapidly.

Meteorological records collected at onshore stations show little diurnal variation in temperature. The maximum daily temperature range of about 10°C occurs in July, while the minimum range of less than 4°C occurs in August or early September. Over open water, air temperatures are strongly influenced by temperatures of the upper water column.

1.2.4 THE ARCTIC TEMPERATURE INVERSION

Normally the air temperature decreases with height. If this temperature decrease exceeds that due to the

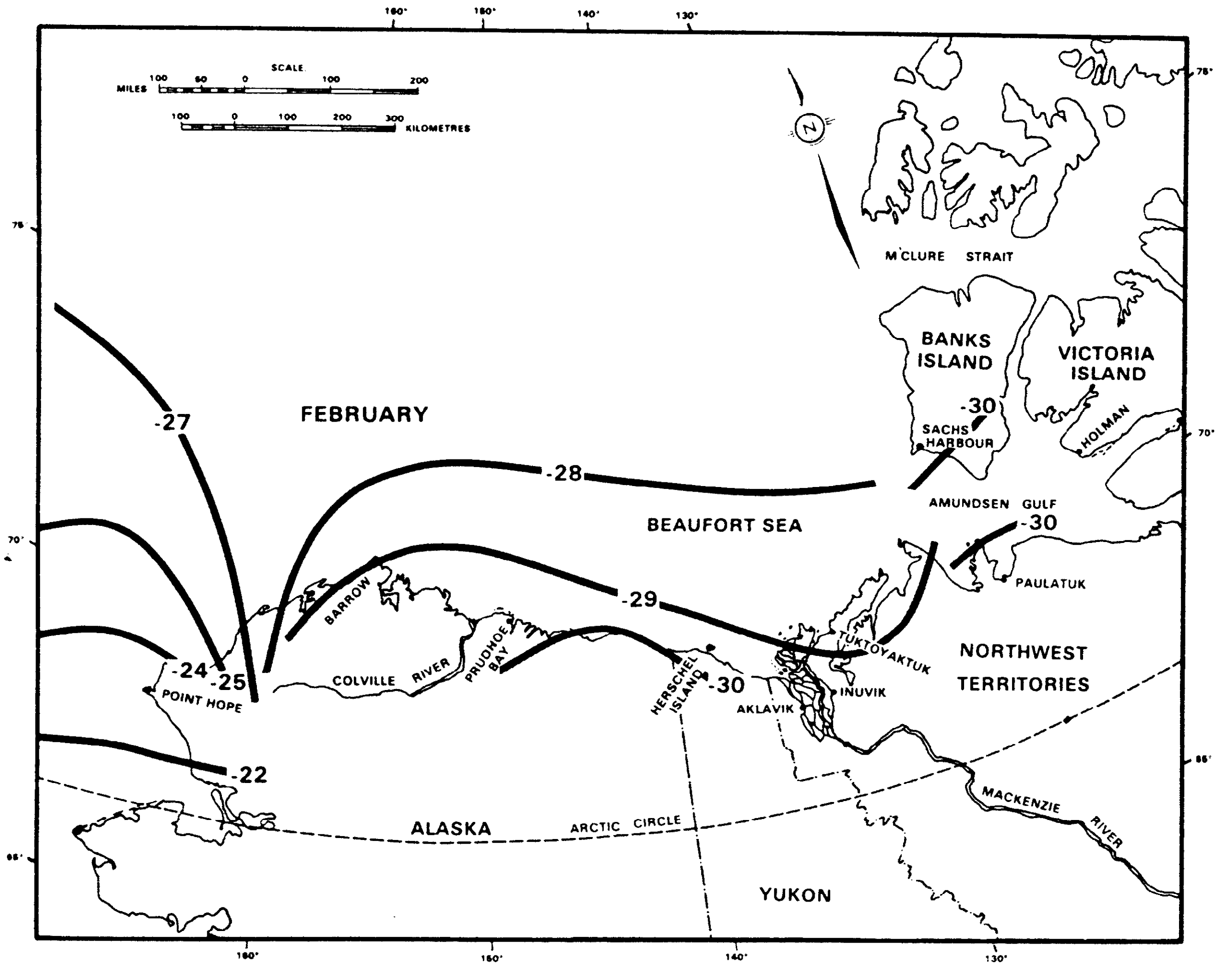


FIGURE 1.2-2 *Mean February air temperatures (° C) in the Beaufort-Chukchi region. The long Arctic winter is a season of persistent rather than extreme cold. (Sources: Brower et al., 1977; Maxwell, 1980).*

decreasing air pressure with height (the adiabatic decrease), the air is unstable and mixing and dispersal can occur. On the other hand, when air temperature increases with height, the air column is very stable and little mixing can occur. This increase in temperature with height, known as the 'Arctic Temperature Inversion' is an important feature which can cause fog and ice crystal haze to concentrate in a layer near the earth's surface and can inhibit the dispersal of atmospheric pollutants (Maxwell, 1980).

The Arctic Temperature Inversion occurs most commonly at night when the earth's surface radiates heat into outer space and surface temperatures drop. Two factors contribute to the intensity and persistence of temperature inversions in the winter months. The first is the long period of continuous darkness, and the second is the presence of ice and snow which reflects solar energy. The reflective surface insures a large loss of incoming solar energy even during months when there is daylight. The intensity of the inversion is also often increased by dynamic processes at higher levels in the atmosphere, such as when warm air moves over cold air (Burns, 1973).

Daytime temperature inversions over the Beaufort Sea are less prevalent in summer than in winter. For example, at Sachs Harbour on the Beaufort coast, daytime inversions occur 75% of the time in winter and decrease to 16% of the time in summer; nighttime inversions occur 77% of the time in winter and 44% of the time in summer. Overland the occurrence of inversions decreases dramatically between daytime and nighttime (see Section 2.1), whereas over the sea they are often maintained continuously by warm continental air flowing over the cold water. By way of contrast, there are no daytime temperature inversions in the summer further inland at Inuvik.

1.2.5 PRECIPITATION

Total mean annual precipitation and snowfall recorded throughout the Beaufort-Chukchi region are shown in Figure 1.2-4. The generally low frequency of storm tracks crossing this region (Section 1.2.10), as well as the limited capacity of cold air to hold moisture, results in a relatively low annual precipitation (Maxwell, 1980). In fact, much of the Arctic is referred to as a polar desert. Total precipitation in the region

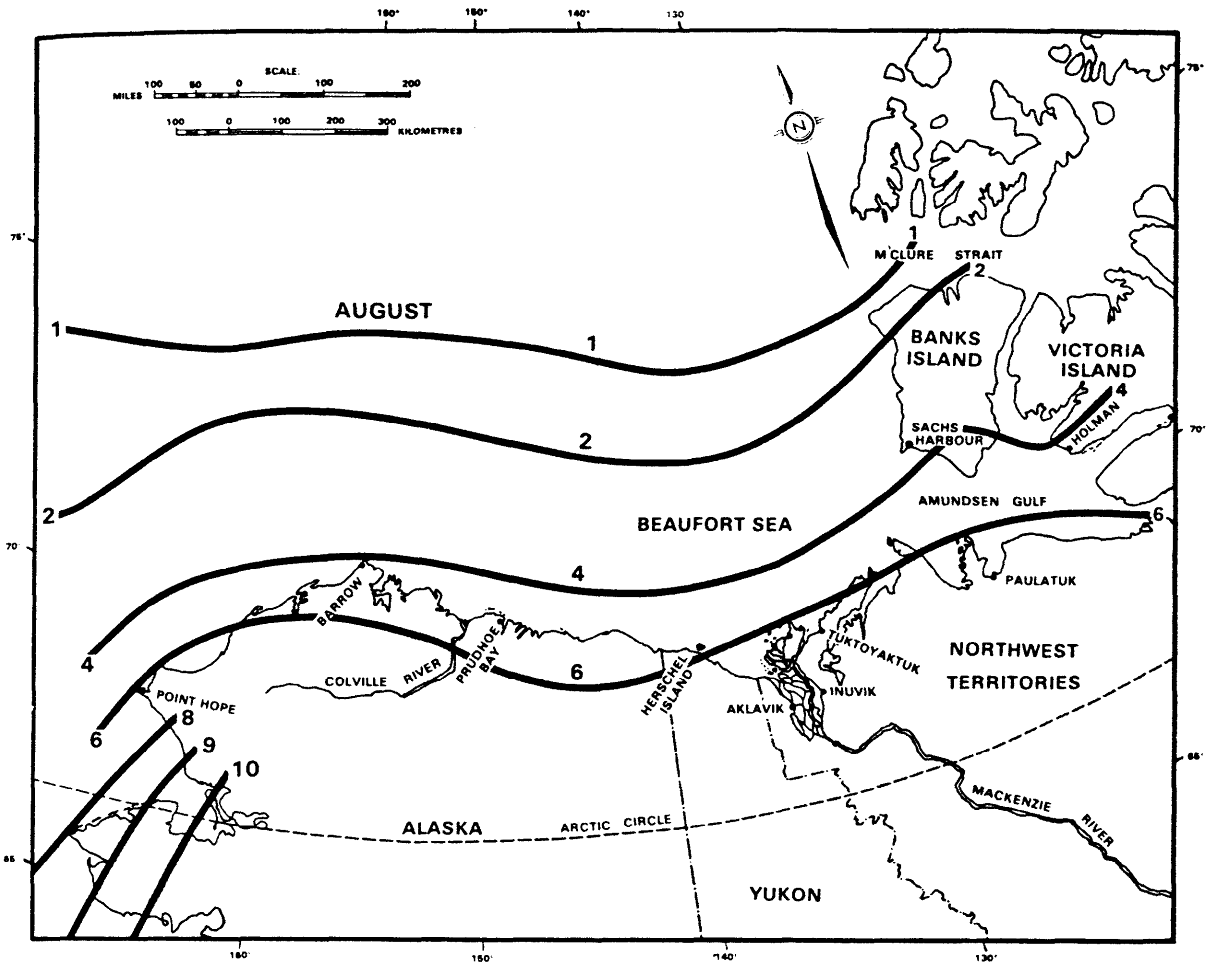


FIGURE 1.2-3 *Mean August air temperatures (° C) in the Beaufort-Chukchi region. Summer temperatures over open water are moderated by the heat exchange from the ocean to the air. (Sources: Brower et al., 1977; Maxwell, 1980).*

varies from just over 10 cm at Sachs Harbour on Banks Island to 46 cm at Tin City on the western Alaskan coast (Figure 1.2-4). The contribution of snowfall to the total precipitation increases toward higher latitudes and at higher elevations. For example, only 38% of the total annual precipitation at Tin City falls as snow, while this proportion increases to over 60% at more northerly coastal locations. North of Cape Lisburne snow can fall during any month of the year, but this is not usually the case at Kotzebue during July and August (Brower et al., 1977). Rain normally falls between June and September, but onshore station records indicate that less than 8 cm can be expected during the summer (MEP, 1981b; Brower et al, 1977; Burns, 1974). Thunderstorms and hail are both rare in Arctic regions.

Most precipitation falls during July and August mainly because synoptic systems follow more northerly tracks, and because more evaporated moisture is in the atmosphere during the summer. The lowest precipitation is generally recorded during January and February in the Beaufort-Chukchi region. During the autumn, open water is an important source of moisture, and evaporation from the relatively warm water into the colder air greatly increases local precipitation (Burns, 1974).

Freezing precipitation occurs when super-cooled water droplets strike below-freezing surfaces and then freeze on contact to form glaze or rime ice. Along the Beaufort-Chukchi coasts freezing drizzle is the most frequent form of freezing precipitation, and this usually occurs when warm moist air over open water moves onto the colder coastal slopes. Freezing rain accompanies synoptic fronts and accounts for about 20% of the freezing precipitation events in this region (Maxwell, 1980).

Coastal records from the Beaufort-Chukchi region show that most freezing precipitation occurs in the fall, with somewhat less in the spring. Locations such as Barter Island and Cape Parry receive up to 50 hours of freezing precipitation annually, compared to 25 hours over Amundsen Gulf and the eastern Beaufort Sea. The western Alaskan shores only receive about 15 to 20 hours of freezing precipitation each year, while Barrow, Alaska, experiences 75 to 80

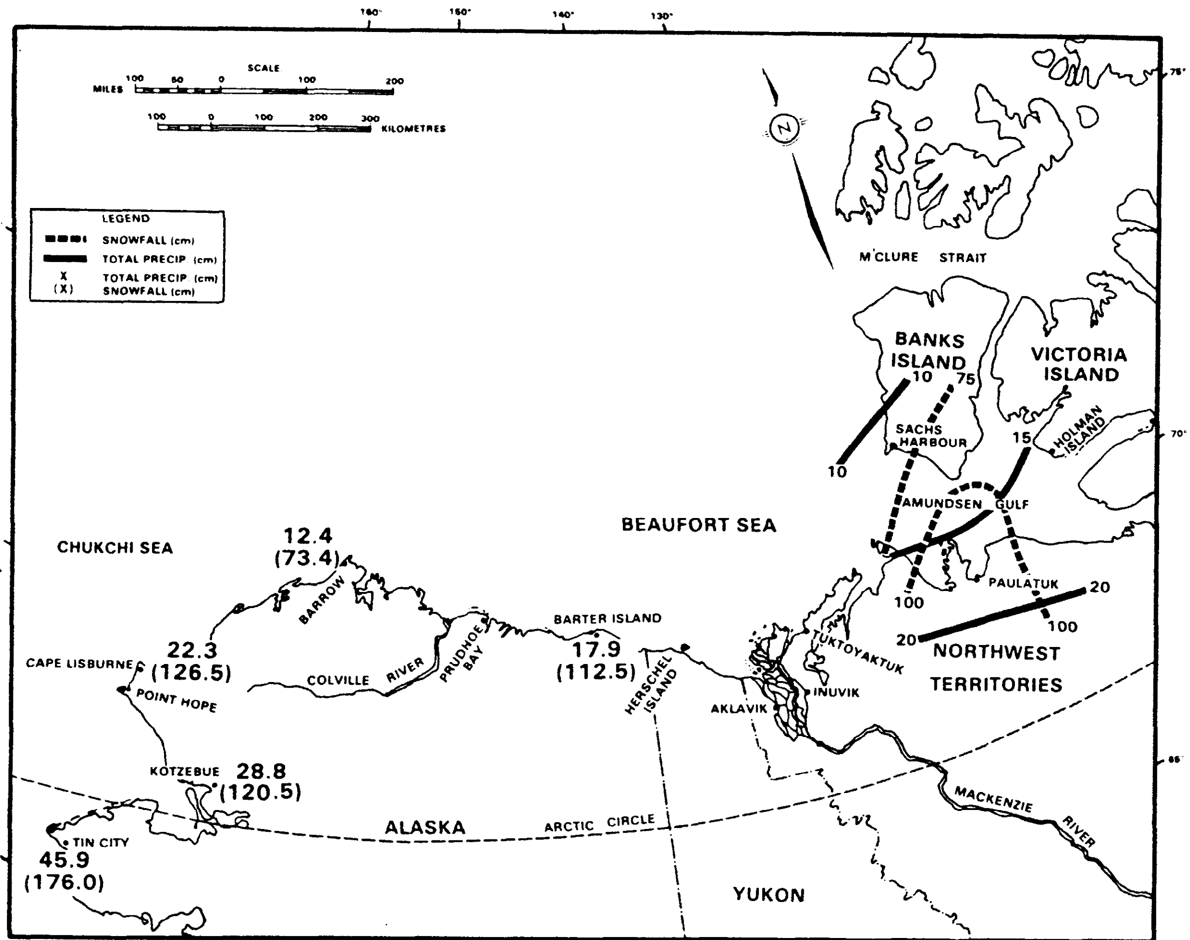


FIGURE 1.2-4 *Total mean annual precipitation and snowfall in the Beaufort-Chukchi region. The low frequency of storm tracks crossing this region, as well as the limited capacity of cold air to hold moisture, results in a relatively low annual precipitation. (Source: Maxwell, 1980).*

hours (MEP, 1981b; Brower et al., 1977). Available coastal data suggest that 20 to 30 hours of freezing precipitation may be expected annually in the offshore Beaufort.

1.2.6 VISIBILITY

Visibility is an important factor affecting aviation and marine operations in the Beaufort Sea region. Limited visibility can adversely affect crew changes, resupply and ice reconnaissance flights. Although aircraft operating in this region are normally Instrument Flight Rated (IFR) and have state-of-the-art radar equipment, minimal ceiling and visibility criteria must be met for landing and taking off.

Generally visibility in the clear Arctic air is high. Although the sun does not rise above the horizon (Figure 1.2-5) for up to three months during the winter at latitudes north of the Arctic Circle (67°N), reflection of moonlight from snow and ice and a long twilight period brighten the polar night.

During the summer, fog mostly limits visibility, particularly in coastal areas. Warm moist air may become saturated as it cools over the cold sea. It then may condense to form fog. Light onshore winds advect the fog into coastal areas, while stronger winds lift the fog to form low cloud. As the summer progresses, fog becomes patchy over the sea and is most prevalent at the edge of ice floes (Burns, 1974).

There is less fog in winter than in summer in the Beaufort region. Steam fog may form near leads or tidal cracks in the ice as cold Arctic air passes over warm open water. This form of fog is patchy and is usually found between October and April. Ice fog (Section 1.2.4) is not common in this region, but when the sun is low it can hamper visibility of the horizon and prevent Visual Flight Rating (VFR) aircraft operations. Blowing snow is the main cause of reduced visibility during the winter (Burns, 1974). Ice crystal haze and whiteout may also reduce visibility in the Beaufort-Chukchi region during the winter.

Over the Beaufort Sea, low visibilities (1 km or less)

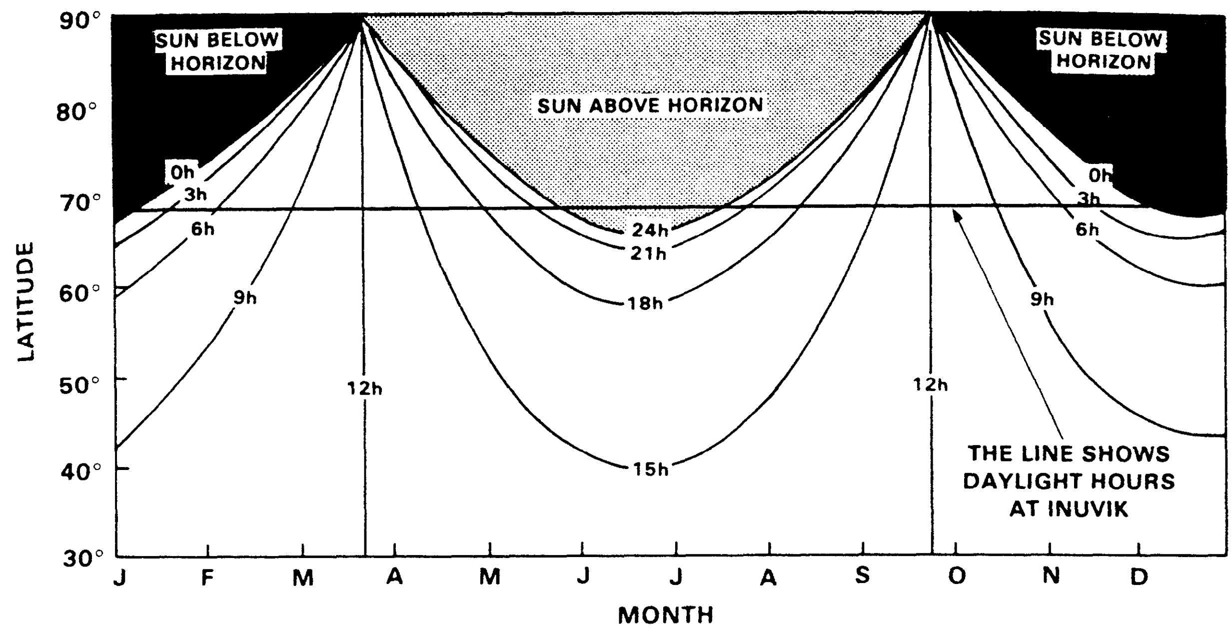


FIGURE 1.2-5 *Duration of sunlight. The sun does not rise above the horizon for up to three months during the winter at latitudes north of the Arctic Circle (67° N). (Source: Burns, 1973).*

are more frequent in summer than in winter, with least visibility occurring in July when it may be less than 1 km, 15 to 20% of the time (Burns, 1974). However, the persistence of visibilities of less than 4 km is greatest during the fall and winter, and least in the summer, when they occur 20 to 30% of the time.

Along the coastline of the Chukchi Sea visibility is less than 4 km, 15 to 20% of the time from November through August (Brower et al., 1977). However, over the sea visibilities of less than 4 km occur mostly during the summer (about 20-25% of the time). September and October are the clearest months in the Chukchi region, with visibility exceeding 4 km over 90% of the time south of Cape Lisburne, and 80 to 90% of the time over northern waters. On an annual basis visibility in the Kotzebue Sound area is less than 4 km, 10% or less of the time.

In general, the poorest flying conditions can be expected along the coast of the Beaufort region during summer and fall. Cloud ceiling and visibility conditions for the area are discussed in greater detail in MEP (1981b).

1.2.7 WIND

Wind mostly affects marine operations by generating high seas, by moving ice into areas where vessels operate and by reducing visibility needed for supporting aircraft. During the late summer and early fall when ice is usually well offshore, strong winds cause high waves when the fetch (extent of open water over which the wind blows) is large - often at its annual maximum. Winds may reduce visibility by causing blowing snow or by advecting sea fog into coastal areas (Section 1.2.5). Finally, with low air temperatures, winds control the severity of freezing spray (Section 1.2.5) and wind chill (Section 1.2.3).

High coastal lands and the sharp thermal contrast between the land and the sea strongly influence coastal winds. For example, katabatic (downslope) winds from the Melville Hills at the base of the Parry Peninsula have been known to approach hurricane speed (Maxwell, 1980). Circulations driven by temperature differences between the land and the sea result in onshore breezes in summer and offshore breezes from the pack ice edge or open water in the winter. For example, the effects of sea breezes on local wind fields at Kotzebue Sound result in over 50% of all winds being westerly (Brower et al., 1977). Sea breezes and conformity of wind direction to the local landforms are also apparent at Sachs Harbour where southeasterly winds predominate (Maxwell, 1980).

Estimates of extreme winds and the expected recurrence period or 'return periods' of these winds are important design criteria applicable to marine operators. Several extreme wind analyses have been completed for the Beaufort-Chukchi region and are described in MEP (1981b). A Beaufort Sea study conducted by MEP (1981a) used pressure data from 1969 to 1978 to estimate extreme winds for ten locations north of Tuktoyaktuk as shown in Figure 1.2-6a. Results shown are an average over the ten locations. It can be seen that, once every 50 years, an extreme hourly average wind speed of 105 km/hr might be expected in the area. Figure 1.2-6b, also from this study, shows how the 50 year return period hourly

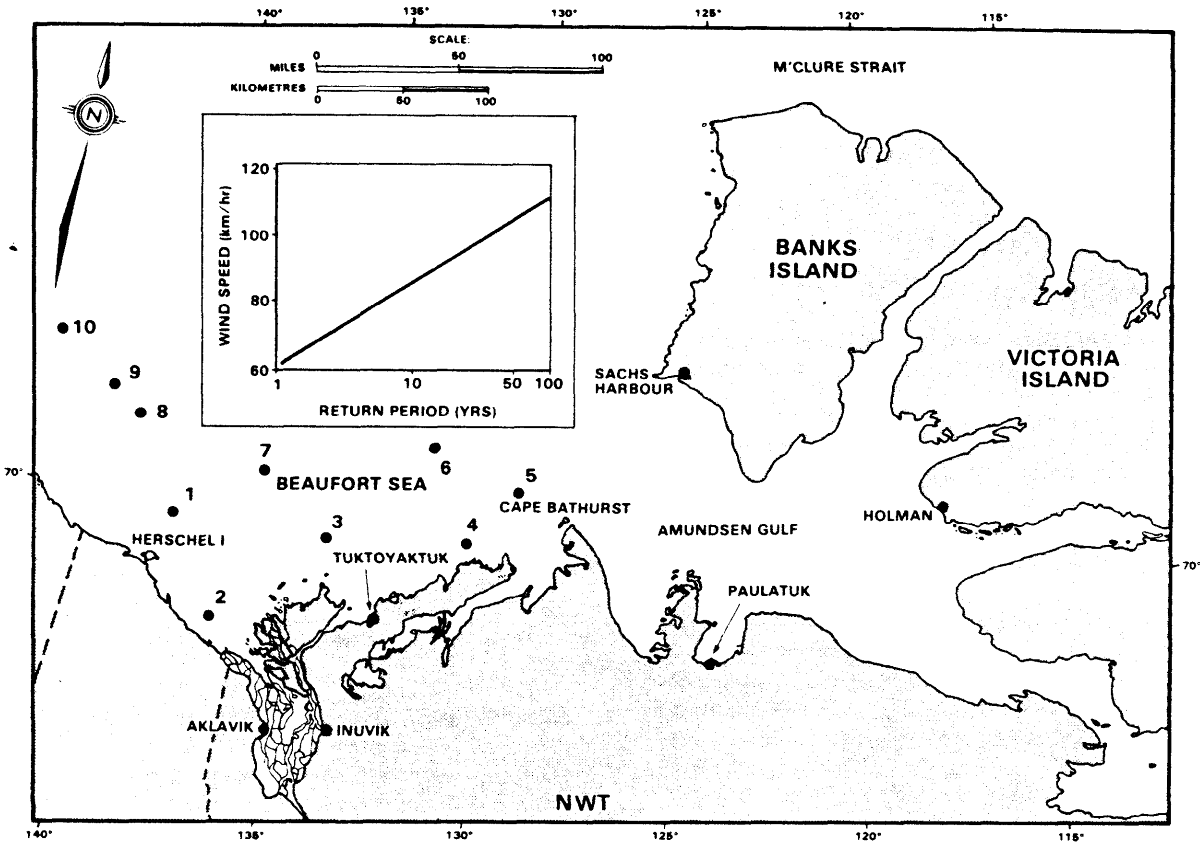


FIGURE 1.2-6a *Extreme wind speeds (average hourly winds) for various return periods and averaged over ten Beaufort Sea locations. It can be seen that, once every 50 years, an extreme hourly average wind speed of 105 km/hr might be expected in the area. (Source: MEP, 1980).*

average wind varied from 97 km/hr to 112 km/hr depending on location, being about 15% higher in the western part of the study area. These results are consistent with another extreme wind analysis conduct by Maxwell (1981). Although not directly comparable, Brower et al. (1977) calculated extreme winds for the Chukchi and Beaufort seas based on one minute averages (instead of hourly as in MEP, 1981a). Figure 1.2-7 shows that extreme winds are expected to be higher in the Chukchi Sea than in the Beaufort Sea. For example, 50 year return period winds are expected to have a speed of 165 km/h in the Chukchi and 139 km/h in the Beaufort - mroe than 20% lower. Caution is advised in comparing results since all hincast studies are limited by the quality and length of the data set used, by topographical influences on the data set, and by the method of analysis used for computing extreme winds.

Knowledge of wind directions over the Beaufort and Chukchi seas is used in the prediction of ice movements. Wind direction also affects the fetch in the generation of waves (Section 1.2.8). The dominant wind direction ranges from northeast to southeast for both the offshore and coastal Beaufort during any month of the year (Berry et al., 1975). However, these wind directions vary seasonally as shown in Figure 1.2-8. Over the Chukchi Sea westerly to southerly winds are most frequent in July, while over the Beaufort Sea easterly winds are dominant and southerly winds are rare during the summer months (Brower et al., 1977). A pronounced shift to westerly winds occurs between Barter Island and Shingle Point. From July to September, westerly to northwesterly winds in excess of 36 km/h become persistant. Fifty percent of all strong winds with speeds exceeding 50 km/h are from the west or northwest, and these winds are often responsible for multi-year pack ice intrusions into coastal Beaufort Sea waters (Berry et al., 1975).

1.2.8 Wind Waves

The wind generated wave climate is an important concern to offshore operations in all areas of the world. Knowledge of the wave climate is required for the design of offshore structures and for selecting equipment that will be able to operate in the wave conditions that are generally present.

The height of wind generated waves depends on wind strength, duration, water depth and the extent of open water, or fetch, over which the wind blows. In the Beaufort-Chukchi region, the fetch is limited by the presence of sea ice and by local landmasses throughout the area. As a result, normal sea states in

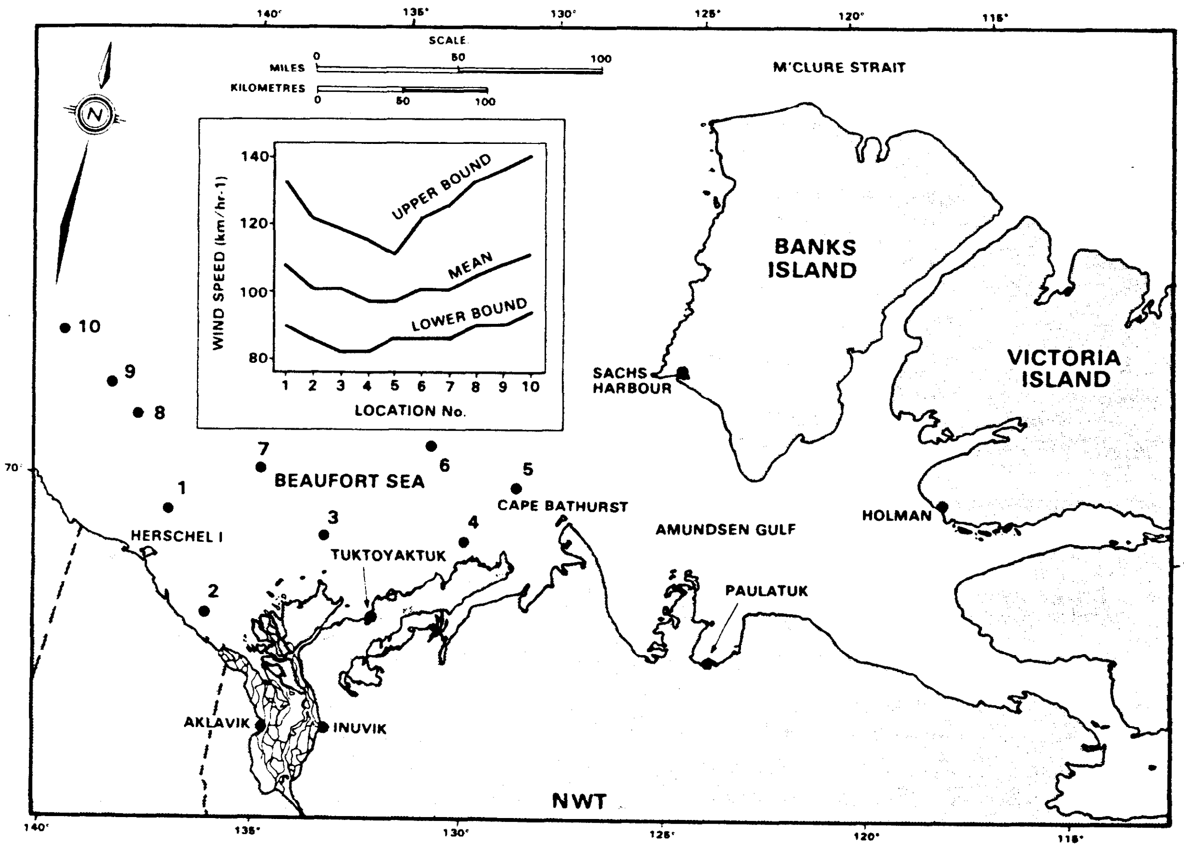


FIGURE 1.2-6b *Error bounds on 50 year return period wind speeds for ten Beaufort Sea locations. This figure shows how the 50 year return period hourly average wind varied from 97 km/hr to 112 km/hr depending on location, being about 15% higher in the western part of the area. (Source: MEP, 1981a).*

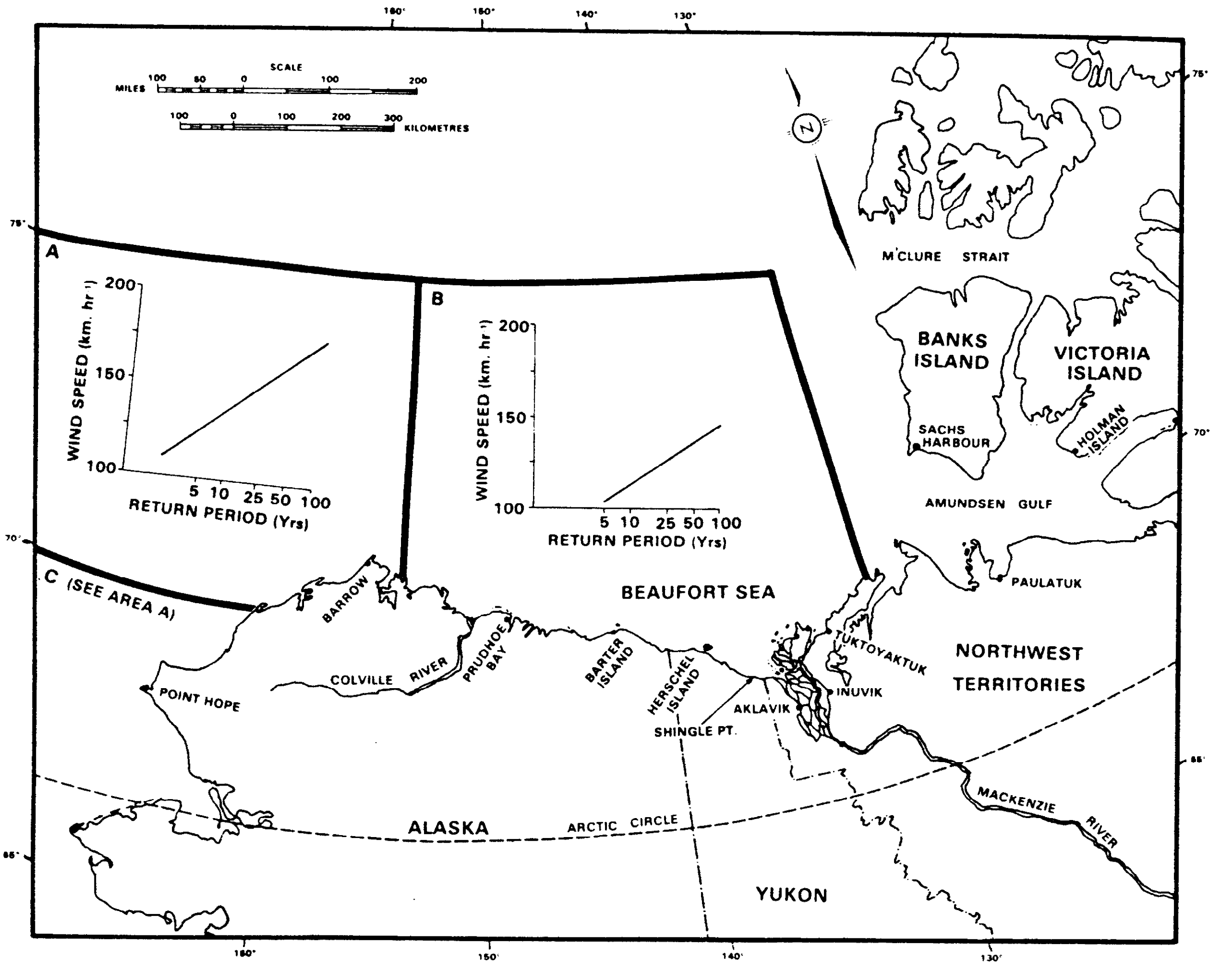


FIGURE 1.2-7 *Extreme wind speeds (one minute averages) in the Beaufort-Chukchi region. Extreme winds are expected to be lower in the Beaufort Sea than in the Chukchi Sea. For 50 year return periods they are expected to be 20% lower in the Beaufort Sea. (Source: Brower et al., 1977).*

the Beaufort Sea are less severe than those in other areas of the world where offshore drilling and production operations are being conducted.

Wave information has been recorded at over 20 sites in the eastern Beaufort Sea with Datawell Waverider buoys since 1975. These records show that locally generated wind-waves as opposed to swell dominate the energy spectrum. The large wind waves have average periods of 6 to 8 seconds, and only rarely are periods of 10 seconds or above observed.

Waverider buoys have provided wave height and period data. However, because of the limited data, hindcast techniques have had to be employed to predict long-term extreme conditions which is a usual approach, as a lengthly record is seldom available. The best description of the wave climate of the Beaufort Sea comes from two recent hindcast studies by Baird and Hall (1980) and Seaconsult (1981). The Baird and Hall study defined the normal wave climate of the Beaufort Sea, Seaconsult concentrated on defining extreme storm conditions.

Baird and Hall (1980) used 10 years of Tuktoyaktuk wind data to determine the normal wave climate at various well sites.

Bretschneider's method was used with fetches determined by the land and the 1/10th ice cover position. Comparison of the hindcast results with waverider buoy wave height and period data showed generally good agreement, although during some storm events differences were observed. This analysis shows that the highest waves occur in September, and are produced by westerly and northwesterly winds. A typical wave height exceedence diagram for Kopanoar is shown in Figure 1.2-9.

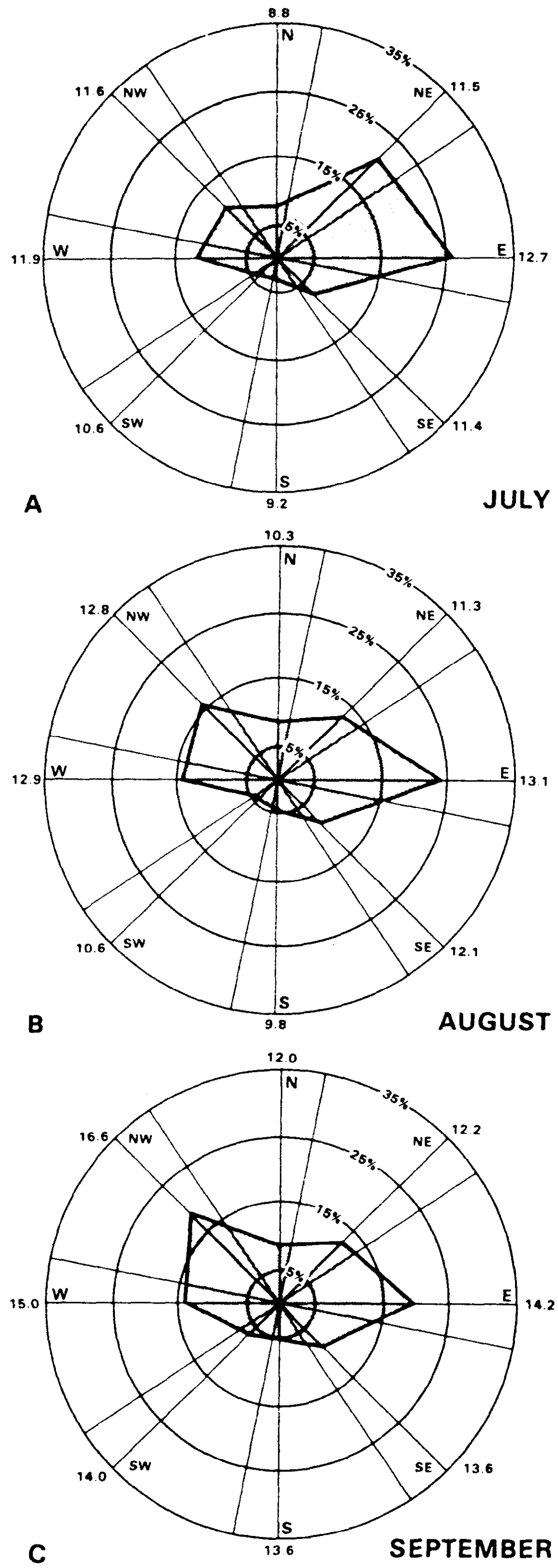


FIGURE 1.2-8 *Percentage frequency occurence of given wind directions for all speeds in July, August and September at 140° W over the Beaufort Sea. Easterly winds are dominant and southerly winds are rare during the summer months. Fifty percent of all strong winds are from the west or northwest and these can push ice into coastal Beaufort Sea waters. (Source: Berry et al., 1975).*

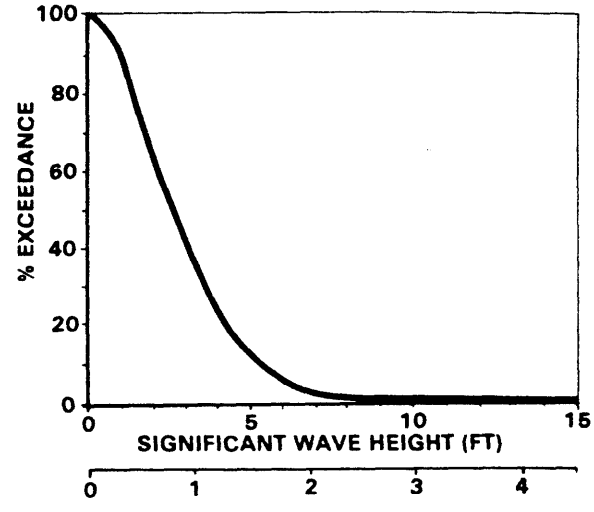


FIGURE 1.2-9 *Percentage of time that significant wave heights exceed a given height during the open water season at Kopanoar. It is seen that significant wave heights exceeded 2 m only 2.5% of the time during the season. (Source: Baird, W.F. and K.R. Hall, 1980).*

Offshore structures have to be designed to withstand the most severe wave conditions that can be expected. The significant wave heights at Kopanoar, extrapolated from the study, are 4.8, 6.4, and 7.2 m for return periods of 10, 50, and 100 years, respectively (Figure 1.2-10). The dotted lines in the figure indicate the range of wave heights associated with a given return period; these reflect the limited data base used. Such analyses are normally not considered too reliable for predicting return periods beyond twice the length of the data base, i.e. 20 year in this case.

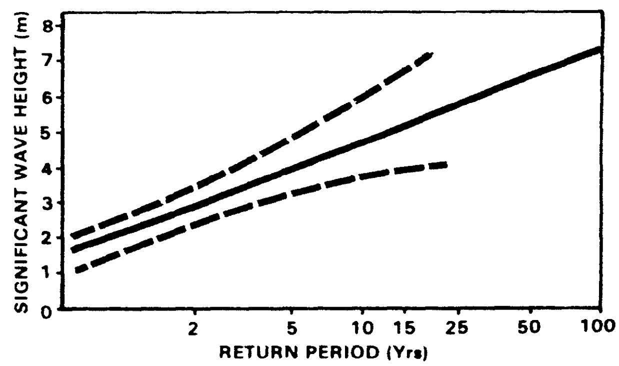


FIGURE 1.2-10 *Maximum significant wave heights vs return period at Kopanoar. The maximum significant wave height for a 100 year return period is expected to be 7 m. (Source: Baird and Hall, 1980).*

The Seaconsult (1981) hindcast used two numerical models. Storm surges were calculated with a finite difference solution to the complete, non-linear shallow water wave equations using two-dimensional ice, wind and pressure fields. The wind-waves were modelled with a descrete directional wave energy spectral model, that included depth-induced refraction, and two-dimensional ice and wind fields.

In this hindcast, extreme winds were derived statistically from a 10-year (1969-1978) wind climatology (MEP, 1981). The extreme storm wind fields were derived from a weather system that occurred over the area on August 26 - 28, 1975, which was representative of the class of storms that can produce the most severe sea-states. The weather system was intensified by increasing the pressure gradients so that the maximum wind speed produced by the weather system equalled the 10, 50, and 100 year return period wind speed previously determined. The pressure and wind fields of this intensified storm were used as input to the numerical models for storm surge and wind-waves. Seaconsult used the most northerly 9/10th ice cover position that has been observed to date as the effective fetch in their models.

This hindcast for the Kopanoar site gives significant waves of 9.2, 12.5, and 13.2 m for the 10, 50, and 100 year return period winds used. It is not possible to attach meaningful wave return periods to these values because of the manner in which they were generated. However, these values are conservative estimates of the 10, 50, and 100 year return period significant wave heights and in fact probably correspond to wave return periods considerably longer than the periods of the winds used to generate them. The conservatism in these estimates comes from the selection of a storm type and trajectory, and ice edge position which maximize the wave heights which can be generated for a given wind speed.

It is also noted that the largest significant wave height recorded in the drill area by a Waverider buoy over the past 5 years is 3.6 m. A concerted effort will be made over the next few years to improve the accuracy of significant wave heights of long return period storms.

1.2.9 STRUCTURAL ICING

A thick coating of ice on the superstructures of vessels and installations at sea can be hazardous. Small ships, such as those used to resupply offshore platforms, can become unstable when ice accumulates and increases the vessel's top-weight. Ice accretion can also place additional stresses on stationary structures, and generally inhibit offshore activities. There have been few actual observations of ice accretion on vessels in the Beaufort and Chukchi seas because the ocean freezes over, thus eliminating the spray, and because the ships generally leave the hazardous area once structural icing has started. The theoretical icing studies presented here cannot be verified in the absence of data describing real icing events in the Beaufort-Chukchi region.

During the spring or fall freezing rain or drizzle can result in icing. However, the annual incidence of freezing precipitation on the western coast of Alaska and over the eastern Beaufort Sea is normally less than 25 hours (Section 1.2.5). There is a potential for more severe icing in the vicinity of Point Barrow where there is freezing precipitation 70 to 80 hours each year (Brower et al., 1977). Icing due to steam fog is only a problem for short periods in the fall before the sea becomes ice-covered.

Freezing spray is the most common and hazardous form of icing, and occurs when the air temperature is below the freezing point of seawater (-2°C). The rate of ice accretion due to freezing spray increases with increased wind speed and decreasing air temperatures according to the relationship illustrated in Figure 1.2-11. However, it should be noted that this nomogram is not applicable when sea ice concentrations greater than 7/10ths diminish wind-generated spray.

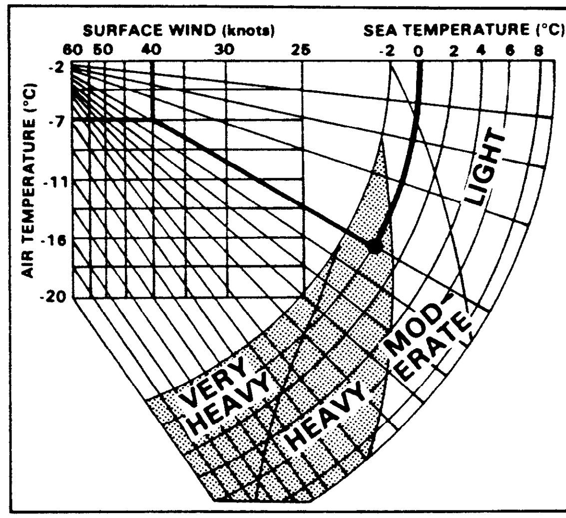


FIGURE 1.2-11 *Nomograph for forecasting ice accumulation from freezing spray. Freezing spray is the most common and hazardous form of icing. (For example: with an air temperature of -7° C, a surface wind-speed of 40 knots and a sea temperature of 0° C, heavy freezing spray is expected).*

As yet there are no quantitative data describing freezing spray events in the Beaufort Sea. Berry et al. (1975) used meteorological data from Cape Parry and Sachs Harbour to estimate ice accretion in the eastern Beaufort (Figure 1.2-12). For any given return period the accumulated ice thickness near Sachs Harbour is expected to be greater than that near Cape Parry, because the former station is further north and closer to the pack ice. The Figure indicates that based on a 25 year return period, accumulated ice thicknesses of 28 and 39 cm were predicted for Cape Parry and Sachs Harbour, respectively. According to Shekhtman (1968), icing conditions become hazardous when ice accumulation exceeds 10 cm. The results of the study by Berry et al. (1975) suggest that ice thicknesses greater than 10 cm have a return period of two years at both Cape Parry

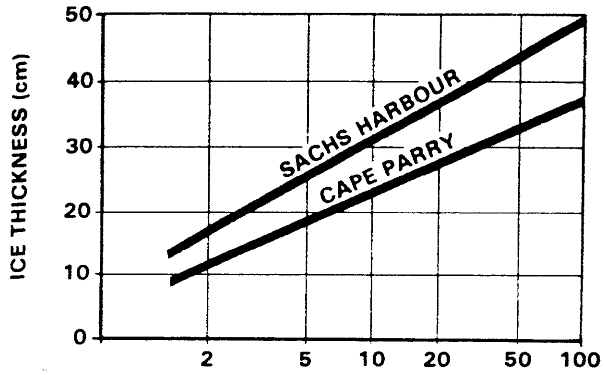


FIGURE 1.2-12 *Return period for structural icing in the Eastern Beaufort. Ice accumulations can become hazardous when they exceed a thickness of 10 cm. (Source: Berry et al., 1975).*

and Sachs Harbour. Consequently, potentially hazardous icing conditions could exist in the Beaufort Sea during September and October. However, structural icing has never been a problem during Dome Petroleum's operations during the summer, or during tests with the icebreaker Kigoriak during the winter of 1979-80 (D.M. Huebner, pers. comm.).

1.2.10 SYNOPTIC STORM TRACKS

The frequency and intensity of storms expected in the Beaufort region are of particular interest to offshore operations. The severity of storms is related to the duration of high wind speeds from the same general direction. North and northwest winds are often responsible for moving pack ice into the Beaufort Sea's shelf where drilling can be disrupted. With sufficient fetch, these winds can produce storm tides, or surges (Section 1.3.4.4), which can inundate low-lying coastal lands. Conversely, sustained winds from the south through east can clear ice off the shelf and produce high waves which can force the suspension of some offshore operations. Analyses of the trajectories of historical low pressure systems that have frequented the southern Beaufort Sea and Mackenzie Valley are displayed in Burns (1973) and described in MEP (1981b). Although such analyses reveal the percentage of time that a low pressure system, or a storm, can occupy a given area, they do not say anything about the severity of the storms in relation to their primary or secondary trajectories. Nor do they reveal the variable nature of storm wind directions and storm durations. Figures 1.2-13 through 1.2-16 (Burns, 1973) show atmospheric low (or storm) trajectories for the months of January, April, July and October, respectively. It is evident that in the Beaufort Sea the passage of storms occurs less than 2% of the time in January, rising to about 8% of the time (in Mackenzie Bay) during July. By October storms are expected to occur between 4 and 6% of the time over most of the Beaufort Sea. They then are expected to reduce in frequency to those of January.

(A more general description of regional synoptic climatology is given in Section 2.1.1).

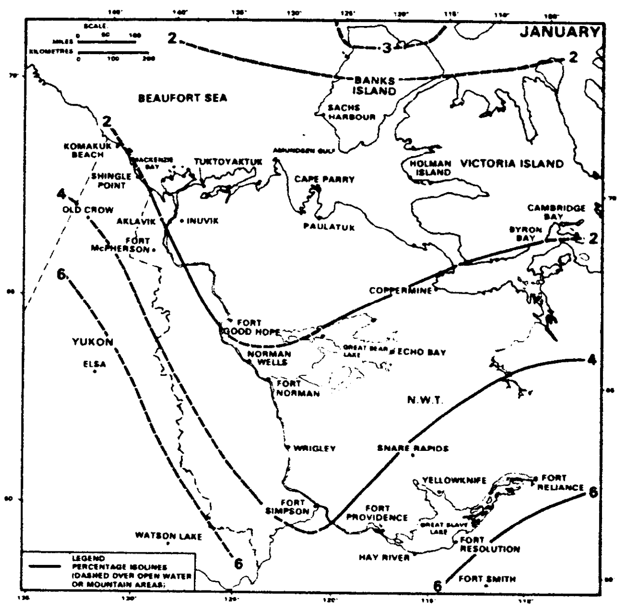


FIGURE 1.2-13 *Percentage of time that atmospheric lows (storms) occupy a 10° lat. by 10° long. area in January (centred at 65° N, 120° W). (Source: Burns, 1973).*

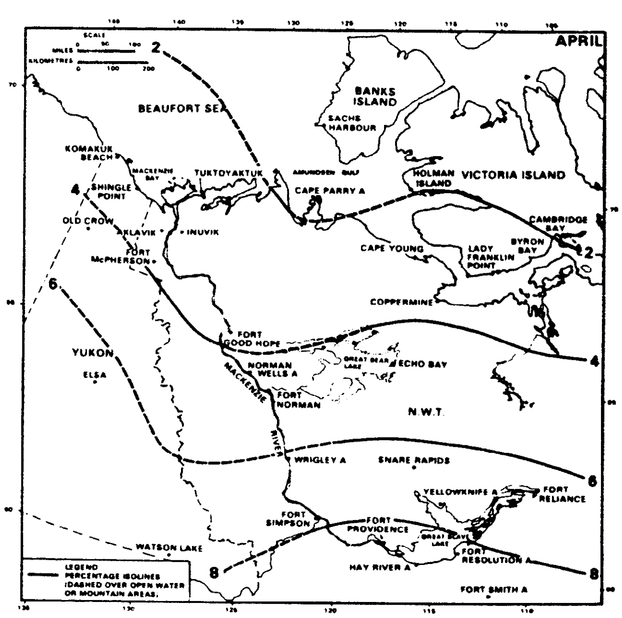


FIGURE 1.2-14 *Percentage of time that atmospheric lows (storms) occupy a 10° lat. by 10° long. area in April (centred at 65° N, 120° W). (Source: Burns, 1973).*

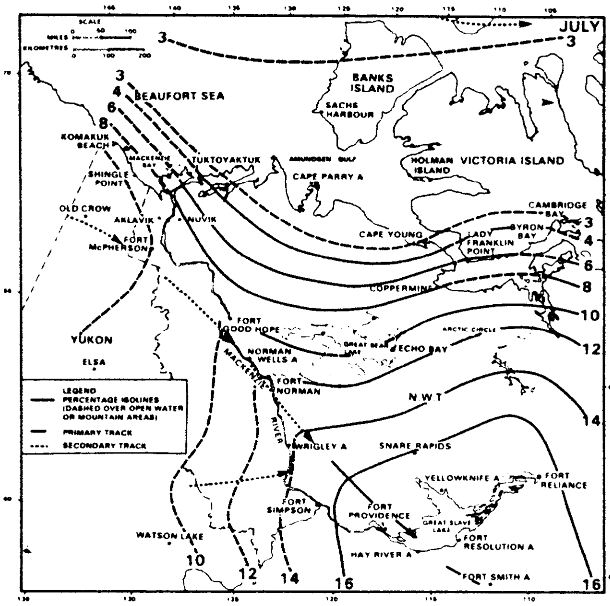


FIGURE 1.2-15 *Percentage of time that atmospheric lows (storms) occupy a 10° lat. by 10° long. area in July (centred at 65° N, 120° W). (Source: Burns, 1973).*

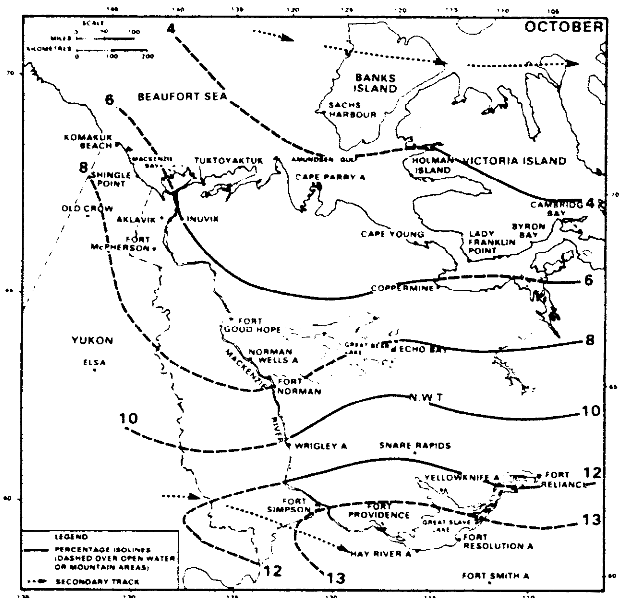


FIGURE 1.2-16 *Percentage of time that atmospheric lows (storms) occupy a 10° lat. by 10° long. area in October (centred on 65° N, 120° W). (Source: Burns, 1973).*

Although there are statistical data classifying expected wind speeds and directions based on past wind-history (Section 1.2.7), no similar studies exist where numerous past atmospheric pressure patterns are classifed by degree of storm severity. The Arctic Weather Centre analyzed 33 storm periods during the 1980 drilling season in the Beaufort Sea (AES, 1980) and classified them according to their severity. However, this study is only a 1980 case-study of Beaufort Sea storms and does not necessarily represent climatological expectations for future years.

AES (1980) defined a storm period as "a period during which reported wind speeds were 20 knots or more for at least 6 hours." From hourly drillship weather reports 33 such storms were recorded between June 20 and October 31. Eleven of these were classified as Category 2 storms and had sustained wind speeds of 30 knots or more for 6 hours. The 33 storms appeared to fit eight synoptic patterns as shown in Figures 1.2-17 to 1.2-24.

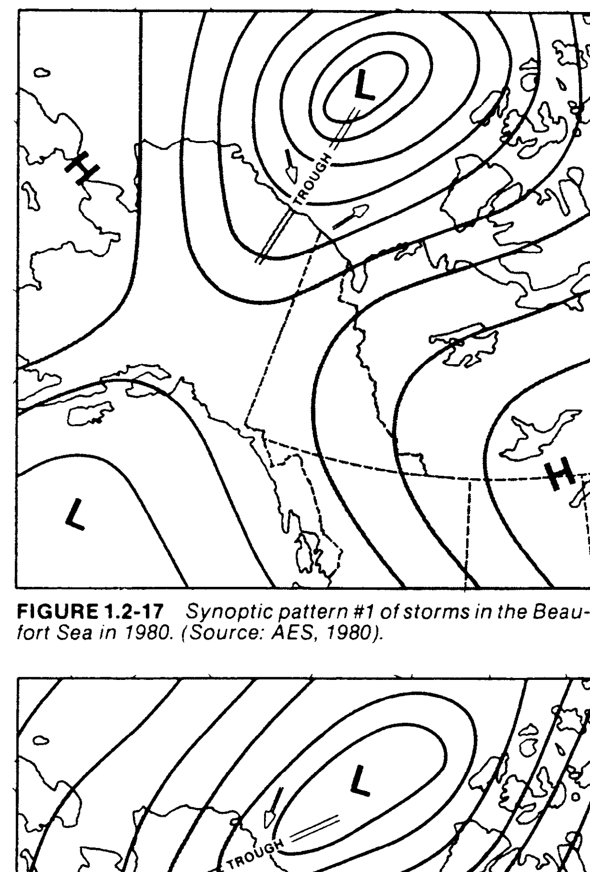


FIGURE 1.2-17 *Synoptic pattern #1 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

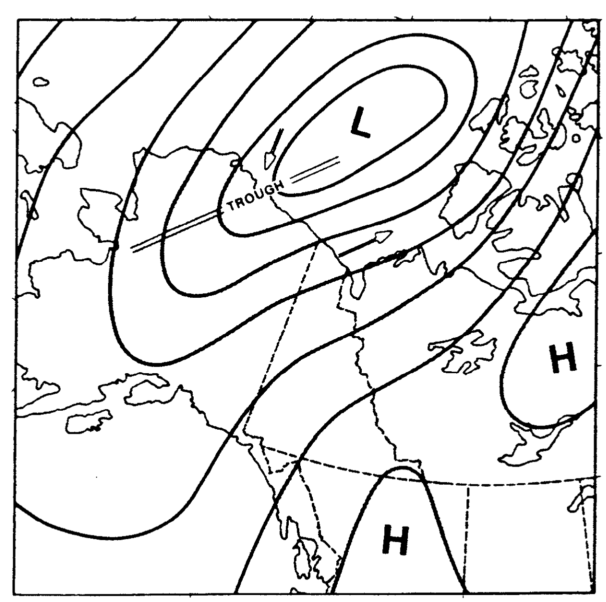


FIGURE 1.2-17 *(cont'd).*

Five storm periods were of particular interest during 1980. The first began on July 30 and lasted 61 hours. It started as a pattern #2 (Figure 1.2-18) and became a pattern #4 (Figure 1.2-20). East-northeasterly winds blew with a maximum speed of 27 knots and generated 2.7 m waves at Koakoak (Figure 1.2-25) for 9 hours.

The second began on August 29 as a pattern #1 storm (Figure 1.2-18) and lasted for 37 hours, having westerly, shifting to northwesterly, winds with a maximum speed of 40 knots. Sustained wave heights of 3.0 m for 5 hours were recorded at Orvilruk (Figure 1.2-25). This storm caused ice to move south eastward across the Kenalooak drillsite (Figure 1.2-25).

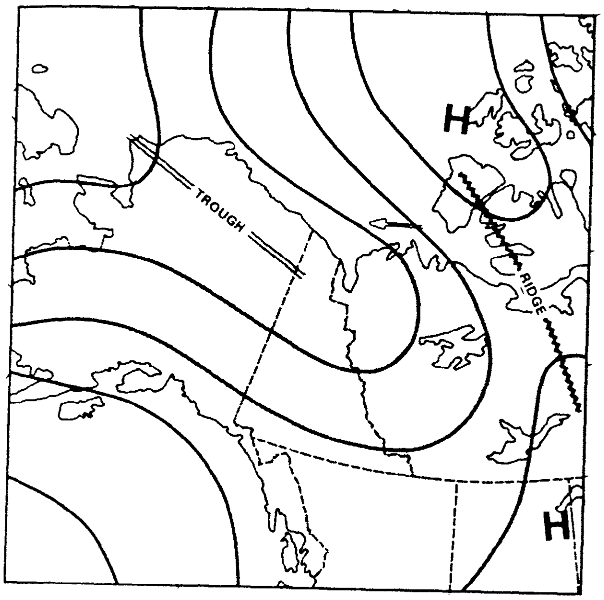


FIGURE 1.2-18 *Synoptic pattern #2 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

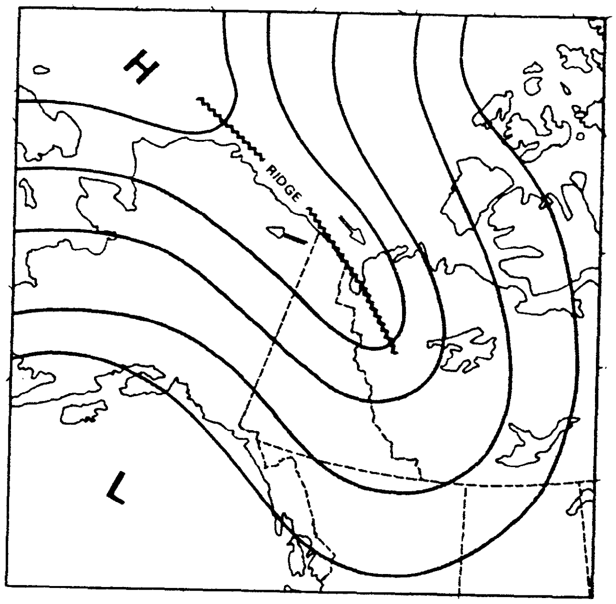


FIGURE 1.2-20 *Synoptic pattern #4 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

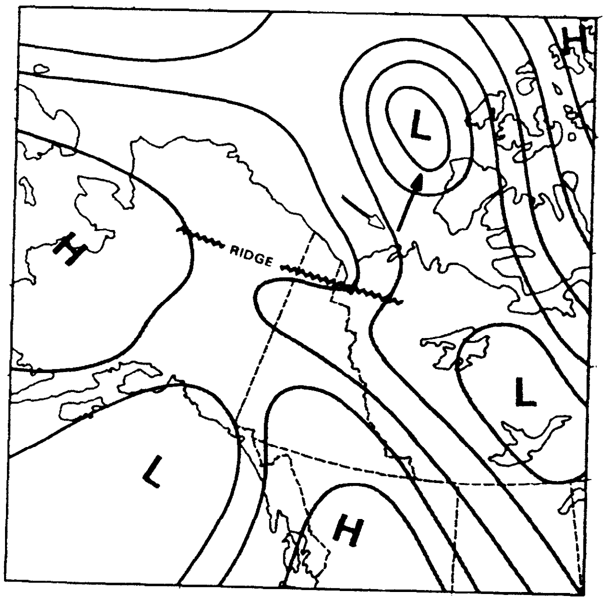


FIGURE 1.2-19 *Synoptic pattern #3 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

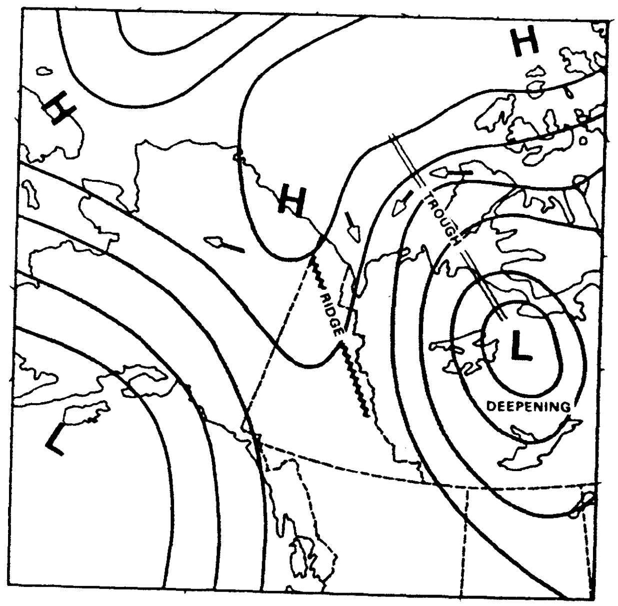


FIGURE 1.2-21 *Synoptic pattern #5 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

The third important storm, also a pattern #1, started September 3 (Figure 1.2-17). It lasted for 19 hours, producing a maximum wind speed of 35 knots and sustained wave heights of 2.7 m for 9 hours. Winds were southwesterly, a rare direction for Beaufort Sea storms.

The fourth storm of interest started on September 16, lasted 49 hours and was a pattern #1 (Figure 1.2-17), which evolved from a pattern #8 (Figure 1.2-24). Winds were northwesterly at 40 knots maximum, with maximum wave heights of 3.7 m. Winds of 30 knots or more lasted 15 consecutive hours.

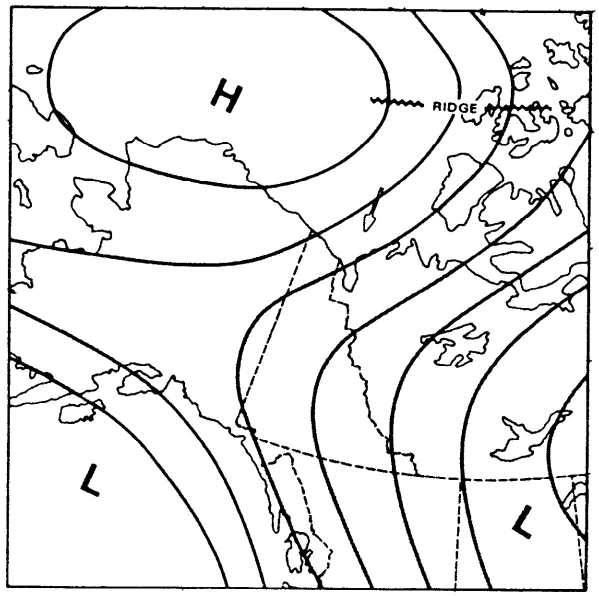


FIGURE 1.2-21 *(cont'd).*

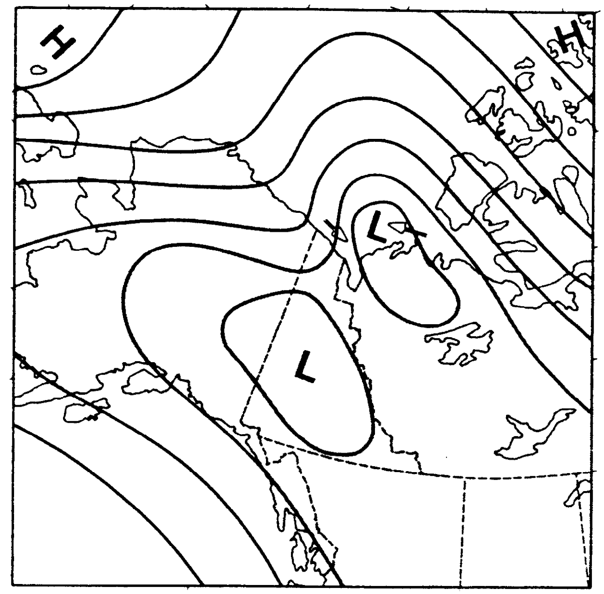


FIGURE 1.2-22 *(cont'd).*

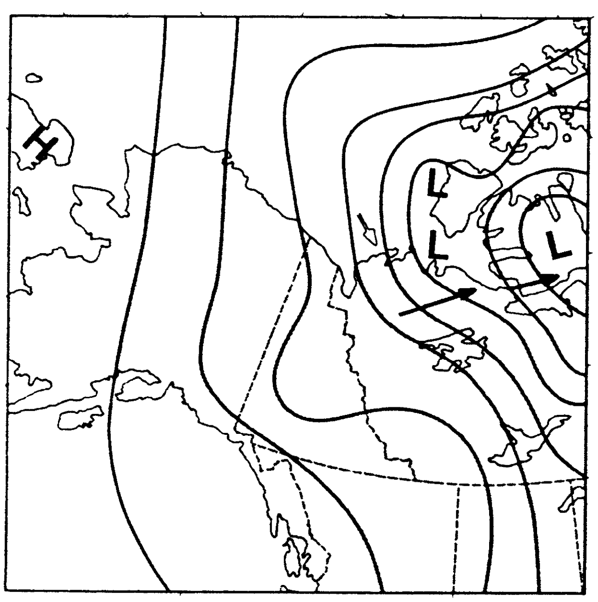


FIGURE 1.2-22 *Synoptic pattern #6 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

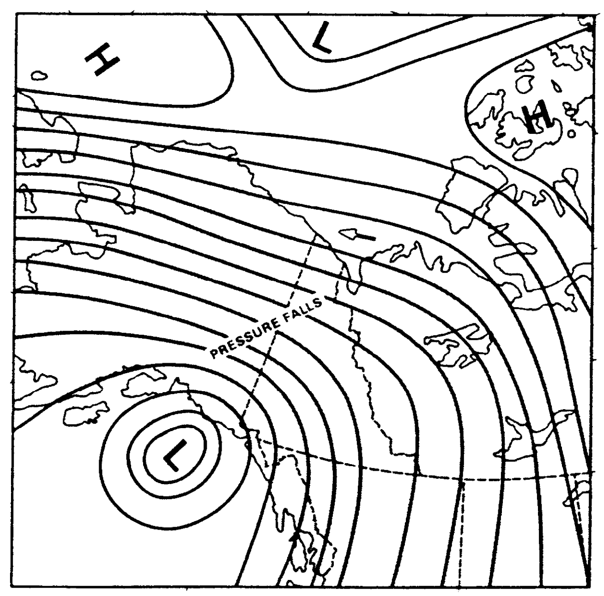


FIGURE 1.2-23 *Synoptic pattern #7 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

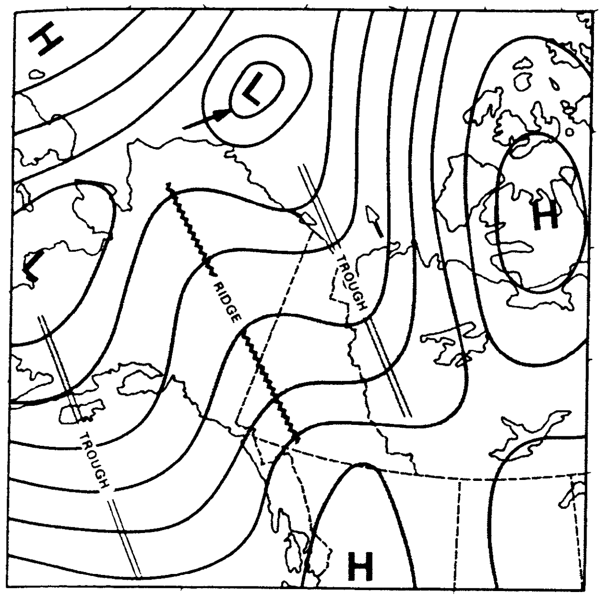


FIGURE 1.2-24 *Synoptic pattern #8 of storms in the Beaufort Sea in 1980. (Source: AES, 1980).*

Finally, the fifth storm started September 26 and lasted 109 hours. It was a pattern #7 (Figure 1.2-23) which became a pattern #4 (Figure 1.2-20) in which easterly winds changed to northerly. This was the season's longest storm.

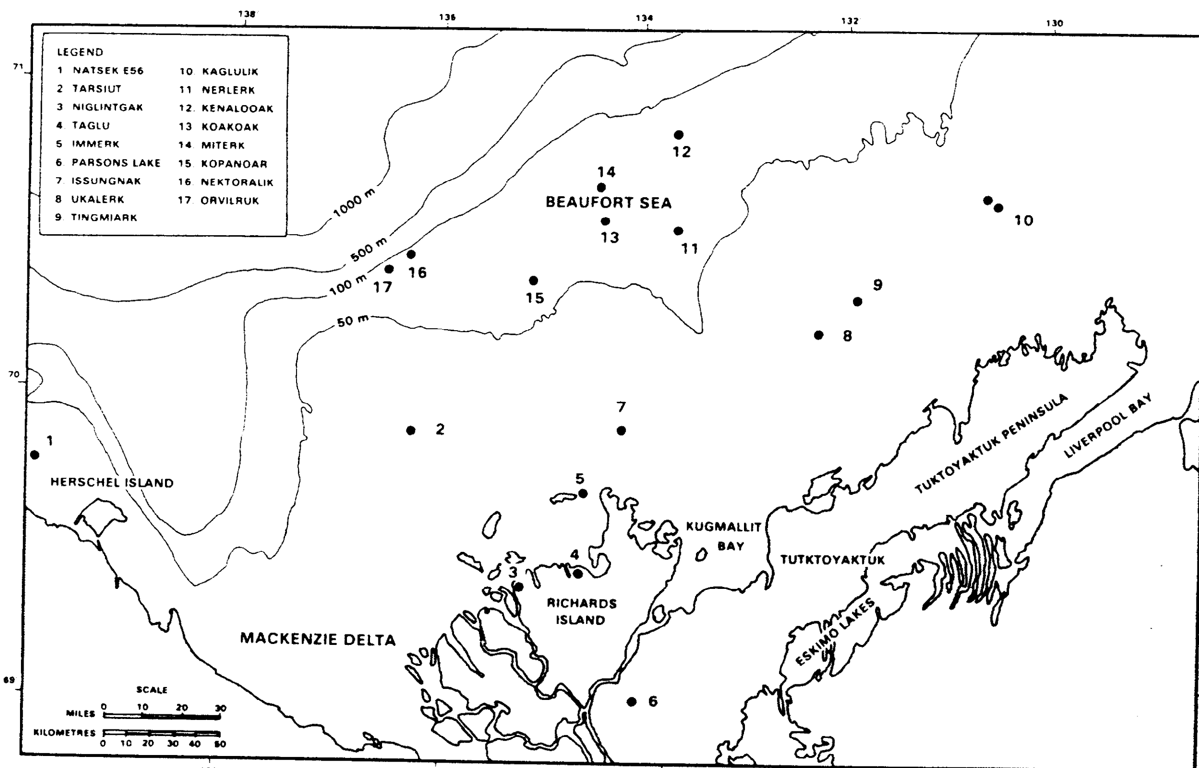


FIGURE 1.2-25 *Beaufort well locations.*

1.3 WATER MASSES AND THEIR MOVEMENTS

1.3.1 SETTING

The general bathymetry of the Beaufort and Chukchi seas (Figure 1.3-1) is an important determinant of regional water properties and circulation patterns. The following provides an overview of the bathymetry of the Chukchi Sea, Beaufort Sea and Amundsen Gulf as a prelude to the discussion on water masses and their movements. A more detailed treatment of bathymetry is provided later in Section 1.4.1.

1.3.1.1 Chukchi Sea

The Chukchi Sea overlies a 50 m deep continental shelf which is an extension of the Alaskan and Siberian land masses (Figure 1.3-1). The shallow depths confine water exchanges with neighboring water masses to the upper layers, and also enhance the effect of winds and other atmospheric forces on circulation. Connection with the waters of the Bering Sea to the south is through the narrow, shallow passage of Bering Strait. Long Strait to the west along the Siberian coast allows interchange of waters of the Chukchi Sea with the East Siberian Sea. The northern boundary of the Chukchi Sea is penetrated by two major canyons, Herald and Barrow, which enter the shelf region from the north. Mountain et al. (1976), Garrison and Becker (1976), and Bourke & Paquette (1976) provide evidence of occasional surges of Arctic Ocean water through Barrow Canyon and onto the continental shelf.

1.3.1.2 Beaufort Sea

The southern portion of the Beaufort Sea contains an extensive, relatively shallow continental shelf. The nearshore portion of this shelf region extending from the coastline to the 10 m isobath, varies markedly in width throughout the area with typical values of 10 km along the Alaskan coast and as much as 40 km off the Tuktoyaktuk Peninsula. In the Alaskan zone the presence of chains of small offshore islands give rise to semi-enclosed, shallow lagoons. Further to the east, the nearshore zone includes the large Mackenzie River Delta, containing more than 50 distributing channels.

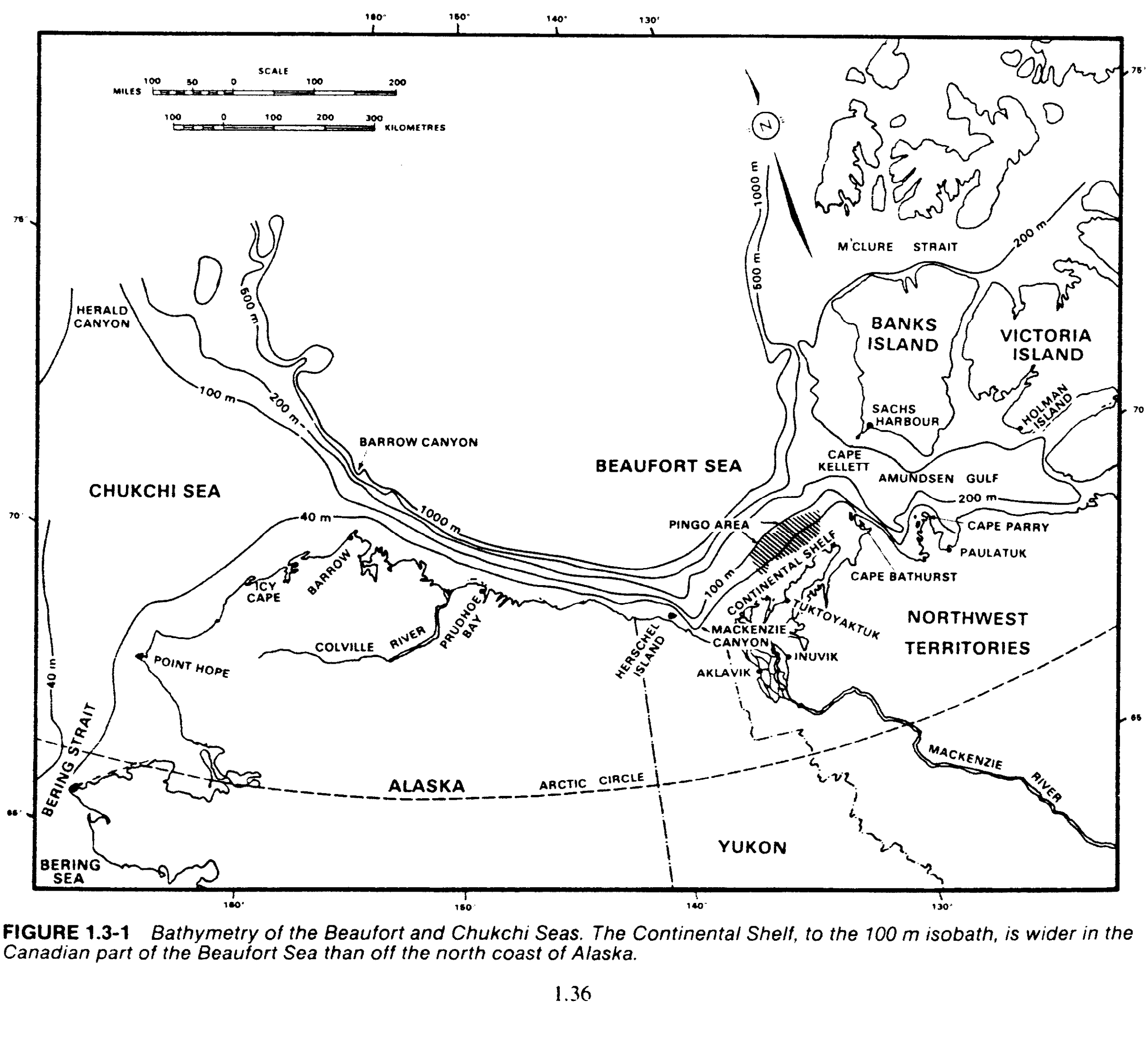


FIGURE 1.3-1 *Bathymetry of the Beaufort and Chukchi Seas. The Continental Shelf, to the 100 m isobath, is wider in the Canadian part of the Beaufort Sea than off the north coast of Alaska.*

The main bathymetric features of the Beaufort Sea beyond the 10 m isobath are the continental shelf, the continental slope, and the deep abyssal plain. In the western (Alaskan) Beaufort Sea, the outer boundary of the continental shelf roughly coincides with the 50 m isobath and is about 70 km wide (Figure 1.3-1). In the southeastern Beaufort Sea, the shelf extends to the 100 m isobath and is 150 km wide in some areas. Major indentations of the continental shelf are Barrow Canyon in the west, Herschel (or Mackenzie) Canyon in Mackenzie Bay, and the trough connecting the Beaufort Sea to Amundsen Gulf in the east. Like the shelf, the continental slope region is much narrower in the Alaskan Beaufort (typically 60 km) than in the Canadian Beaufort (700 km wide). Beyond the continental slope, the relatively flat abyssal plain of the Canadian Basin is more than 3,500 m deep.

The Mackenzie is the dominant river in the southeastern Beaufort Sea region and enters the sea through an intricate maze of large channels and small waterways. In the summer, the river exerts a major influence on the shallow water of Mackenzie Bay as well as on nearshore waters along the Tuktoyaktuk Peninsula. Recognizable portions of its plume are observed as far as 85 km to the west of Herschel Island and north of Richards Island. As indicated in a subsequent section, the influence of the Mackenzie River discharge can extend as far as Amundsen Gulf to the east. The fresh river water, which is often warmer than the underlying seawater, forms a thin but very stable upper layer. This layer has a marked effect on the circulation in the southeastern Beaufort Sea. Additional strong influences on circulation in this region are asssociated with direct outflowing currents, and from buoyancy effects which produce alongshore flows to the east of the prevailing Mackenzie River discharge.

In contrast to the eastern Beaufort Sea and Siberian Shelf, no large rivers drain into the western Beaufort Sea. The largest of the watercourses in the latter region, the Colville River, has an estimated annual discharge $^{1}/_{25}$ that of the Mackenzie. In 1971, 60 % of the annual discharge from the Colville occurred over the three week period immediately following breakup. For other, small rivers 50% of the annual discharge typically occurs over a 10 day period.

1.3.1.3 Amundsen Gulf

Amundsen Gulf is a large embayment to the east of the southeastern Beaufort Sea. The connection between these waters is restricted by a sill, approximately 400 m in depth, which follows the edge of the continental shelf about 125 km west of an imaginary line between Cape Kellett and Cape Bathurst (Figure 1.3-1). Amundsen Gulf is connected to the shallow waters of Prince of Wales Strait in the north, and Dolphin and Union Strait to the east. A subsurface extension of Cape Parry separates Amundsen Gulf into an eastern and a western basin (Figure 1.3-1).

1.3.2 WATER MASS CHARACTERISTICS

1.3.2.1 Chukchi Sea

The areas occupied by the three upper water masses of the Chukchi Sea are reflected by the near-surface summer salinity distributions shown in Figure 1.3-2. The more saline (32.3-33.2$^{0}/_{00}$) Bering Sea water is formed by the lateral mixing of Anadyr and Bering shelf waters which flow northward through Bering Strait to dominate the central Chukchi Sea (Coachman et al., 1975). In the eastern Chukchi Sea, the Alaskan coastal water mass from the Bering Sea combines with the outflow from Kotzebue Sound to form a northward coastal flow of relatively fresh water (less than 32.4$^{0}/_{00}$). As this water moves along the Alaskan coastline toward Point Barrow, the Alaskan water mass is cooled and its salinity increased through mixing with the waters of the northern Chukchi Sea. Water of Bering Sea origin has been found far north in the Arctic Ocean (Coachman and Barnes, 1961; Hufford, 1973). Siberian coastal water enters the Chukchi Sea from the East Siberian Sea and flows southeasterly along the Asiatic coast toward Bering Strait, and may occasionally penetrate as far as Bering Strait.

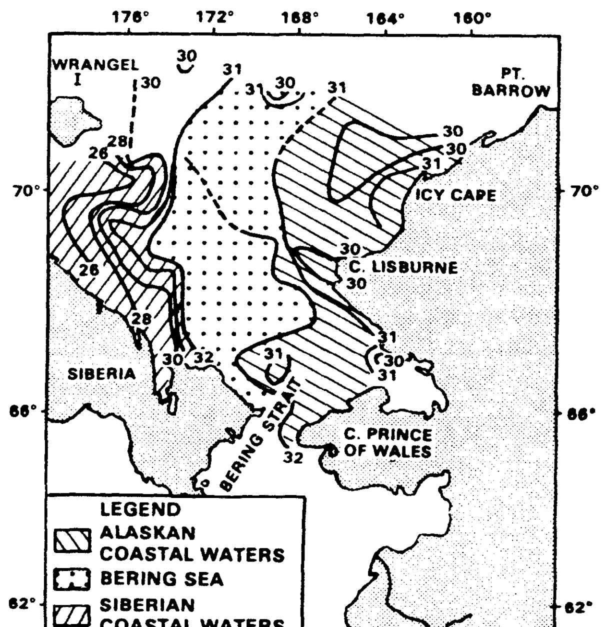


FIGURE 1.3-2 *Near-surface summer salinity and areas occupied by three water masses in the Chukchi Sea (Source: Coachman et al., 1975).*

South of Icy Cape, there is relatively little stratification in salinity (and hence density) within the central Bering Sea and Alaskan Coastal water masses. To the north, however, the Alaskan coastal water overlies colder, more saline water believed to be residual Chukchi water (Coachman et al., 1975). Near the Siberian coast a frontal zone separates Bering Sea water from the East Siberian Sea deep and Siberian coastal waters. This zone has a distinctive layered character (Coachman et al., 1975) as a result of the differing water mass densities.

1.3.2.2 Beaufort Sea

The water column in the Beaufort Sea is composed of three distinct layers, each with a characteristic range of temperatures and salinities. The upper layer, termed the Arctic water mass, extends to a depth of about 200 m. The Atlantic water mass forms a layer between 200 and 900 m, while Arctic bottom water is located at depths 900 m to the bottom (Figure 1.3-3) (Coachman and Aagaard, 1974). All three water masses are cold, and as a result, their densities are almost solely determined by salinity. Consequently, in all vertically stable distributions, salinity increases with depth, although water temperatures can either increase or decrease with depth.

Temperatures and salinities in the Beaufort Sea are most variable in the upper portion of the Arctic water mass. This variability is most pronounced in the nearshore zone and over the continental shelf, where the Mackenzie River plume and intense solar radiation during the ice-free season greatly alter the physical character of surface waters. In the portion of the southern Beaufort Sea where most past and proposed hydrocarbon-related activities are centred, the surface layer is typically 5 to 20 m deep in summer and has salinities as low as a few parts per thousand and temperatures as high as 15°C. Typical temperature and salinity data for Mackenzie Bay during the summer open water season and early spring prior to ice break-up are provided in Figure 1.3-4. Further offshore where the ice-free season is brief or nonexistant, and there is no influence of the freshwater Mackenzie River plume, the surface salinity is typically near 30 °/oo and temperatures are near the freezing point (approximately -1.6°C).

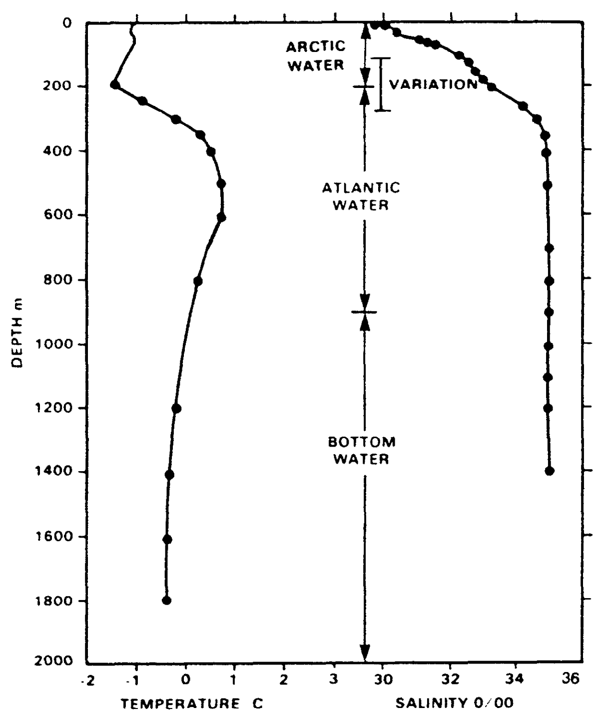


FIGURE 1.3-3 *A typical temperature and salinity profile from the Beaufort Sea. Since the water masses are cold, density depends almost solely on salinity. (Source: Coachman and Aagaard, 1974).*

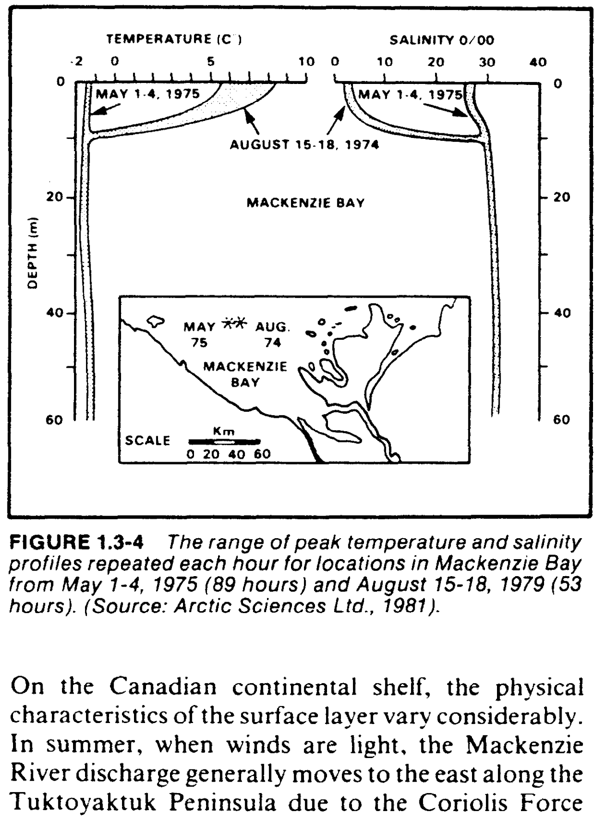


FIGURE 1.3-4 *The range of peak temperature and salinity profiles repeated each hour for locations in Mackenzie Bay from May 1-4, 1975 (89 hours) and August 15-18, 1979 (53 hours). (Source: Arctic Sciences Ltd., 1981).*

On the Canadian continental shelf, the physical characteristics of the surface layer vary considerably. In summer, when winds are light, the Mackenzie River discharge generally moves to the east along the Tuktoyaktuk Peninsula due to the Coriolis Force associated with the rotation of the earth, and may often reach into Amundsen Gulf. During the open water season, and when prevailing winds are from the west or northwest, water is driven onshore and this tends to concentrate the river water in a coastal band extending eastward from the Mackenzie River Delta. However, under easterly winds, the Mackenzie River plume moves offshore and remains in the western and central portion of the area. During these periods, the surface water along the Tuktoyaktuk Peninsula may be replaced from beneath by the more saline Arctic water (Herlinveaux and de Lange Boom, 1975).

During the winter months, when the flow from the Mackenzie River is reduced, river water is generally confined to nearshore areas. Outside this area, the surface waters cool and increase in salinity due to ice formation. The resultant downward mixing replaces the highly stratified summer surface condition with an upper layer (up to 50 m thick) of uniform temperature (-1.65° to -1.85°C) and salinity (30-33.3$^0/_{00}$).

The decreasing variability in the physical properties of water with increasing depth allows detection of sublayers of the Arctic water mass on the basis of their temperatures and salinities. These sublayers originate from adjacent seas and move through advection into the Beaufort Sea. For example, two sublayers identified in the western Beaufort Sea have been used to trace the coastal current which moves northeastward past Point Barrow (Hufford, 1973; Paquette and Bourke, 1974). In addition, there appears to be a relatively warm (0.5°C) tongue of water extending westward from Amundsen Gulf at a depth of 30 to 50 m (Mountain, 1974).

The Atlantic water mass is separated from the overlying Arctic water by a distinct pycnocline or transition region (Figure 1.3-3). The layer itself has a broad temperature maximum of 0.0° to 0.5° between 250 and 500 m, as well as a relatively uniform distribution of salinities (34.6-35.0$^0/_{00}$) over the core of the water mass. It has been estimated that the Atlantic water requires 6 years to reach the Beaufort Sea from its source off eastern Greenland (Coachman and Aagaard, 1974). Once in the Canadian Basin of the Arctic Ocean, it is known to circulate in the Basin, although the direction of circulation remains unresolved.

Arctic bottom water in the Beaufort Sea extends from depths of approximately 900 m to the bottom (Figure 1.3-3). It is primarily distinguished from Atlantic water by the decrease in temperature with depth below the core of the Atlantic water. By definition, the Arctic bottom water has temperatures of 0°C or less, although the salinity is virtually identical to the lower portion of the Atlantic water and ranges from 34.92 to 34.99$^0/_{00}$.

1.3.2.3 Amundsen Gulf

The waters of Amundsen Gulf include all of the major water masses which occur in the Beaufort Sea, with the exception of the Arctic bottom water which is excluded from this region by the western sill.

The Arctic water salinities in Amundsen Gulf are less than 33.5$^0/_{00}$, while temperatures are below 0°C except in the shallow, warm near-surface layer (0-30 m). Here, solar heating in summer results in surface temperatures as high as 10°C. Surface salinities are strongly affected by the discharge of the Mackenzie River in the open water season which, under certain wind conditions, can penetrate past Cape Bathurst and cause low salinities in the surface layer of the western Gulf.

1.3.3 MEAN CIRCULATION

The mean surface circulation of the Beaufort-Chukchi region is shown in Figure 1.3-5. This pattern is only a rough estimate of the circulation in some areas due to the lack of reliable current meter data. In general, the circulation patterns illustrated in Figure 1.3-5 have been based on calculations from temperature and salinity data, or measurements of ice drift and drifting buoys. Determination of residual currents in the nearshore region are greatly complicated by their small magnitude relative to local wind-driven currents. (Residual currents are those which determine the net water movements.)

1.3.3.1 Chukchi Sea

The mean flow in the Chukchi Sea is northerly, as it is in the Bering Sea to the south. Sea levels of the Chukchi Sea exceed those of the Bering Sea, thereby providing the major driving force for the northerly mean flow. The mean summer surface circulation is shown in Figure 1.3-5, where the appended numbers indicate typical current speeds in cm/s. The strongest flows, sometimes exceeding 90 cm/s, occur in Bering Strait. The northerly flow splits near Point Hope, with the Alaskan coastal water continuing to follow the coast to the northeast at speeds of typically 25 cm/s. The western branch of the flow, composed primarily of Bering Sea water, tends to move to the northwest in the direction of Herald Canyon. A counterflow of Siberian coastal water along the Asiatic coast has speeds of roughly 10 cm/s. In addition, backeddy-like counterflows have been observed in the lee of Cape Lisburne and Icy Cape.

1.3.3.2 Offshore Beaufort Sea

In the offshore Beaufort Sea, the surface flow is dominanted by the clockwise circulation of the Beaufort Gyre in the Canadian Basin of the Arctic Ocean. Centred at 76°N, 145°W, near the mean high of atmospheric pressure, this Gyre is believed to be driven by the wind field (Campbell, 1965; Galt, 1973). The mean drift speed of the Gyre is 2 to 3 cm/s over the abyssal plain of the Canadian Basin, based on the calculations of Kusunoki (1962), Newton (1973) and the ice drift observations of Sater (1969).

The speed of the gyral movements vary greatly, particularly at the peripheries where it extends over the outer continental slope. The flow intensifies over the western portion of the continental slope according to Galt's (1973) numerical modelling study. Estimates

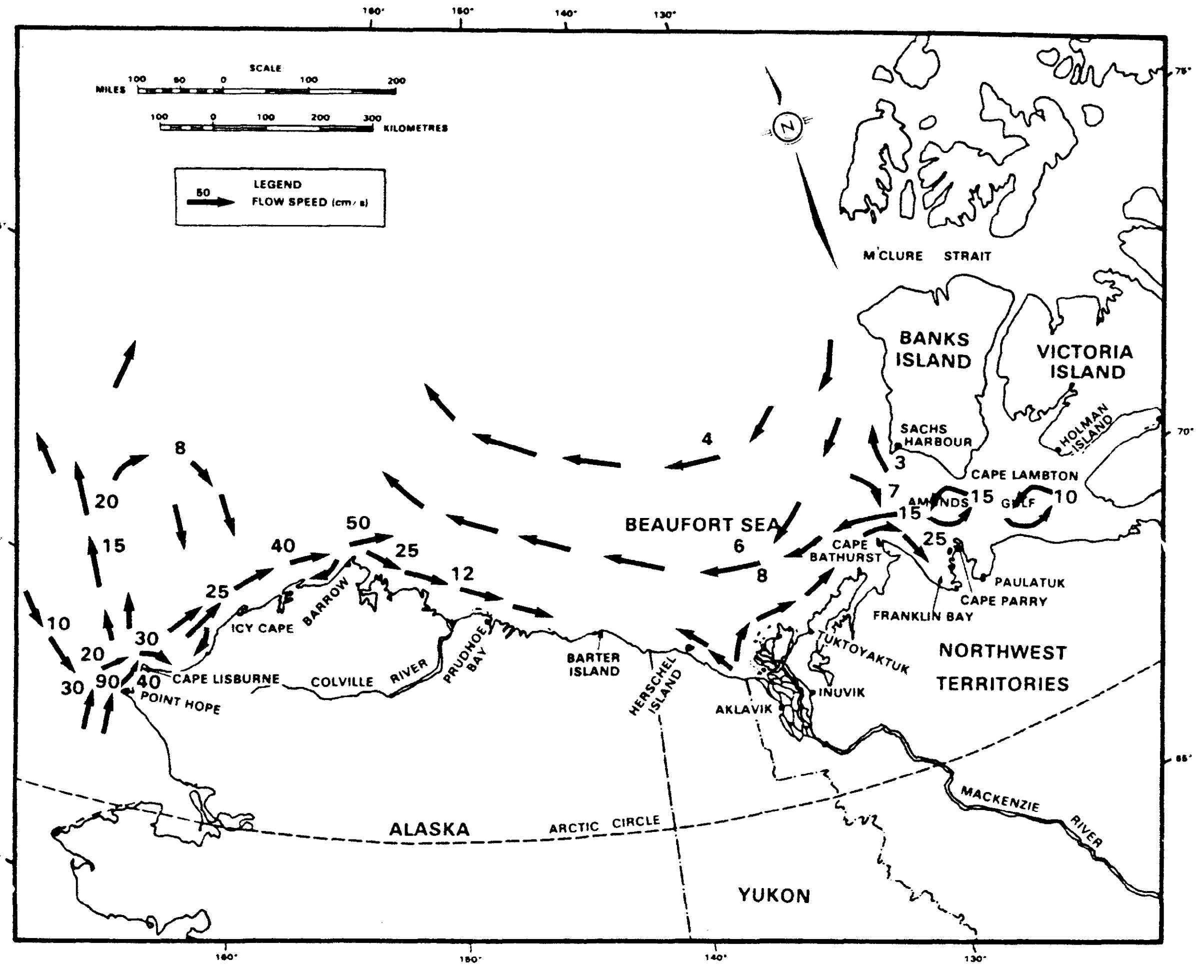


FIGURE 1.3-5 *Mean general summer circulation of surface waters in the Beaufort and Chukchi Seas. (Adapted from Arctic Sciences, 1981). In the nearshore regions, mean surface currents are generally weak compared to wind-driven currents.*

by Newton (1973) indicate that flow speeds reach 5 to 10 cm/s at the southern rim of the Gyre over the western Beaufort Sea.

1.3.3.3 Western Beaufort Sea

The major surface circulation features of the western Beaufort Sea are an eastward current which flows past Point Barrow, roughly following the shelf break (Figure 1.3-5) and westward currents further offshore which are associated with the Beaufort Gyre.

The eastward circulation component which follows the shelf break begins as a strong northward flow from Bering Strait and along the eastern edge of the Chukchi Sea.

Easterly current speeds reach 50 cm/s near Point Barrow with the main core of the flow following Barrow Canyon offshore to the northeast (Mountain et al., 1976; Hufford, 1975). The northeastward flow appears to be a result of momentum accumulated before the water enters Barrow Canyon. Winds cause fluctuations in the strength of this current, but have not been observed to reverse the northeasterly flow (Mountain et al., 1976). Near the mouth of Barrow Canyon, the flow turns eastward and follows the inner edge of the continental slope. This easterly current contains Pacific Ocean plankton and has salinities similar to that ocean's water (Johnson, 1956). Hufford (1973) found evidence that these easterly flows extended beyond 156°W in 12 out of 17 years, and in some years may have reached Barter Island (143°W). Calculations based on water mass data indicate that speeds associated with this flow range up to 50 cm/s just north of the shelf break.

No significant residual currents have been identified in the nearshore zone of the western Beaufort Sea and surface currents are largely wind-driven, except near estuaries. Although fewer data are available on the water circulation of the adjacent continental shelf, it also appears to be dominated by local wind forces. Subsurface currents have been measured over the inner continental slope between 146°W and 152°W since 1977 (Aagaard and Haugen, 1977; Aagaard, 1978, 1979). These data have been obtained from current meters positioned at depths of 34 m or greater and indicate that the usual alignment of the currents is with the local bathymetric contours. Although the occurrence of relatively strong flows in both directions has been documented (Aagaard and Haugen, 1977), net flows were generally eastward at 5 to 10 cm/s.

1.3.3.4 Southeastern Beaufort Sea

The pattern of surface circulation on the inshore continental shelf of the southeastern Beaufort Sea tends to be controlled by winds, and modified by the Mackenzie River outflow, interactions with the underlying water layer, and local bathymetry. The mean response of these currents to either strong northwesterly or easterly winds has been examined during surface drifter studies with results shown in Figure 1.3-6. Easterly winds tend to drive drifters northwestward past the edge of the continental shelf, while westerly winds move drifters toward the shore and eastward (McNeill and Garrett, 1975).

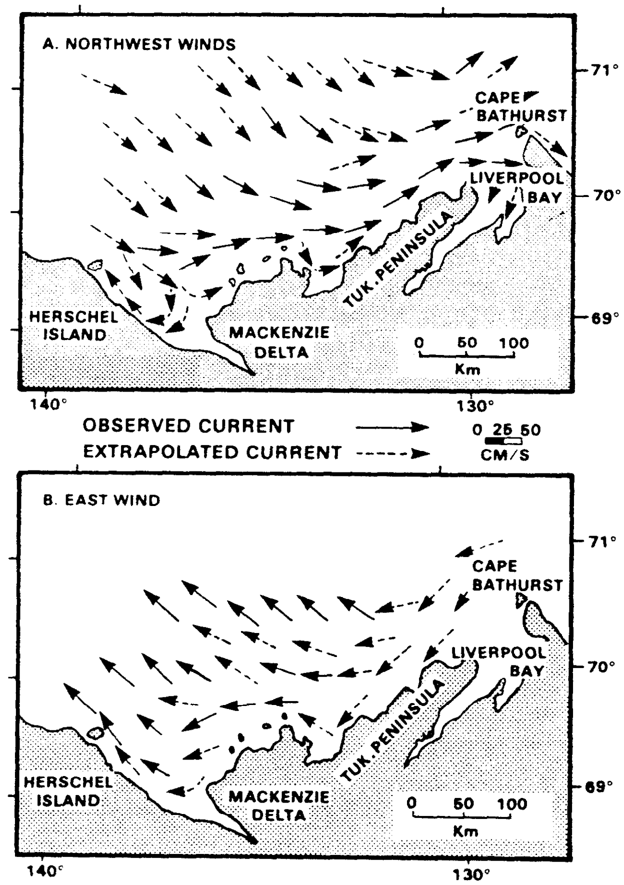


FIGURE 1.3-6 *Surface circulation in the Southeastern Beaufort Sea for northwest and east winds from surface drifter studies. (Source: McNeill and Garrett, 1975).*

Studies completed by McNeill and Garrett (1975) and the U.S. Coast Guard in 1980 (Murphy et al., 1980) also indicated that inshore drifter movements were generally aligned with the trend of the coastline. For example, during periods of northwesterly winds, drifters moved southeast toward the coast, but turned increasingly eastward (to the left of the wind) and northeastward along the coastline as they approached within a few kilometres of the shore. Nearshore drifters, moving northeastward along Tuktoyaktuk Peninsula during westerly winds, also moved appreciably faster than those 50 to 100 km offshore. As the drifters moved from Liverpool Bay around Cape Bathurst, they turned southeasterly into Franklin Bay with increased speed. Although surface currents generally ranged from 25 to 45 cm/s, speeds of 50 to 70 cm/s were reported on one occasion.

Drifter studies show that surface waters of the nearshore and continental shelf zones of the southeastern Beaufort Sea respond quickly to local winds, typically within one day. These surface movements are more subject to change near the coastline where the influences of river discharges and shoaling waters become increasingly important. Drifters released during periods of light winds move at slow speeds in varying directions.

In the absence of strong winds, the Mackenzie River discharge is expected to move as a slow, broad easterly flow paralleling the coastline under the influence of the Coriolis Force. The river flow also appears to produce eddies as large as 50 km which are visible during calm conditions along the edges of the freshwater plume.

There is evidence of a persistent flow to the northwest along the western side of Mackenzie Bay. Strong northwest flows were measured over Herschel Canyon under easterly winds, but during northwesterly winds, similar but weaker northwest surface flows were observed (McNeill and Garrett, 1975). Regarding the circulation further north over the continental slope, available data suggest that the Arctic water mass moves westward over the continental slope under the influence of the Beaufort Gyre (Newton, 1973; H. Melling, pers. comm.). A weak westerly outflow from Amundsen Gulf also contributes to the westerly movement over the continental slope, based on currents inferred from water mass distributions (Cameron, 1952; Bailey, 1957; U.S. Naval Oceanographic Office, 1963) and a study of surface sublayer temperature-salinity characteristics (Mountain, 1974).

Near-bottom and midwater currents on the continental shelf appear to be poorly correlated with surface winds. All studies show that the subsurface circulation is weak and variable over most of the shelf (Huggett et al., 1975; Fissel, 1981). Although distinct northeasterly bottom currents occur with speeds of 5 to 10 cm/s, there is no evidence to suggest that these currents extend to the surface. In Herschel Canyon, Huggett et al. (1977) measured strong bottom flows aligned with the Canyon's northwest-southeast axis. However, the net flow was small and northeasterly.

Figure 1.3-7 shows the mean monthly current speeds at Kopanoar for various water depths and figure 1.3-8 shows the percentage of time that the current exceeded indicated values. These data were obtained from measurements made on the drillships during the open water season (Fissel, 1981). As expected from wind driven currents, the near surface currents are largest, with decreasing currents at greater depths. These currents are mainly inertial (Fissel, 1981), although long term residual currents are often observed. Inadequate data are available at present to predict extreme currents, but the maximum currents that have been measured are 70 cm/s at Nektoralik in August 1977 and 63 cm/s at Natsek between late August and October, 1979.

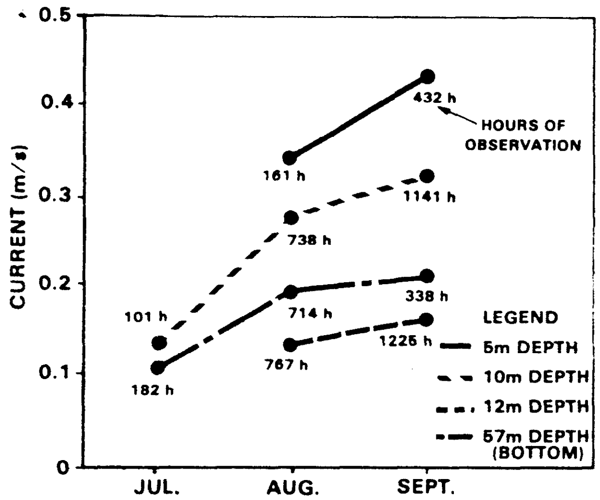


FIGURE 1.3-7 *Mean monthly current speeds at Kopanoar 1976-79. (Source: Fissel, 1981).*

1.3.3.5 Amundsen Gulf

The trough between the Beaufort Sea and Amundsen Gulf is up to 400 m deep, with its sides rising steeply to the bordering shelves of the mainland and Banks Island. The surface flow through the mouth of Amundsen Gulf appears to be banded (Figure 1.3-5), with a weak (3 cm/s) northwesterly flow near Banks Island, a moderate (7 cm/s) southeasterly flow over the northern portion of the trough, a stronger (15 cm/s) northwesterly flow over the southern half of the trough, and a variable, but at times intense, southeasterly coastal flow rounding Cape Bathurst into Franklin Bay (Melling, pers. comm.). The net result of these currents is a clockwise intrusion of surface water into Amundsen Gulf from the Beaufort Sea. Within Amundsen Gulf itself, there are two counterclockwise Gyres, one centred to the west, and the other to the east of the line between Cape Parry and Cape Lambton. Surface currents appear to be stronger in the western Gyre (MacDonald et al., 1978).

1.3.4 LOW FREQUENCY VARIABILITY IN CURRENTS

Changes in currents on time scales of two days or more are considered to be low frequency variations.

1.3.4.1 Chukchi Sea

Varying winds and atmospheric pressure gradients are the major sources of low frequency changes in currents within the Chukchi Sea. During fall and winter, frequent southerly flow-reversals occur with periods of 3 to 10 days (Coachman and Aagaard, 1981). The southerly flows are comparable in magnitude to the northerly currents and are generally stronger on the Alaskan side of the Chukchi Sea. Similar reversals occur less frequently during the summer. Winds produced by changing atmospheric pressure patterns may be the cause of these variations in flow since during the fall and winter, winds from the north increase in strength and frequency and often extend over the entire Bering Sea. These winds drive water southward off the Bering Shelf and induce a southward-sloping sea surface. The resulting gradients in pressure in the water column, combined with the surface wind stress, are sufficient to reverse the mean surface flow to a southerly direction. Thus, the mean circulation patterns shown in Figure 1.3-5 must be viewed with some degree of caution.

1.3.4.2 Offshore Beaufort Sea

The surface drift of pack ice in the Beaufort Gyre exhibits low frequency variations. The mean monthly drift rates increase to 3 to 5 cm/s in summer and autumn from their winter values of 1 to 2 cm/s. This is apparently caused by seasonal differences in surface winds (Coachman, 1969). However, on short time scales of a month or less, ice motions respond in part to local winds. Ice, when free to drift, moves at 2 to 3.5% of local wind speeds and at angles ranging from 25 to 45° to the right of the wind direction (Hunkins, 1966; Colony and Thorndike, 1980). Other more complicated ice movements also occur in response to winds and currents elsewhere, depending on ice concentrations and the proximity of land masses.

Strong low frequency subsurface currents occur at deep water locations in the offshore Beaufort. These are in the form of intense eddies occurring over a period of a few days, and are confined to depths between 50 and 300 m where the sharpest density gradients exist. The eddies can have diameters of 10 to 20 km and are roughly 20 to 50 km apart. These subsurface currents are stronger than wind-driven currents in the upper layer, and have peak speeds of 20 to 60 cm/s (Hunkins, 1974).

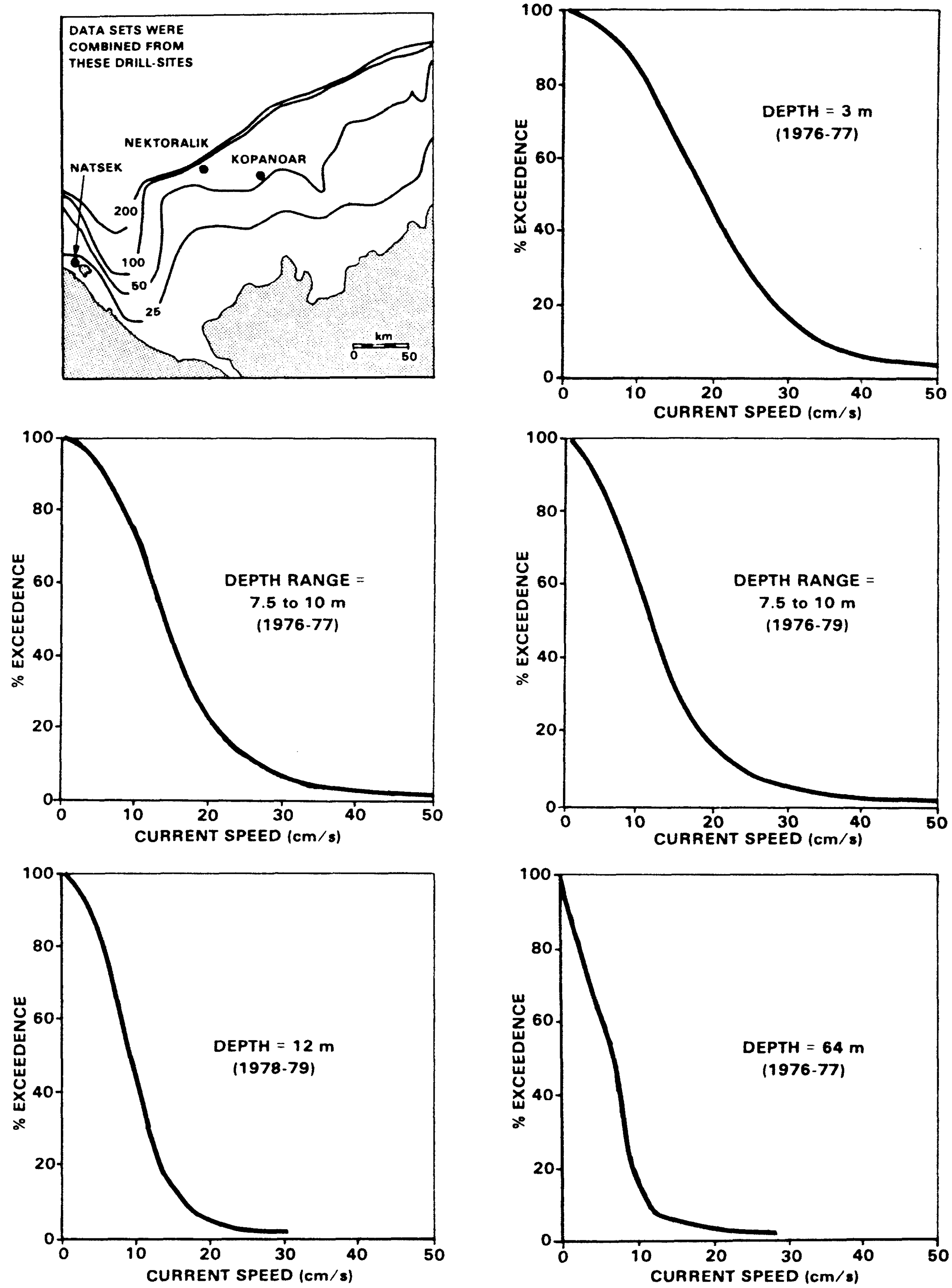


FIGURE 1.3-8 *Percentage of the time that current speeds exceeded given speeds at various depths during the open water season. Data sets from the Natsek, Nektoralik and Kopanoar drill-sites were combined in various years. (Source: Fissell, 1981).*

1.3.4.3 Western Beaufort Sea

During summer the near-surface circulation over the continental shelf and in the nearshore zone of the western Beaufort Sea varies with local winds. In the semi-enclosed lagoons off the North Alaskan coast, the surface waters move at 3 to 4% of the surface wind speed, but this motion is greatly reduced by winter ice cover. However, even in summer, knowledge of local winds will not permit low frequency surface currents to be predicted, since additional spatial and temporal variations have been observed which are not completely understood.

Low frequency variations occur in the easterly current which flows onto the inner continental shelf through Barrow Canyon. For example, at depths near 100 m in the Canyon there is evidence of current variations having periods equal to, or greater than, two months. Other variations in this easterly current are believed to result from atmospheric pressure gradients having periodicities of 10 to 20 days. Nearer to the surface (25 m) low frequency variations in the net easterly flow appear to be related to local surface winds.

Further to the east along the inner continental slope of the western Beaufort, the general eastward flow is characterized by frequent highly energetic, pulse-like westward reversals. These reversals may last from one to ten days or more, and have typical speeds of 15 to 30 cm/s (Aagaard and Haugen, 1977; Aagaard, 1978, 1979).

1.3.4.4 Southeastern Beaufort Sea

Low frequency or subtidal variations in the surface and near-surface circulation occur in the southeastern Beaufort Sea on time scales ranging from one day to several years. Near the shore and on the continental shelf in summer, variations in the wind appear to control the surface layer circulation. However, other factors such as river flow characteristics, water stratification, local bathymetry, and proximity to the coastline tend to modify these surface currents. As a result, the normal assumption that surface currents move at 3% of the local wind only provides a rough estimate of the surface circulation in the region.

Storm surges are caused by winds driving the surface water onto the shallow continental shelf waters. The resulting high waters flood the adjacent low-lying lands of the southeastern Beaufort Sea. Storm surges, which raise sea levels by 0.5 m over a few days, are frequent during persistent westerly or northwesterly winds. A more abnormal storm surge was observed in 1944, when sea levels were reportedly raised up to 3 m at Tuktoyaktuk. A simulated example of sea level changes resulting from a storm surge during September 1972 is shown in Figure 1.3-9 (Henry and Heaps, 1976).

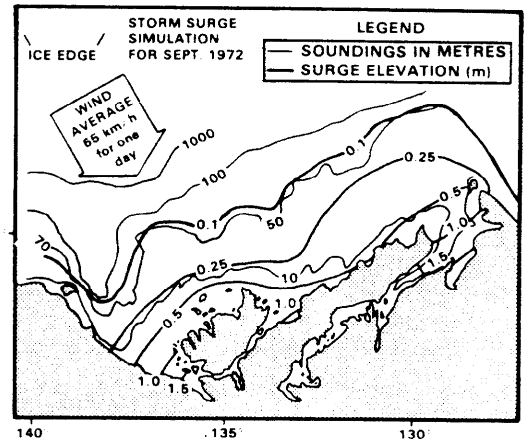


FIGURE 1.3-9 *A simulation of the rise in sea level resulting from northwesterly winds in September 1977. (Source: Henry and Heaps, 1976).*

Current variations in the subsurface layer on the Canadian Beaufort Shelf do not appear to correlate well with local winds over most of the water column. Near-bottom currents respond, in part, to changes in local winds. East winds result in offshore flows near the bottom, while west winds produce onshore flows at depth (Fissel, 1981).

1.3.4.5 Amundsen Gulf

There are only limited data describing low frequency variability of currents within Amundsen Gulf. However, it is likely that changes in wind patterns are the major source of surface and near-surface current variability, given the observed dominance of wind in producing surface water motions in the Beaufort Sea and other areas of the western Arctic Archipelago.

1.3.5 HIGH FREQUENCY VARIABILITY IN CURRENTS

"High frequency variability" refers to periodicity in currents which occur over one day or less. The two primary souces of these variations are tidal and inertial oscillations. Inertial oscillations take the form of looping clockwise motions in the horizontal plane, and result from water masses moving under their own inertia and being deflected by the Coriolis Force. Such motions can occur when there are rapidly changing winds. However, since the semi-diurnal tidal period and the inertial period are very similar in the Arctic, it is difficult to distinguish between these two forms of high frequency motion.

Tidal currents in the Beaufort Sea are a mixture of diurnal and semi-diurnal flows. Semi-diurnal tides predominate along the entire Beaufort coast and mean tidal ranges are less than 0.5 m, although larger ranges occur during storm surges (Section 1.3.4.4). Tidal currents are weak (generally less than 5 cm/s for any component) and can vary significantly in amplitude and direction from the inner slope to the continental shelf of the Beaufort Sea (Aagaard, 1978; Henry and Foreman, 1977).

Inertial oscillations are produced intermittently during periods of pronounced change in the local surface winds. Typical inertial current speeds range up to 30 cm/s, and are, therefore, much larger than tidal currents (McPhee, 1980; Fissel, 1981). The speed and duration of these inertial currents depend on the rate of change in the local surface winds. These oscillations also tend to be present throughout the upper wind-mixed layer, but rapidly disappear beneath the seasonal pycnocline.

Internal (or interfacial) waves cause an additional form of high-frequency variablity in the Beaufort Sea. These waves occur at the horizontal boundaries of a stratified water column, and have periods that range from as short as a few minutes to several hours (Munk, 1981). In the Arctic Ocean, internal wave amplitudes tend to be small because ice cover limits the input of atmospheric energy necessary for their generation. However, internal waves are easily generated in areas where ice-melt or river runoff produces thin, fresh upper layers overlying denser seawater. At present, there are very limited data describing these types of water motions in the Beaufort Sea.

There are few tidal data available for Amundsen Gulf and the Chukchi Sea. As in the Beaufort Sea, tide amplitudes in Amundsen Gulf are small, largely semi-diurnal, and, typically ranging from 0.3 to 0.4 m (Canadian Hydrographic Service, 1981), with a maximum of 0.7 metres. In the Chukchi Sea, semi-diurnal currents are about three times stronger in the west than the east. Coachman et al. (1975) reported that just north of Bering Strait, semi-diurnal tidal currents over one 6 day record were oriented in a WNW-ESE direction and had maximum speeds of 10 cm/s. Mean tidal ranges in the Chukchi Sea are 0.6 m or less, but storm surges can raise sea levels up to 3 m in late summer and fall, particularly in Kotzebue sound.

1.4 THE SEA BOTTOM

1.4.1 BATHYMETRY

There are three main bathymetric features in the southeastern Beaufort Sea: the continental shelf which slopes gently from the coastline to water depths of approximately 100 m, the continental slope angling steeply from the edge of this shelf to depths of about 1,000 m, and the trench-like Mackenzie (or Herschel) Canyon which transects a portion of the shelf (Figure 1.4-1). The proposed offshore hydrocarbon production facilities and activities described in Volume 2 of this EIS will be located over the continental shelf. Part of the seafloor in this area is also characterized by numerous conical mounds rich in ice referred to as pingo-like features. In some cases, these formations rise from a base which is up to 1,000 m in diameter on the seafloor, to within 18 m of the surface and as a result, can represent a serious navigational hazard if their location has not been charted. Pingo-like features are discussed further in Section 1.4.6.

The only region in the southern Beaufort Sea that has been surveyed to modern standards is the area between the eastern border of the pingo area and the entrance to Amundsen Gulf (Figure 1.4-1). The pingo area is identified on present charts by a cautionary note related to the known presence of underwater hazards since the exact location of individual pingos remains largely uncharted. However, detailed bathymetric surveys will be completed in this area and in all uncharted shipping lanes prior to initiation of tanker transport of petroleum hydrocarbons from the Beaufort Sea. In recognition of this priority, the Canadian Hydrographic Service began surveys in parts of the Beaufort Sea during the summer of 1981.

1.4.2 HISTORICAL GEOLOGY

Surficial sediment depositions (up to 100 m deep) on the continental shelf have been highly influenced by sea level fluctuations which have occurred during the recent geologic past (Figure 1.4-2) (O'Connor, 1980).

Twenty thousand years ago, when the sea level was approximately 100 m lower, much of the present continental shelf of the Beaufort Sea was exposed dry land. Erosion of the sands and silts which comprised this land surface, produced an unconformity in the geologic sequence. During this period the Mackenzie River flowed through a system of channels cut into these exposed sediments. Permafrost developed in the surficial sediments as a result of cold air temperatures, but as the sea level rose, warmer shallow waters gradually covered the land surface and thawed some of the permafrost. Fine grained suspended sediments from the Mackenzie River began to blanket the continental shelf and fill in the old river channels. During the sea level rise, some of the original coarse grained sediments were eroded and redeposited along with the more recent marine clays, ultimately creating the modern sequence of surficial sediments which exists on the Beaufort continental shelf (O'Connor, 1980).

1.4.3 SURFICIAL SEDIMENTS

Since 1970, hundreds of boreholes have been drilled

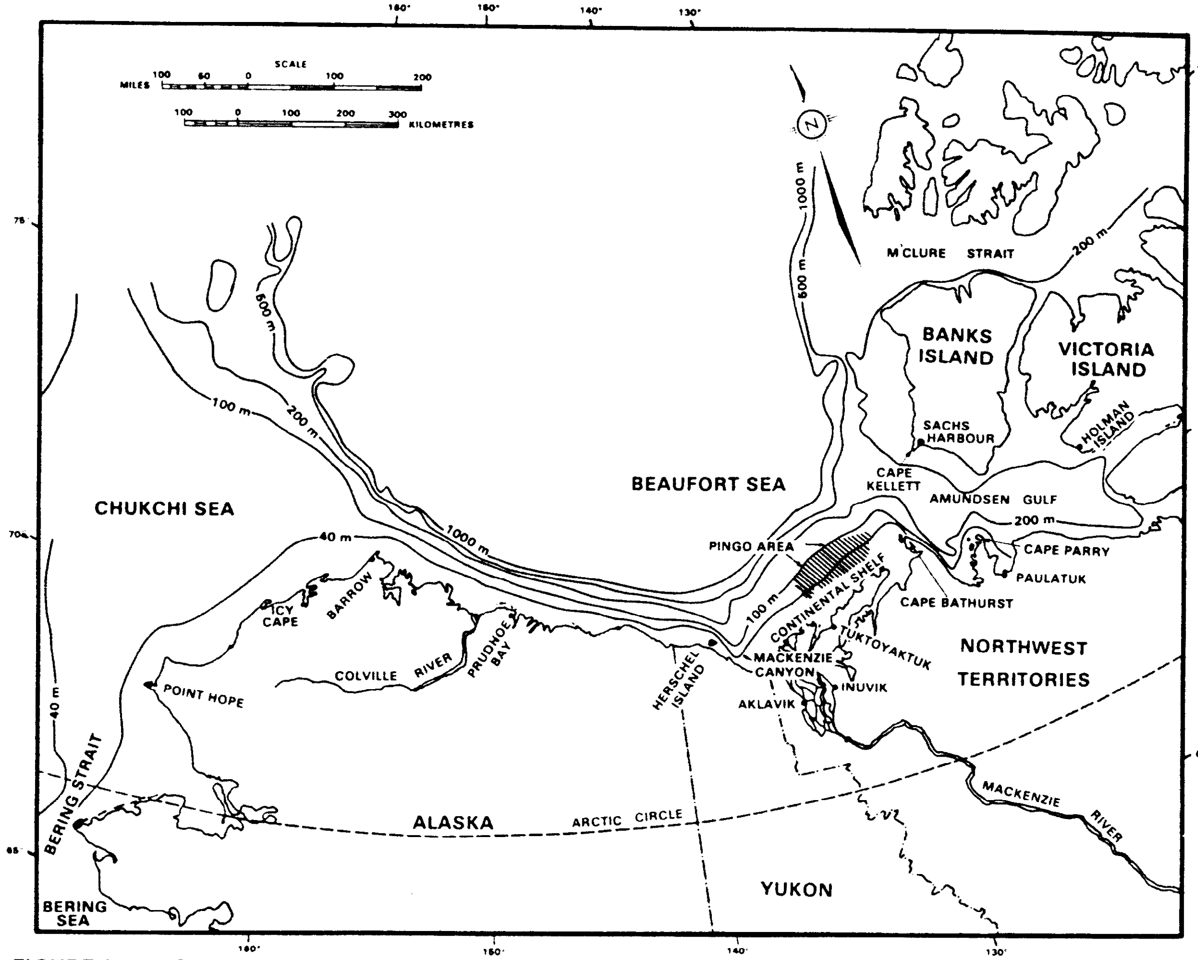


FIGURE 1.4-1 *General bathymetry of the Beaufort and Chukchi Seas.*

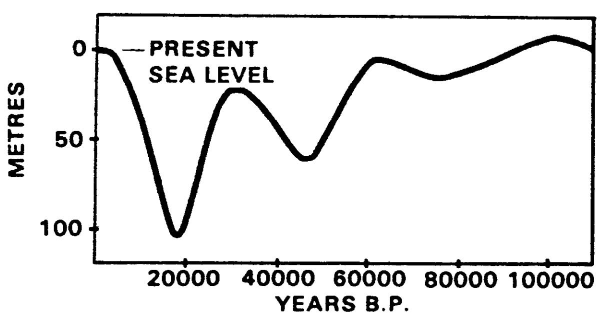


FIGURE 1.4-2 *World-wide changes in sea level.*

in the southern Beaufort Sea. Some of these were drilled by the Geological Survey of Canada (GSC) to support geological and geophysical studies, but the majority have been drilled by the petroleum industry to assess foundation conditions for seafloor structures and to find borrow material for the construction of artificial islands. Many of these boreholes only penetrated the seabottom to depths of 20 m or less, and are therefore of limited value in describing the composition of surficial sediments. However, more recently boreholes have been drilled to 125 m, and sediments from greater depths have been recovered during the drilling of hydrocarbon exploration wells.

Using high resolution seismic data, along with shallow (less than 6 m) piston cores and geotechnical or geological borehole information, it has been possible to classify the surficial sediments examined to date into three stratigraphic units, as shown schematically in Figure 1.4-3 (O'Connor et al., 1979; O'Connor, 1980).

In most locations, the seabed consists of 0.5 to 35 m of recent marine clays or silty clays which have been carried onto the continental shelf from the mouth of the Mackenzie River. These sediments, which are generally referred to as Unit A, are gray to black, soft to firm and often contain traces of fine sand and organics, usually in the form of thin layers. The clays are gradually replaced by gray, loose to very loose silts as shorelines are neared. Coarse materials such as sands and fine gravels may also be encountered over small areas of the seafloor, usually at depths from 0.5 to 3 m. It is hypothesized that they may have originated either as a relic beach or were carried by ice (ice-rafted) to their present location. (O'Connor, 1980)

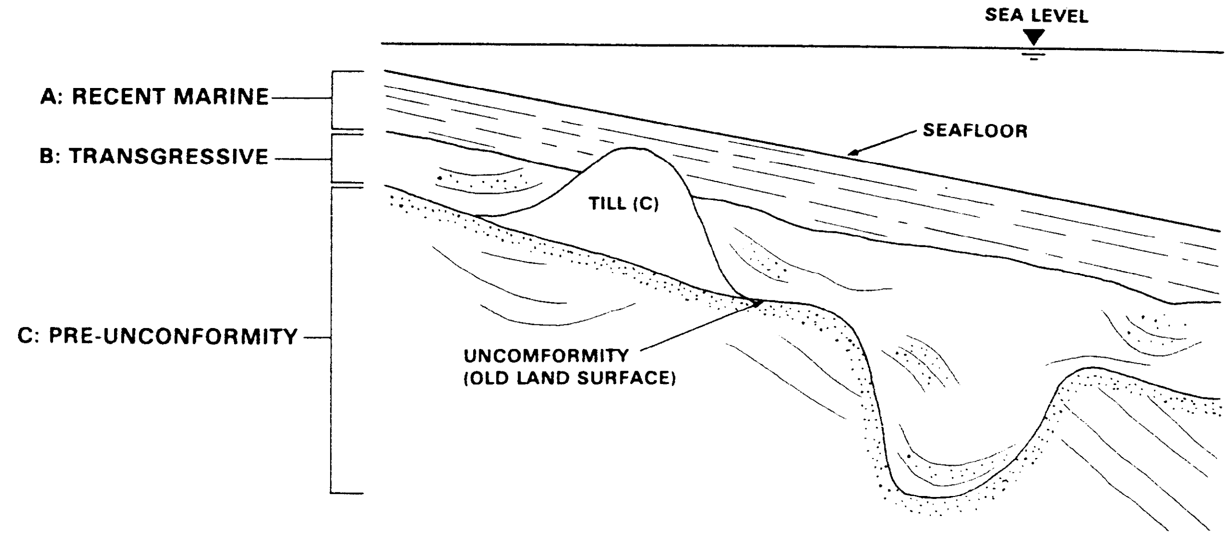


FIGURE 1.4-3 *Schematic cross section of the Beaufort Sea continental shelf showing the three major stratigraphic units which comprise the surficial sediments. (Source: O'Connor et al., 1979, O'Connor, 1980).*

A discontinuous and highly variable series of sand, silt and clay beds, referred to collectively as Unit B, often underlies the recent marine clays. It is postulated that these sediments were deposited during the last sea level rise (O'Connor, 1980). The thickness of this unit is believed to range from 0 to about 15 m. It has been reported that this transgressive sequence, as it is commonly called, may also contain organic rich and/or stoney clay layers (O'Connor et al., 1979), but its detailed nature and distribution are poorly understood at the present time.

The transgressive sequence (Unit B) rests directly on the old erosional (unconformity) surface which was exposed approximately 20,000 years ago, before the most recent sea level rise. The sediments immediately beneath this erosional surface are presently referred to as Unit C. Although their exact character has not been determined at all locations on the continental shelf, they are believed to be composed of both glacial and fluvial-deltaic sediments (O'Connor, 1980).

East of 136°W longitude, Unit C sediments consist mostly of fine to medium grained, gray, brown or yellow sand (O'Connor et al., 1979). This sand normally contains from a trace to some silt and only minor amounts of organics, although clay, silt and gravel layers have also been found in some areas. North of Garry Island, Unit C may also include an upper complex sequence of silty fine sand interbedded with gray to black, stiff to hard, stoney clay (O'Connor et al., 1979). Indications are that these sediments may form part of a glacial till (See Figure 1.4-3) or moraine deposit on the old land surface, which was then partially buried during the deposition of more recent sediments. Seismic information suggests that similar glacially-related sediments also occur near Herschel Island in the Mackenzie Canyon, and immediately north of Pullen Island. Since all such occurrences appear to be confined to the nearshore zone, they are considered to represent the northern limit of one of the previous glaciations (O'Connor, 1981; pers comm.).

Echo sounding records have been used to map the apparent thickness of soft sediments on the Beaufort Shelf (Meagher, 1978; Shearer, 1972). Although not always clear, the layer measured during these studies appears to be generally equivalent to Unit A, the recent marine sequence. These studies also suggest that this sequence is generally thinner than 6 m on the continental shelf east of Mackenzie Bay, but may thicken to 15 to 20 m or more where it infills certain large north and northwest trending depressions. Thicknesses between 0 and 2 m are common at the shelf-edge. They are also common in nearshore high energy environments composed principally of sand, and over large areas north of Pullen Island or east of 133°W longitude.

The observed distribution of the surficial sediments described above is consistent with the modern sediment dispersal patterns described by Pelletier (1975). Sediments from the Mackenzie River are carried in a northward direction onto the continental shelf and then eastward under the influence of the Coriolis Force. Much of the coarse material settles near the mouth of the Mackenzie, but fine grained sediments may be carried much greater distances, to accumulate in the river channels and depressions which originally formed the old, exposed land surface. Modern depositional rates appear to be higher on the west side of the shelf, close to the major source of sediment supply. On the eastern shelf, modern sediment dispersal patterns appear to be partly due to active sedimentation of fine grained particles over the relic land surface, and partly due to possible erosion of this relic surface by intermittent westward-moving bottom currents. The eastern part of the shelf therefore appears to serve alternately as both a depositional and erosional site (Pelletier, 1975).

1.4.4 SHELF-EDGE STABILITY

The edge of the continental shelf in the southern Beaufort Sea generally occurs between the 70 and 100 m isobaths (O'Connor, 1980). Shoreward of this edge, the seafloor rises to the land surface at a slope of 0.03° to 0.06°. Seaward, it falls off to the continental rise at an average slope of between 1° and 3°.

Seismic profiles have been used to examine the nature of the shelf-edge, in order to assess the relative stability of the shelf-break and upper continental slope (O'Connor, 1981). This study indicates that the shelf-edge east of 130°W longitude is relatively gentle. West of 132°W, however, the upper continental slope becomes significantly steeper and a progressive decrease in the stability of the shelf-edge sediments is evident. The shelf-break in the latter region is characterized by a series of parallel scarps (Figure 1.4-4) formed by slumping of the surficial 30 to 120 m of recent sediments on the upper continental slope. A preliminary study conducted on behalf of the Geological Survey of Canada concluded that some of these slumps are large, having downslope displacements of 150 to 250 m and surface areas of more than 500 km^2 (O'Connor, 1981a). According to the seismic sections, much of the original bedding within the slumped sediments is preserved, suggesting that the sediments moved downslope en masse.

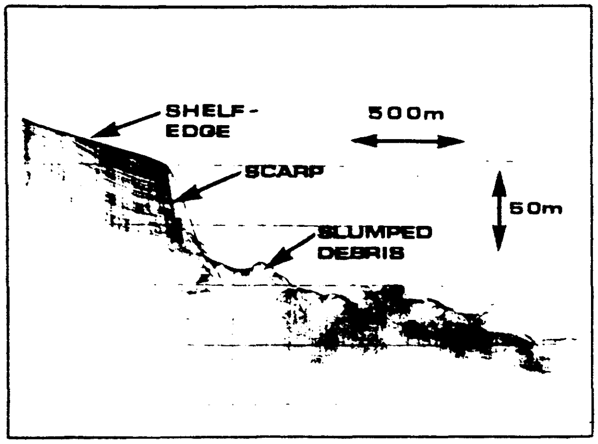


FIGURE 1.4-4 *High resolution seismic profile across the Beaufort Sea continental shelf-edge near 136° W longitude. (Source: O'Connor, 1981a).*

Figure 1.4-5 illustrates those features which are typical of the shelf-edge and upper continental slope in the region near 136°30' W longitude. Piercement folds or shelf-edge mud diapirs, scarps, slump debris, dislocated strata, and compression and extension features indicate that significant downslope movements of the surficial sediments have occurred in the recent geologic past. There is no information which suggests that these movements are not active at the present time.

Catastrophic forms of sediment movement, such as turbidity currents, have not yet been recognized on seismic records from near the shelf-edge. Such movements may occur on the continental slope, but are not likely to occur on the continental shelf east of the Mackenzie Canyon where resource development is presently taking place. In the Mackenzie Canyon itself where the Mackenzie River deposits large amounts of sediment each year, major sediment gravity flows of this type are probably common.

1.4.5 SUBSEA PERMAFROST

Permafrost is widespread beneath the Beaufort Sea and has been well documented by both industry and government. Permafrost includes all soils or rocks having a mean annual temperature of less than 0°C (Brown and Kupsch, 1974), irrespective of whether or not moisture in the form of water or ground ice is present. Since the presence of ice increases the veloc-

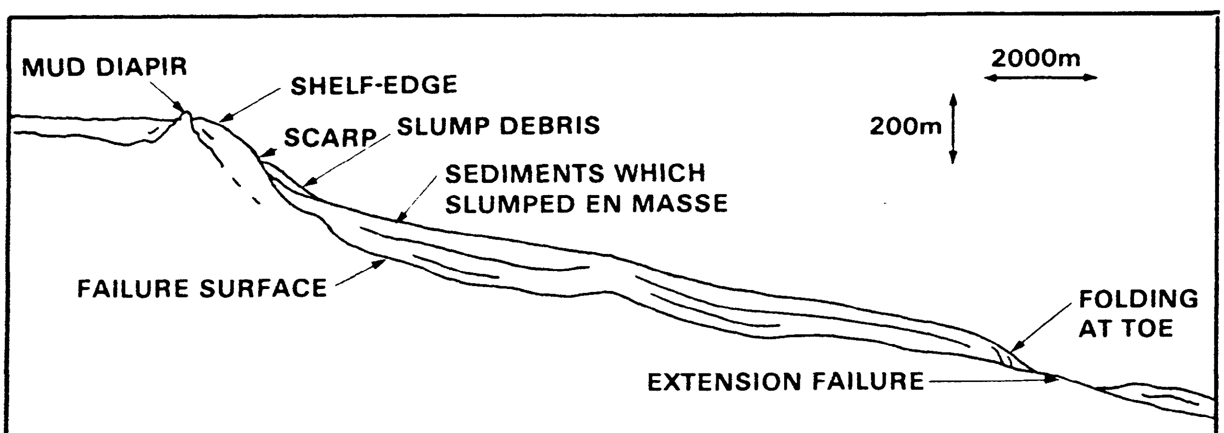


FIGURE 1.4-5 *Typical shelf-edge features near 136° 30' W. longitude in the Beaufort Sea. The shelf-edge is progressively less stable west of 132° W than to the east where the continental slope is less steep. (Source: O'Connor, 1981a).*

ity of sound waves in the soil, ice-bonded sediments can usually be detected using shallow seismic techniques. To differentiate between the thermal and seismic definitions of permafrost, the term acoustic permafrost (APF) is generally used (O'Connor, 1977).

Sub-bottom temperatures from -0.5° to -2°C have been recorded in numerous boreholes drilled in the seabottom beneath the shallow waters of the Beaufort Sea continental shelf by the Geological Survey of Canada (Judge et al., 1976; Macaulay et al., 1977, 1979). Ice lensing and visible intergranular ice were recorded at some but not at every location examined. Ice-bonded submarine sediments have also been recovered from several geotechnical boreholes drilled by the petroleum industry in the Beaufort Sea (MacLeod and Butler, 1979; O'Connor et al., 1979). Resistivity logging in several offshore exploration wells confirms the presence of ice-bonded permafrost to depths in excess of 700 m at some locations.

Industry seismic records have been examined by the GSC to determine the lateral distribution of high velocities (assumed acoustic permafrost) in the southern Beaufort Sea (Judge et al., 1975). These studies suggest that the continental shelf area can be divided into three zones comprising continuous, discontinuous and non-ice-bonded strata (Figure 1.4-6). Very little acoustic permafrost was observed in the offshore region west of Kopanoar and in the inshore zone north of Cape Dalhousie between the 20 and 30 m isobaths. Acoustic permafrost was not detected in water depths greater than 90 m, and Judge et al. (1975) concluded that the continuous zone is surrounded by a discontinuous or "patchy" zone of acoustic permafrost.

Recent studies using both refraction and high-resolution reflection data suggest that more than one layer of acoustic permafrost may be present on the Beaufort continental shelf (O'Connor, 1981b). The top of the acoustic permafrost layer usually occurs between 10 and 50 m below the seafloor near the shelf-edge. Other lower permafrost layers have been found in core-samples as deep as 450 m below the seafloor.

Figure 1.4-7 shows the lateral distribution of the uppermost shallow acoustic permafrost layer (O'Connor, 1981b). Even on the basis of these limited data, it is evident that the distribution of acoustic permafrost laterally and with depth is highly complex. The recent studies generally substantiate the acoustic permafrost distribution shown in Figure 1.4-6 but only insofar as indicating areas where permafrost is most prevalent. Acoustic permafrost is present near Tarsiut in the west and at Kaglulik on the eastern continental shelf. Further to the west, subsea permafrost is generally absent. It presently appears that much of the shallow acoustic permafrost is encountered in those areas where recent marine sediments are either thin or absent (Meagher, 1978; O'Connor, 1980).

Acoustic permafrost underlying the seafloor is thought to have two possible origins (Mackay et al., 1972). In the inshore areas near Pullen Island and along the Tuktoyaktuk Peninsula, most of the observed ice-bonding is probably relic, originating when permafrost formed beneath the old land surface which was

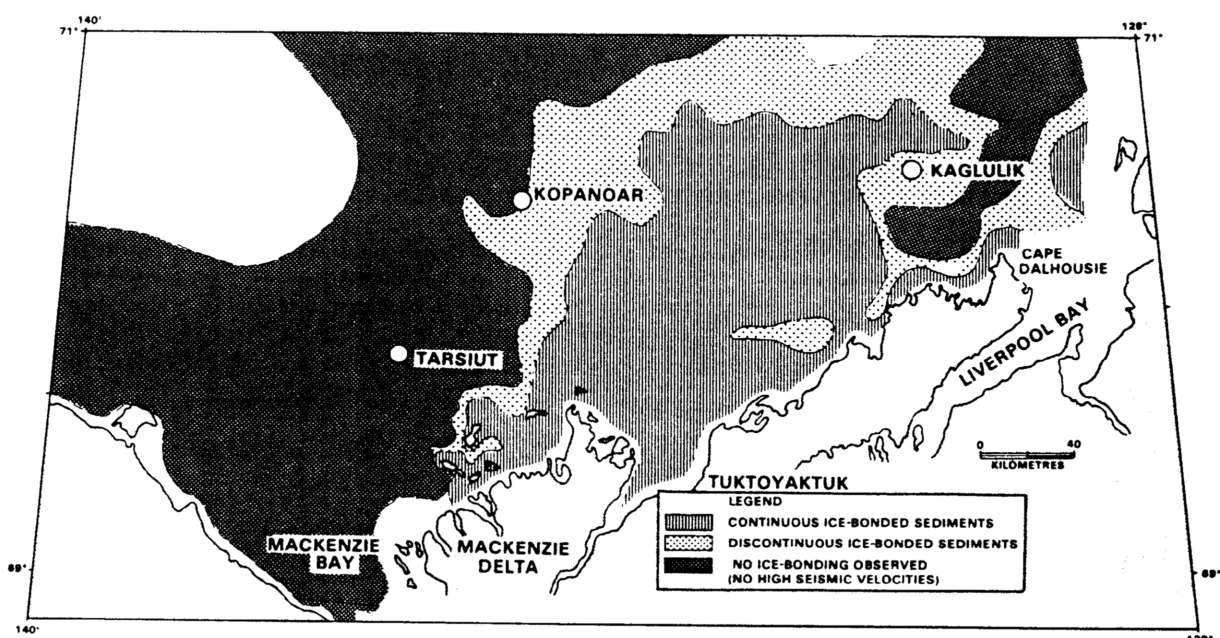


FIGURE 1.4-6 *Distribution of ice-bonded sediments in the Beaufort Sea. (Source: Judge et al., 1975).*

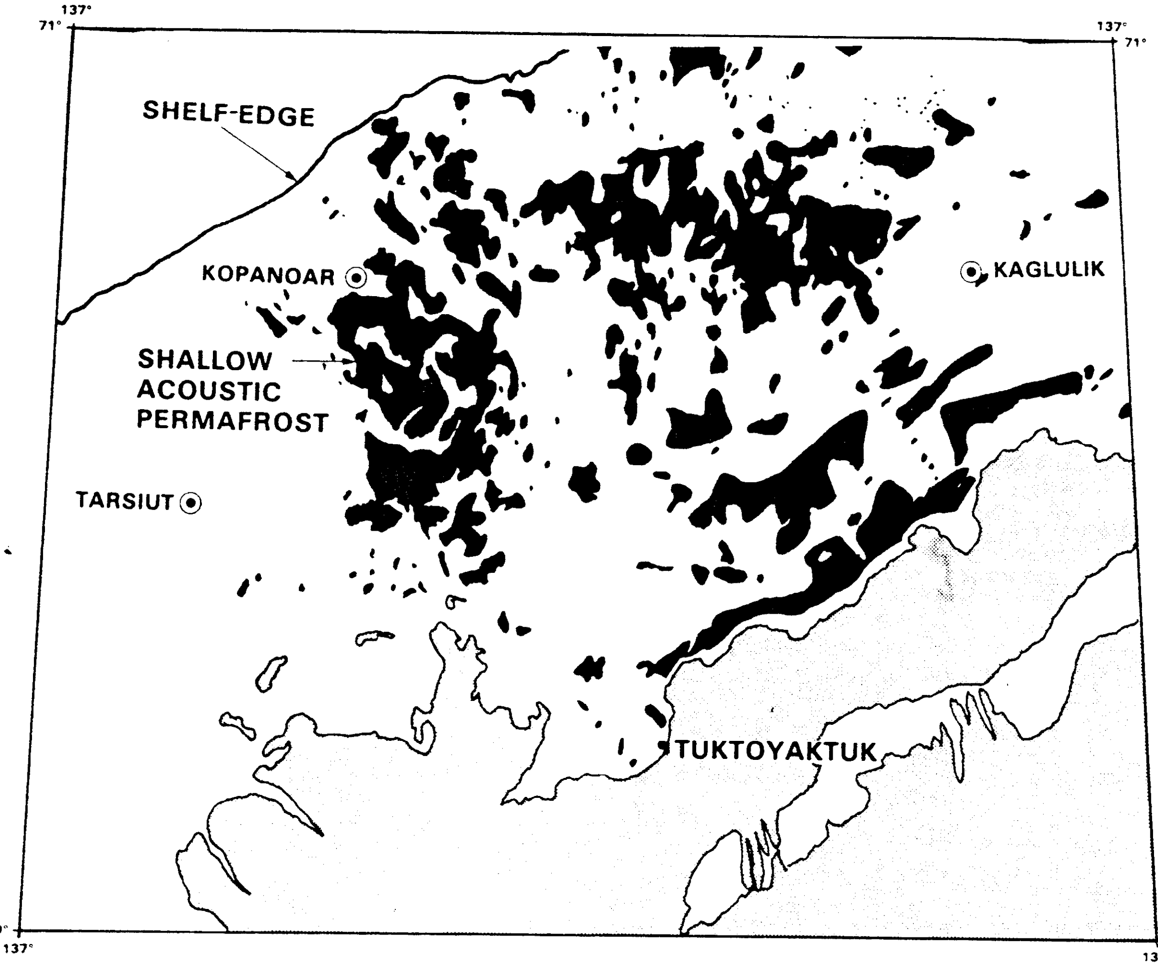


FIGURE 1.4-7 *The distribution of shallow acoustic permafrost on the continental shelf of the Southeastern Beaufort Sea. (Source: O'Connor, 1981b).*

exposed when the sea level was much lower (Section 1.4.2). In very shallow water (less than 2 m) where the sea ice becomes grounded each year, the present mean annual seafloor temperatures may be slightly less than 0°C (Judge, 1981; pers comm.). Under these thermal conditions, the relic shallow acoustic permafrost table is probably fairly stable. However, in water depths from 2 to 20 m, the mean annual seafloor temperatures are often above the freezing point and the acoustic permafrost is probably degrading (thawing) at the present time.

In the offshore areas, where the mean annual seafloor temperatures are presently negative, permafrost has grown downward from the present seafloor. However, ice-bonding is not generally found in the recent seafloor sediments, because the combination of salinity, grain size and only slightly below zero temperatures in these sediments precludes the development of much ice in the pore spaces (O'Connor, 1981b). In the deeper, coarse grained sediments, where the pore waters often have a much lower salinity, ice-bonding may be actively forming as a result of freezing point seawater temperatures. In those areas where relic acoustic permafrost (relic ice-bonded) survived the last marine transgression and now underlies deep water, the present subzero seafloor temperatures may have initiated growth of the relic permafrost. As a result, relic ice-bonding may appear to be growing upwards as it is gradually blanketed with a skin of modern ice-bonding, so that the acoustic permafrost which eventually forms has a relic core and a modern skin in thermal equilibrium with the present seafloor conditions (O'Connor, 1981).

1.4.6 PINGO-LIKE FEATURES

A number of large, conical shaped mounds or shoals (Figure 1.4-8) occur on the floor of the southern Beaufort Sea. The origin of these features is presently unknown, although they have been termed pingo-like features (PLF's) due to their apparent similarity to the ice-rich hills along the Tuktoyaktuk Peninsula (Mackay, 1979). The Canadian Hydrographic Service has identified over 200 of these features between the 20 and 200 m isobaths and from 128° to 136°W longitude (Figure 1.4-9). Most of the pingo-like features are between 200 and 1,000 m in diameter, have

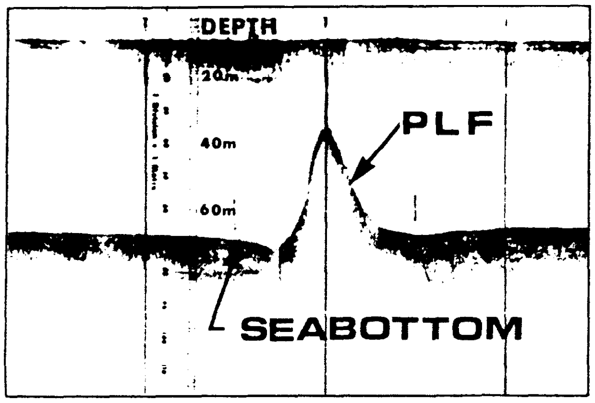


FIGURE 1.4-8 *Bathymetric profile across a pingo-like feature (PLF) in the Beaufort Sea. Some can rise to within 18 m of the sea surface. (Source: O'Connor, 1981).*

side slopes of less than 5°, and can rise to within 18 m of the sea surface.

Observations indicate that the top of some of these features contain ice-bonded sediments. The apparent association of the pingo-like features with water depths where the mean annual temperature is less than 0°C has led to speculation that they may either have developed in their present location (under the sea), or have developed on land (the classical pingo origin) and were somehow preserved during the sea level rise which followed the last glaciation. Present evidence suggests that the former hypothesis is probably more reasonable (O'Connor, 1980).

Many authors have also recognized that all the pingo-like features observed in the southern Beaufort Sea do not have identical origins. It is suggested that some pingo-like features may be due to mud slumps (unstable sediments squeezed onto the seafloor from below) as shown in Figure 1.4-10 (Pelletier, 1979; Shearer and Meagher, 1980; and O'Connor, 1980). In other areas, they may simply be an expression of relic relief on the unconformity (Section 1.4.3). In addition, the pingo-like features found along major geologic discontinuities may be related to active faults (O'Connor, 1980).

1.4.7 ICE SCOURING

Extensive scours, resulting from onshore and long-

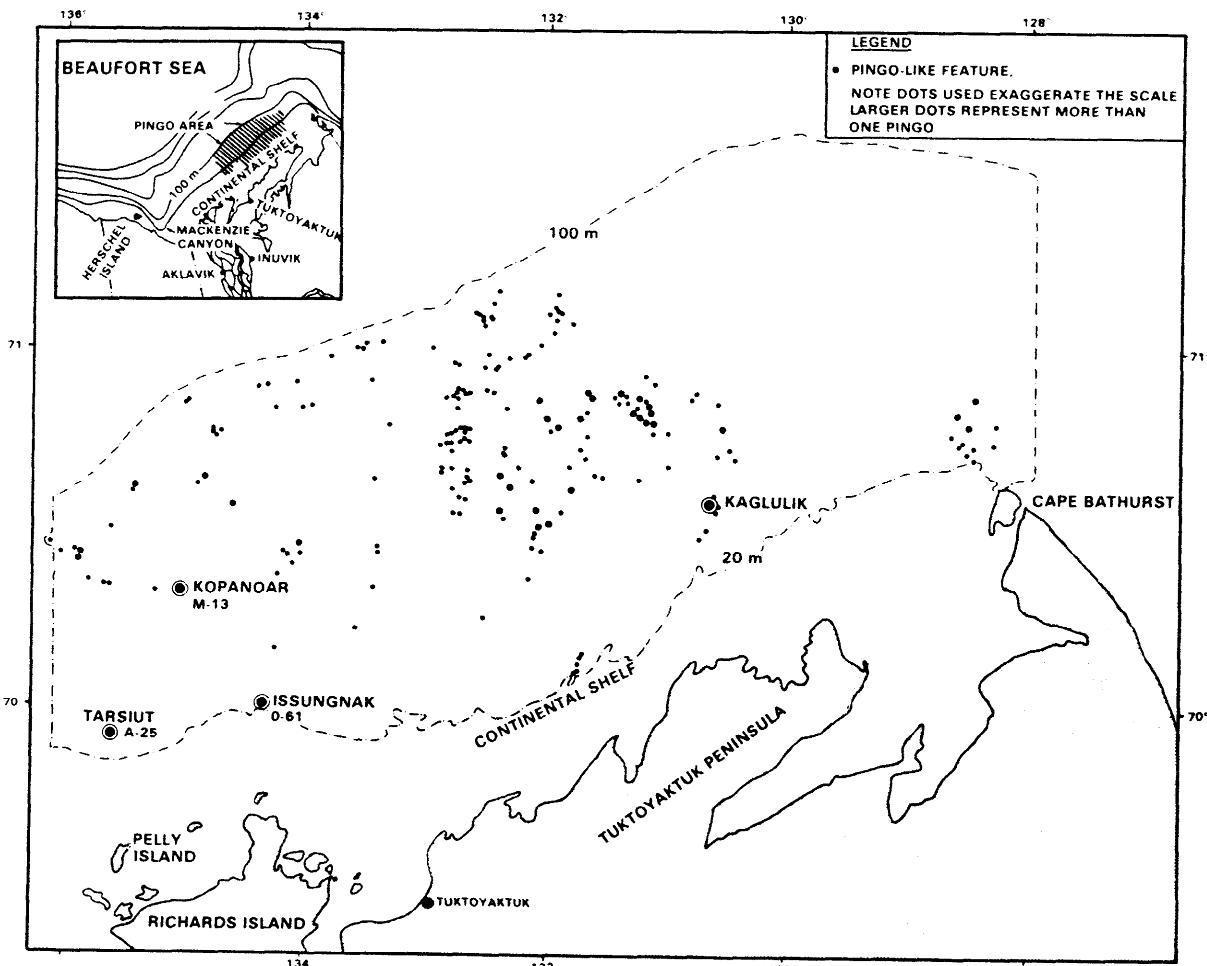


FIGURE 1.4-9 *The general area of recorded pingo-like features in the Canadian Beaufort Sea. (Source: Canadian Hydrographic Service, 1981).*

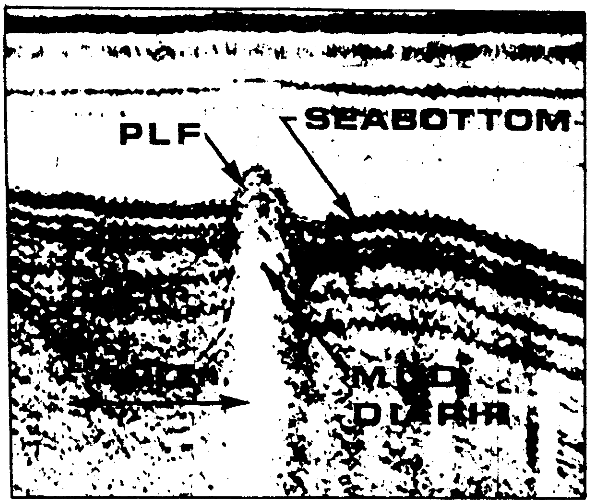


FIGURE 1.4-10 *A pingo-like feature (PLF) caused by mud diapirism near the Beaufort continental shelf-edge. (Source: O'Connor, 1980).*

shore movements of pressure ridge keels and glacial ice, are common on the Beaufort Sea continental shelf. Figure 1.4-11 shows the scour frequency in this region while the maximum scour depths in the same area are illustrated in Figure 1.4-12 (MacLaren, 1977; Shearer, 1979, 1980). Generally, scouring is most prevalent shoreward of the 50 m isobath, with maximum scour frequency occurring about 56 km offshore at the 25 m isobath. Scour trenches usually do not exceed 2 m in depth, although they may be as much as 7 m deep in some areas (Figure 1.4-12).

Their usual orientation is 105° and 285°, which is most likely associated with the predominant direction of ice motion causing the scours (MacLaren, 1977). Scour widths vary from only a few metres to as wide as 300 m, and individual scours have been traced for up to 11 km (Lewis, 1977). These features may be linear, curved or crosscut in form. They occur either as single grooves, believed to be caused by multi-year ice, or as groups of parallel grooves in the seafloor, believed to be caused by first year ice ridges. In the area of present and proposed hydrocarbon-related activities, scouring is relatively severe, with 15 to 20 scours per kilometre, and average scour depths of 2 m being common in 25 m water depths. However, to the north, the frequency of scours decreases rapidly and seafloor trenches are scarce. A summary of the scour frequency and maximum scour depths for various areas across the southern Beaufort Sea is provided in Table 1.4-1.

Scours observed in the Beaufort Sea are a combination of modern and relic features. Rates of scouring have been measured over the last few years using side-scan sonar (Lewis, 1977; Shearer, 1979, 1980). These measurements indicate rates of 0.43 and 0.1 scours per km/year in water depths of 15 m (North Pullen Island) and about 26 m (East Mackenzie Canyon), respectively. In waters less than 15 m deep, the seabed is totally saturated with scours which are

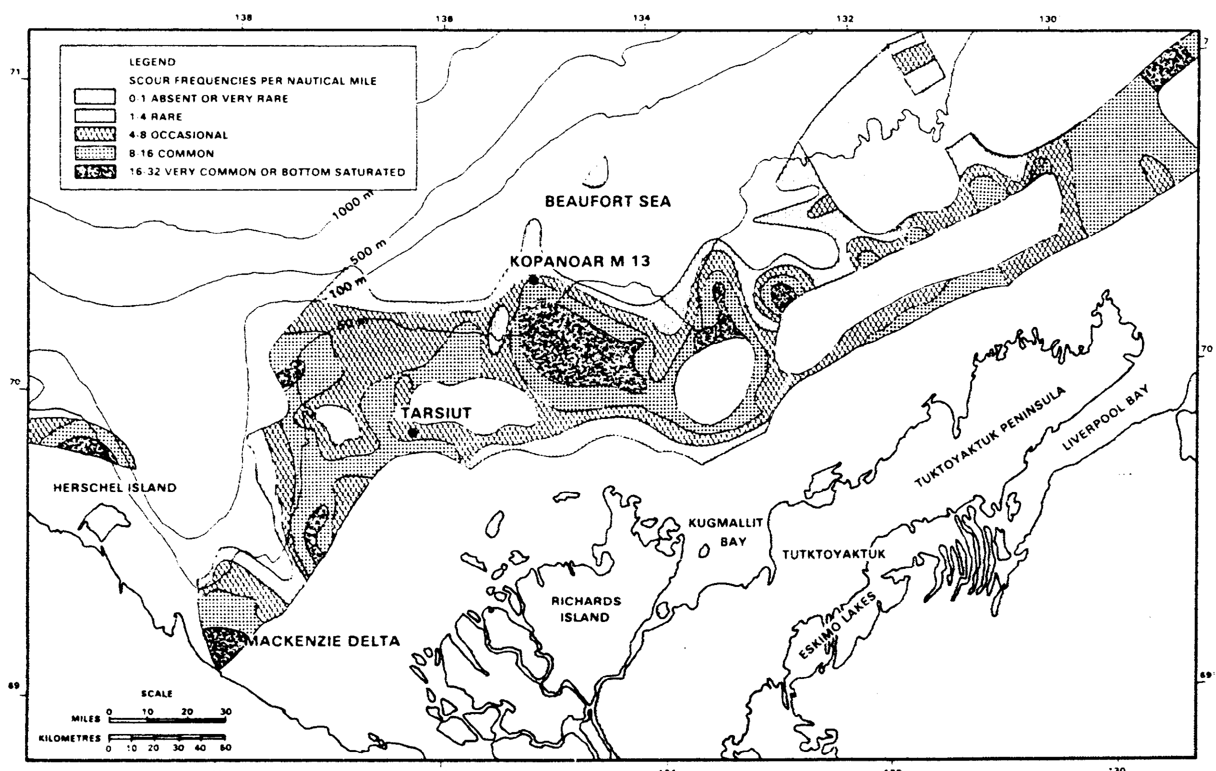


FIGURE 1.4-11 *Frequency of ice scouring in the Southeastern Beaufort Sea. Ice scouring is relatively severe in the area of present and proposed offshore hydrocarbon development. (Source: MacLaren, 1977).*

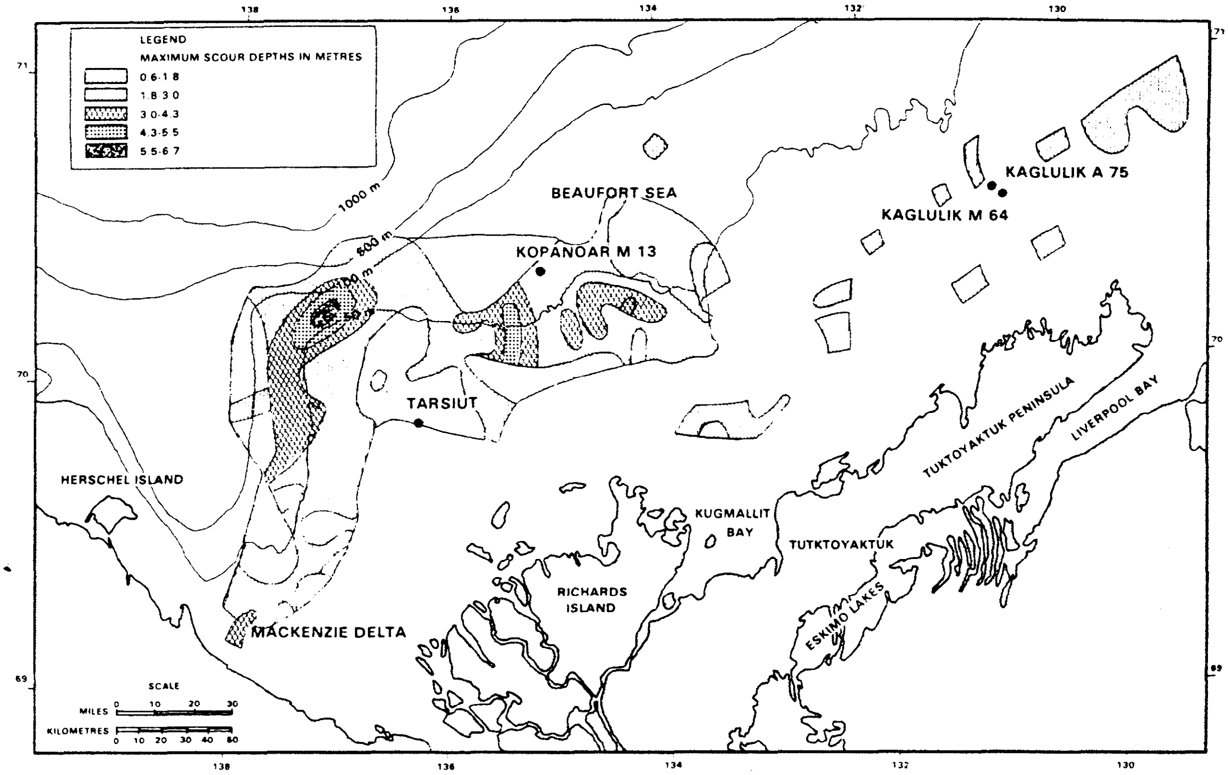


FIGURE 1.4-12 *Maximum depths of ice scouring in the Southeastern Beaufort Sea. In water depths greater than 50 m, scouring is infrequent and most are believed to have occurred during or just after the last glaciation when sea levels were lower. (Source: MacLaren, 1977).*

erased rapidly by waves and currents during the open water season. In water deeper than 50 m, the rate of scouring is infrequent due to the few ice keels of a size which can reach the bottom here, and it is believed that the majority of the scours in this region were caused during or just after the last glaciation when the sea level was lower. The deepest ice keel recorded in recent times in the Beaufort Sea was 47 m deep (Lewis, 1977).

1.4.8 SEISMICITY

It is standard practise in engineering design to take account of possible changes to foundations and foundation motions as a result of earthquakes. Ground motions which shake and possibly damage installations are of concern. Of equal, or greater concern is that movement of the seabottom may cause slumps, turbidity flows, or alter the foundation characteristics of artificial islands and other offshore structures.

Earthquakes have epicentres where they originate, and their intensities are measured on the Richter Scale in magnitudes. In the vicinity of an earthquake, magnitude 3 (M3) is usually felt, M 5 results in minor damage and M 7 is at the lower limit of major earthquakes.

Seismicity data for the eastern Beaufort Sea are sparse. The historical records date back to 1920, but more accurate measurements have only been taken since 1961. The distribution of earthquakes in the region up to mid 1977 of magnitude 3 or greater on the Richter Scale is shown in Figure 1.4-13 (Hasegawa et al., 1979). Review of the published data suggests there are four areas that generate, or have the potential for generating earthquakes in the Canadian Beaufort Sea. These are: (1) a broad area on the continental slope which is termed the Beaufort Sea seismicity cluster, (2) the Eskimo Lakes fault zone, located along the coastline east of the Mackenzie Delta, (3) a north-northeast trending zone in the vicinity of Martin Point, referred to as the Martin Point seismicity cluster, and (4) a projection of the Rapid Fault Array/Kaltag fault, west of the Mackenzie Delta. The seismicity associated with each of these areas is described below.

1.4.8.1 Beaufort Sea Seismicity Cluster

The locations of earthquakes associated with the Beaufort Sea seismicity cluster are shown in Figure 1.4-14. Between 1920 and mid 1977, more than 38 events were located on the continental slope in a zone approximately 300 km long and 200 km wide. Most of these events have been in the magnitude range of approximately M 3 to M 5, although larger earthquakes of M 5.5 (in 1937) and M 6.5 (in 1920) have also occurred in this region. Gutenberg and Richter

TABLE 1.4-1

FREQUENCY OF SCOURS AS PERCENT OF TOTAL AREA INVESTIGATED IN THE SOUTHERN BEAUFORT SEA

Division	Frequency of Scour Number Scours/ Nautical Mile	Percent of Total Area	Maximum Scour Depth (metres)	Comment
Very Rare	0-1	16	1	Mackenzie Canyon Area & Area 70°30'N to 71°00'N between 131°00'W & 134°30'W
Rare	1-4	11	3.5	Mackenzie Canyon Area & Area 70°30'N to 71°00'N between 131°00'W & 134°30'W
Occasional	4-8	13	6	Principally in narrow bands following 50 m isobath except in eastern part of area
Common	8-16	21	4	
Very Common	16-32	35	4.5	Area of dense scouring 69°40'N to 70°20'N and 133°40'W to 137°00'W
Bottom Saturated	32+	4	5	Minor areas north of Herschel Island and North of Liverpool Bay

(1954) reported that the depth of the 1920 event was 50 km. Event BS 75 of M 5.1 (Figure 1.4-13), is the best known seismic event from this region. It has been shown to have a left slip mechanism (i.e. looking across the fault, the ground on the other side moves to the left) in addition to a normal (or vertical) slip, and has been located at a depth of 40 km below the seafloor (Hasegawa et al., 1979). Depths and focal mechanisms of other events in this cluster are not documented. Hasegawa et al. (1979) suggest that BS-75 occurred on faults associated with the transition between the continental slope and oceanic crust. However, the deep structure of this earthquake source region is not well understood, and no simple major faults have been identified.

1.4.8.2 Eskimo Lakes Fault Zone

The Eskimo Lakes fault zone (Yorath and Norris, 1975; Cote et al., 1975; Hawkins and Hatelid, 1975) is a northeast trending zone at least 80 km wide, that extends approximately 230 km from the Mackenzie River along the Tuktoyaktuk Peninsula, and out below the continental shelf (Figure 1.4-14). Faults within the zone are predominantly normal or vertical-slip, with displacement occurring down to the northwest.

Scattered seismic events of M 5 occurred in the Eskimo Lakes area up to mid 1977 (Hasegawa et al., 1979) (Figures 1.4-13 and 1.4-14). Five of the events recorded along this portion of the Beaufort Sea coastline have been located within the mapped fault zone, while four others occurred 25 to 45 km to the southeast. However, the locations of epicentres of events of M 4 or greater in this region have location uncertainties of up to 30 km with smaller events having even larger location uncertainties (Basham et al., 1977). Consequently, past seismic events cannot be accurately related to individual faults within the Eskimo Lakes fault zone.

1.4.8.3 Rapid Fault Array/Kaltag Fault

Figure 1.4-14 shows the boundaries of the offshore projection of the Rapid Fault Array/Kaltag fault (Yorath and Norris, 1975; Young et al., 1976). This projection is extrapolated from onshore faults to coincide with the landward portion of a positive free air gravity anomaly. Continuation of the Kaltag

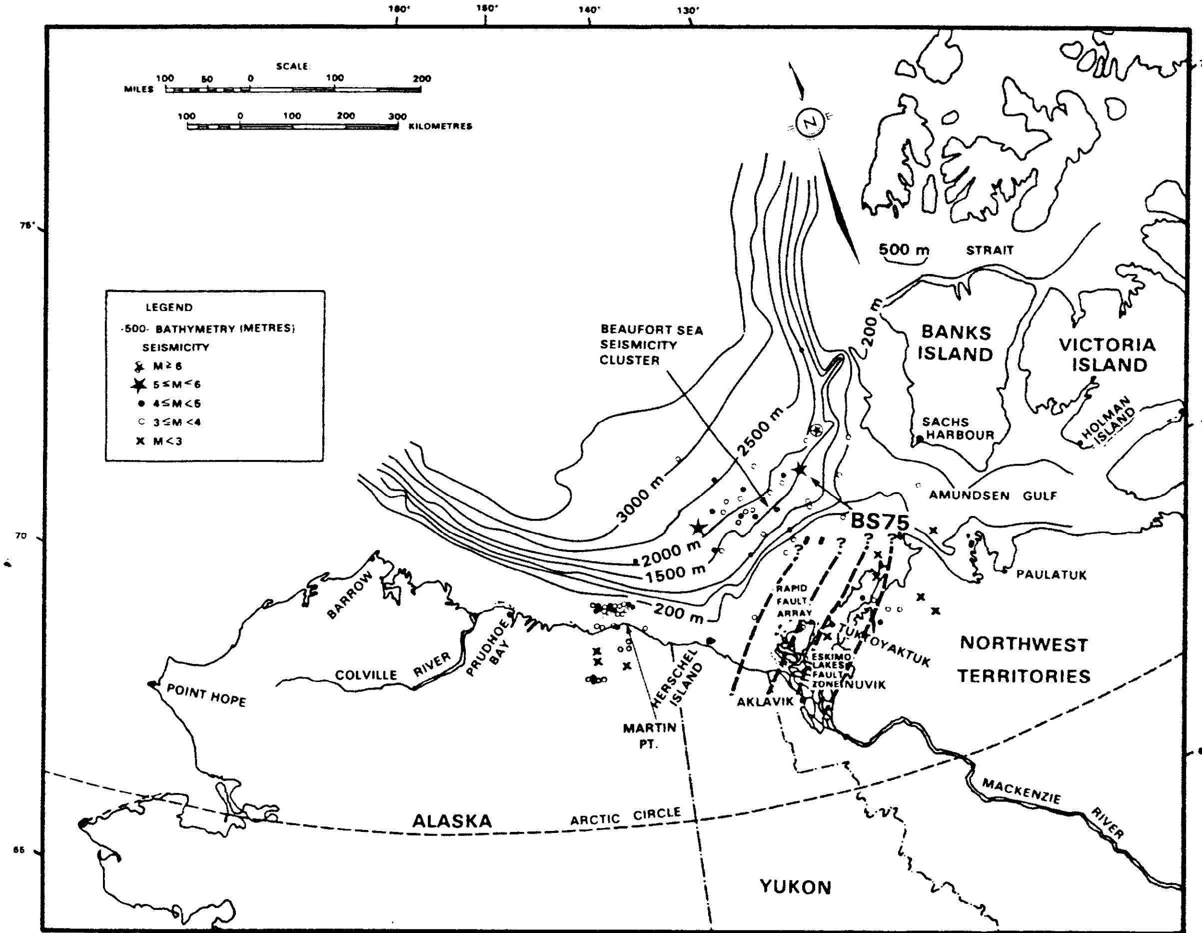


FIGURE 1.4-13 *Known seismicity (to mid-1977) under the Beaufort Sea and adjacent coastline. Event BS75 of magnitude 5.1 is the best known seismic event in the region. (Source: Hasegawa et al., 1979).*

fault below the Beaufort Sea has also been suggested (Jones, 1980), although Sobczak (1977) suggests that a major northeast trending structure does not continue offshore across Mackenzie Bay. Faults within the Rapid Fault Array are thought to have a slip with a high angle reverse component that generally heads to the south.

Seismicity data for the Beaufort Sea (Figure 1.4-13) indicate an absence of earthquake epicentres along the Rapid Fault Array. Young et al. (1976) suggest that the array formed as a result of a sharp bend in, and splaying out of, the Kaltag fault, which is an active fault in Alaska. If this is the case, faults within the Rapid Fault Array may be potential seismic sources. In addition, onland faults in the array are generally aligned with faults extending northward from the seismically active area of the Richardson Mountains and Peel River.

1.4.8.4 Martin Point Seismicity Cluster

Nearly forty earthquakes, with some events up to M 5, have occurred in an apparent northeast trending zone of seismicity in the area of Martin Point, Alaska; most of these events occurred in 1968 (Hasegawa et al., 1979). This zone is at least 180 km long, and extends from land onto the continental shelf (Figure 1.4-13). However, focal mechanisms of the Martin Point seismicity cluster have not been determined, and the relationship between these earthquakes and local faults is not known.

Earthquake swarms such as the one that occurred at Martin Point are common throughout the Canadian Arctic Archipelago (Basham et al., 1977). However, none of these swarms has been studied in sufficient detail to permit association with geological structures or determination of the orientation of the regional stress fields.

1.4.8.5 Present Seismic Instrumentation Program

Up to 1981, the closest seismic stations to the Beaufort Sea were at Mould Bay (900 km to the northeast) and Inuvik (150 km to the south). These distances and the types of data collected at these stations leads to data deficiencies regarding the location and the

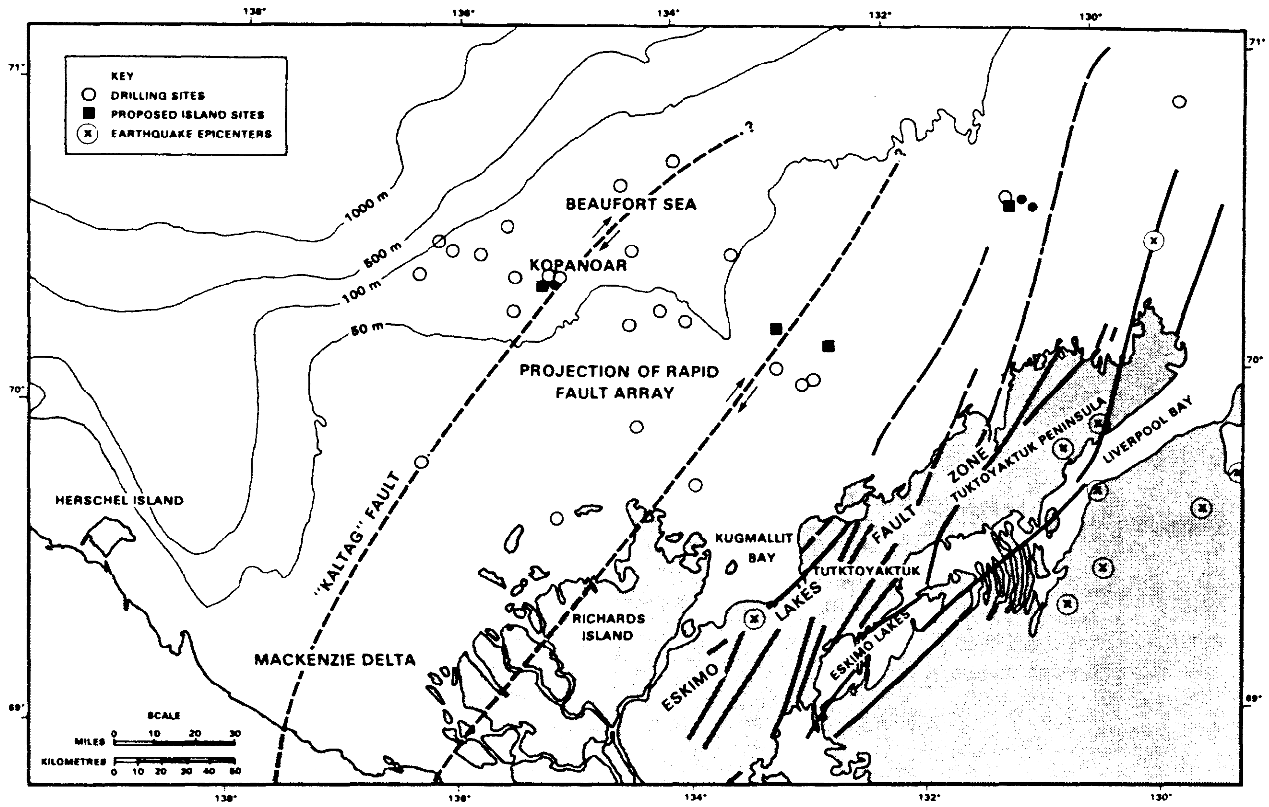


FIGURE 1.4-14 *Location of geologic structures and earthquake epicentres in the Beaufort Sea-Mackenzie Delta area. Earthquakes have not yet been detected along the projection of the rapid fault array. (Source: Hasegawa et al., 1979).*

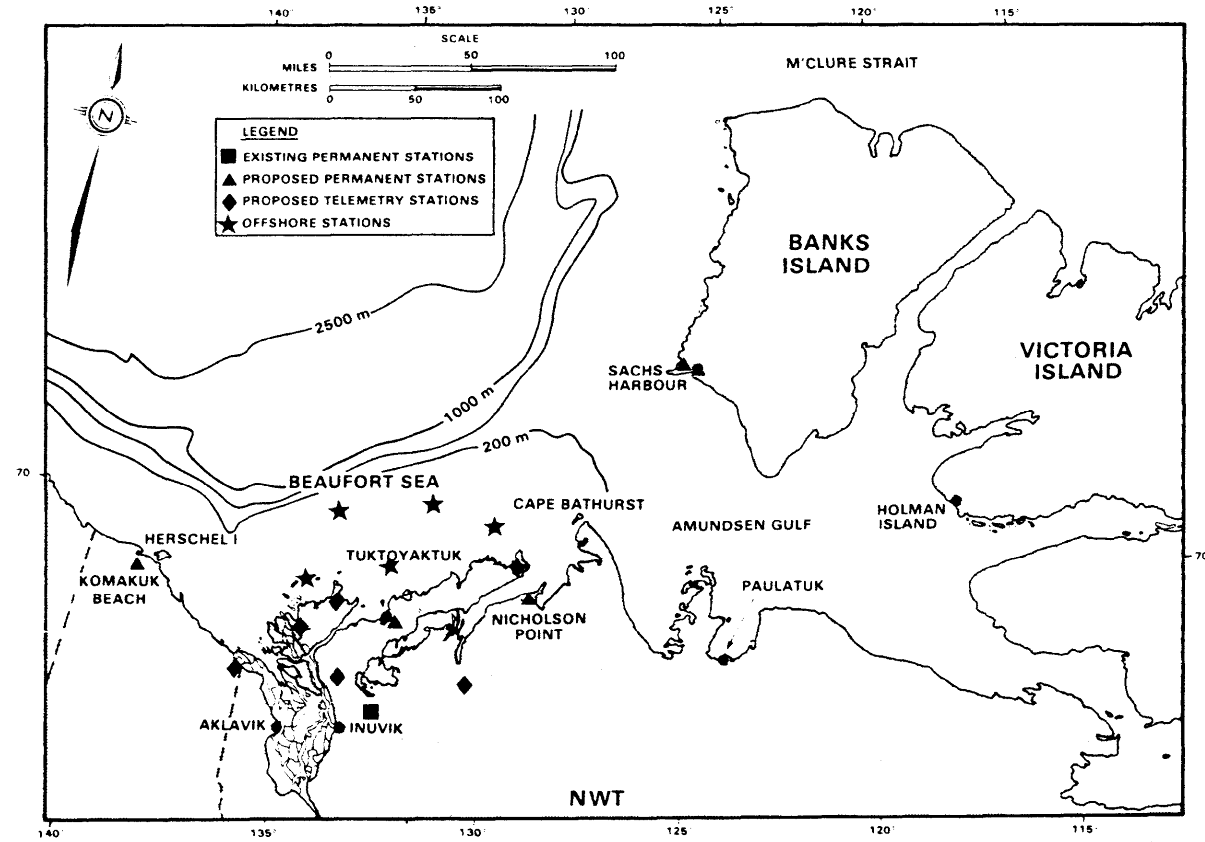


FIGURE 1.4-15 *Locations of existing and proposed seismograph stations. The new stations will allow epicentral locations to be more precisely determined and allow the detection of low magnitude events in the region. (Source: Hasegawa et al., 1979).*

magnitude of seismic sources in the region. For example, this seismographic network could only record events of magnitude greater than 3.5 (Hasegawa et al., 1979). Since the distance between stations was so large, the precise determination of epicentral locations of the more frequent small events was low. This in turn prevented precise location of active geologic structures. In 1981 a seismicity measurement program was initiated by the Earth Physics Branch of the Department of Energy Mines and Resources (EMR), in conjunction with Industry, which will eventually satisfy many of the existing data deficiencies. The program involves the establishment of five additional land-based seismograph stations along the Beaufort Sea coast (Figure 1.4-15), as well as the installation of several ocean bottom seismographs. The land-based instruments were calibrated during 1981 using an 800 kg offshore underwater explosion. The use of ocean bottom seismographs will allow a more precise determination of focal depths and the indentification of earthquake sites, particularly small events that cannot be detected from land.

1.5 CHEMICAL OCEANOGRAPHY

The following section briefly summarizes available information regarding trace metal, hydrocarbon and nutrient levels in the Beaufort Sea region. While Section 1.4 described physical aspects of the seabottom in this area, topics related to sediment chemistry are addressed here. Available information describing uptake of hydrocarbons and trace metals by biological resources will also be discussed in this section.

1.5.1 SETTING

The most comprehensive studies of the chemical oceanography of the Beaufort Sea were conducted in conjunction with the Beaufort Sea Project, although the data obtained in this program were limited to short periods in the summer (August, 1974; August, 1975) and few trace metal data were obtained.

The waters of the Beaufort Sea shelf are dominated by two factors which are subject to wide seasonal and annual variability:

1. ice coverage, which is permanent except for a relatively small area in the southern Beaufort Sea that is usually free of ice between mid July and mid October; and

2. the large freshwater runoff from the Mackenzie River, providing approximately half the mean total yearly freshwater discharge into the southern Beaufort Sea ($8.13 \times 10^{11} m^3/y$).

The combination of variable riverflow (Section 2.4), ice coverage (Section 1.1) and wind conditions (Section 1.2) can have a marked effect on the seawater properties of this region by modifying the two-layer estuarine system, thereby affecting both the spatial and vertical distribution of chemical oceanographic parameters. However, it should be noted that, prior to 1981, there was almost a complete lack of time-series measurements for this region, thus hampering delineation of potential spatial and temporal oceanographic trends.

In 1981 two site-specific studies of the temporal variation of chemical oceanographic parameters were undertaken in the Beaufort Sea by Arctic Laboratories Limited. The first study (Erickson, 1981), scheduled for completion in June 1982, is being conducted over an 18 month period in the vicinity of the Issungnak 0-61 artificial island site (Figure 1.5-1). Parameters measured include heavy metals, polyaromatic hydrocarbons, reactive nutrients, alkalinity, total organic carbon, particulate organic carbon, dissolved organic carbon, dissolved oxygen, chlorophyll *a* and alkalinity in the water column. Concurrent measurements of bacteria, zooplankton and larval fish, phytoplankton, benthic invertebrates, sediment chemistry, ice chemistry and epontic algae are also being made. The resulting data set will be useful for estimating the seasonal variability of parameters in the Mackenzie estuary and for examining the interactive relationships among the various chemical, physical and biological factors. The second study was conducted at McKinley Bay from January to June of 1981 (Thomas, 1981). The objective of this study was also to obtain a broad data base and time series information. Measurements included dissolved oxygen, reactive nutrients and particulate concentraions in the water column and concurrent sampling of physical and biological parameters in sea ice, the water column and sediments (Plate 1.5-1).

1.5.2 TRACE METALS

The term trace metals, as used in current literature, includes those elements which occur in small concentrations in natural biologic systems, and is commonly used interchangeably with the terms heavy metals, trace inorganics, microelements and micronutrients.

At least 11 trace metals, namely iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), manganese (Mn), chro-

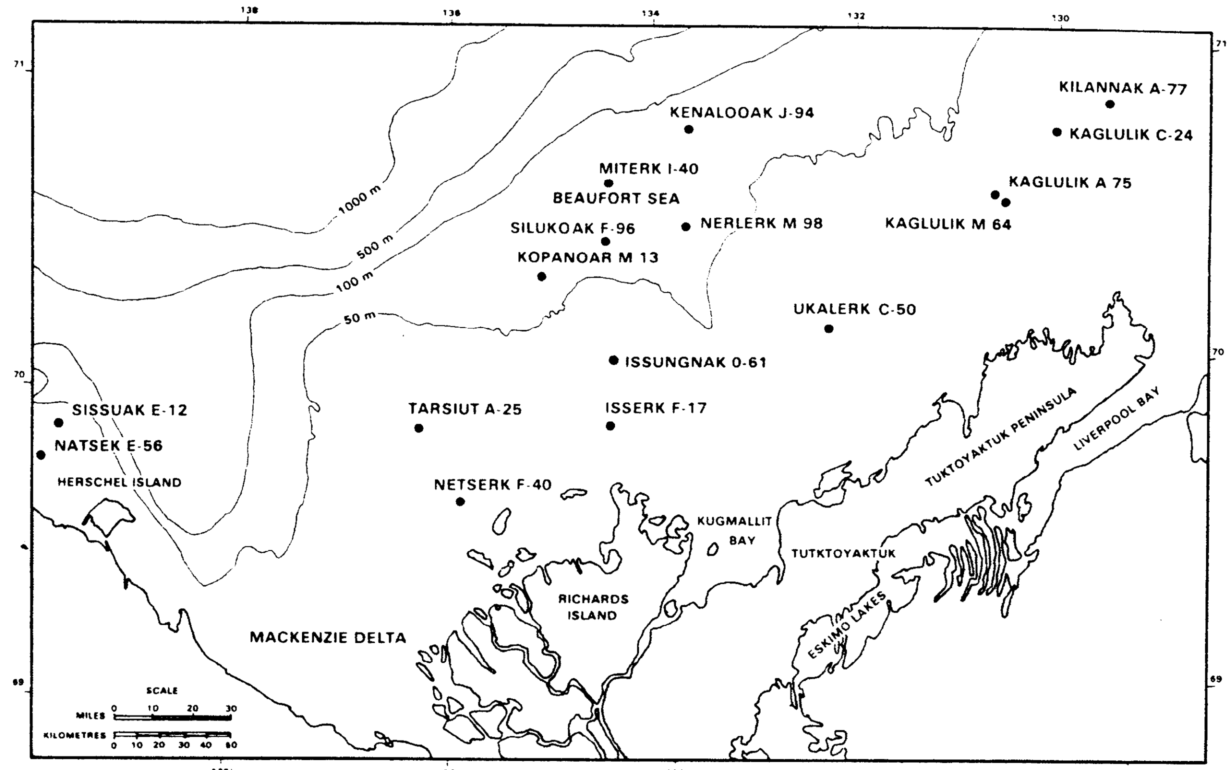


FIGURE 1.5-1 *Beaufort sea drill sites with trace metal data.*

PLATE 1.5.1 *Scientist with array of chemical oceanographic sampling equipment on the ice at the McKinley Bay, 1981.*

mium (Cr), molybdenum (Mo), selenium (Se), nickel (Ni), vanadium (V), and tin (Sn), are essential for cellular metabolism and optimal growth of organisms. Although some trace metals are essential for enzymatic activity, they also form an important group of enzyme inhibitors when natural concentrations are exceeded. Metals such as silver (Ag), mercury (Hg), cadmium (Cd), lead (Pb), and copper (Cu) are particularly toxic, and usually inhibit enzymes by affecting sites of catalytic activity. Cadmium, chromium, copper, lead, mercury, selenium, silver, tin and zinc are of primary concern in this regard, while antimony (Sb), arsenic (As), nickel and vanadium may also have adverse effects on some organisms. Other metals, such as cobalt, iron, manganese and molybdenum (and also copper and zinc under certain circumstances), may cause temporary effects through excessive biostimulation. The biological effects of trace metals are reviewed in a supporting document (ESL and LGL, 1982).

When applied to seawater, the term trace metal is generally taken to include all metals present at concentrations of less than 1 mg/kg. This broad definition includes most of the metallic elements present in the earth's crust, although many are present in concentrations below the detection limits of current analytical techniques. In practice only a relatively small number of metals (usually the biologically active ones) have been regularly investigated and their concentration in seawater is typically in the ng/kg to the µg/kg range. Many of the metals are trace constituents of sea water because of their high reactivity in solution, but they may be more concentrated in sediments where levels are typically in the mg/kg range.

1.5.2.1 Trace Metals in Seawater of the Beaufort Sea Shelf

Data on the trace metal content of Beaufort Sea shelf water, together with comparative data for other areas, are summarized in Figure 1.5-2. The raw data used to plot this and subsequent summary figures are presented in Thomas (1982). Concentrations are expressed in µg/kg (ppd by weight) or µg/L (ppb weight to volume). Data documenting trace metal levels in seawater of the Beaufort shelf is limited in comparison with the amount describing metal concentrations in sediments and biota. This partly results from difficulties in obtaining accurate data owing to the chance of contamination during the collection, storage and analysis of samples containing exceedingly small quantities of dissolved metals.

Thomas (1978b, 1978c, 1979a) measured the trace metal content of near-bottom seawater at twelve Dome Petroleum drill sites in the Beaufort Sea (Figure 1.5-1). The ranges of iron, copper, zinc, cadmium, chromium, lead and mercury concentrations

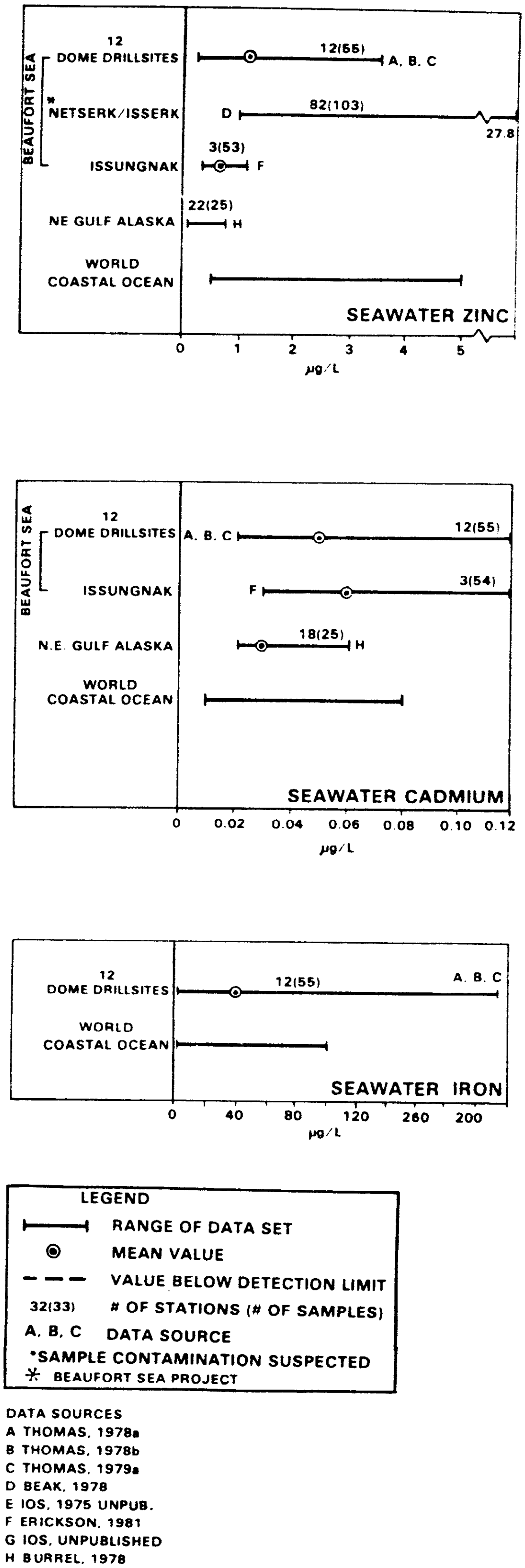
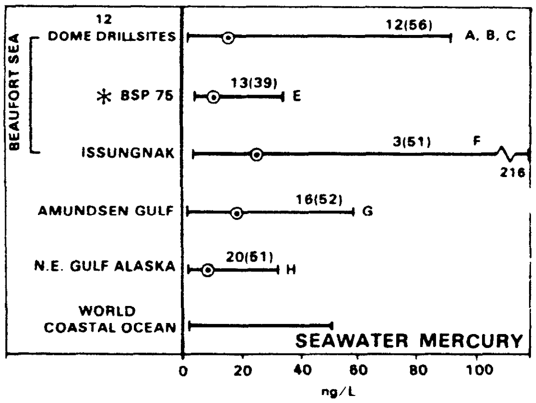


FIGURE 1.5-2 *Summary of trace metal in Beaufort Sea waters and those of other areas (continued on the next page).*



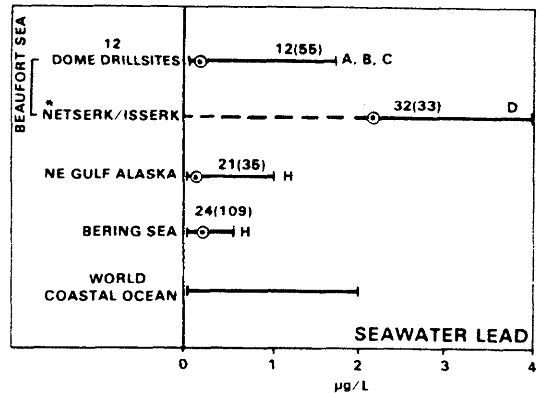
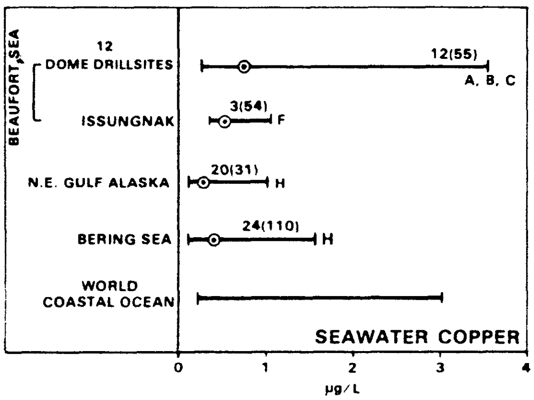
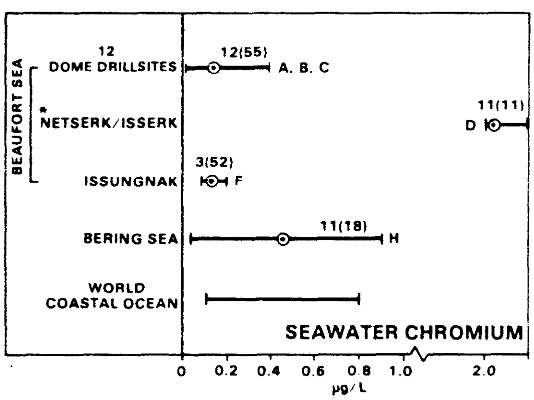
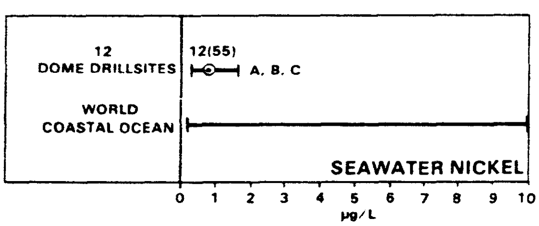


FIGURE 1.5-2 *Cont'd.*







were 1.0-213.0 µg/kg, 0.1-3.5 µg/kg, 0.2-3.0 µg/kg, 0.01-0.12 µg/kg, 0.01-0.40 µg/kg, 0.02-0.57 µg/kg and 1.41-7.5 µg/kg, respectively. Nickel concentrations at Tarsiut A-25 and Kilannak A-77 were 0.32-1.59 µg/kg and 0.41-0.77 µg/kg, respectively. These values generally fall within the range of values considered typical of unpolluted world coastal oceans (Figure 1.5-2).

The Institute of Ocean Sciences (unpublished data) found that total dissolved mercury ranged from 9 to 34 ng/L for thirteen Beaufort shelf stations. This compares with a range of less than 1 to 57 ng/L measured at sixteen stations in the waters of Amundsen Gulf. Chromium concentrations in the seawater of the U.S. Beaufort Sea shelf were reported by Gosink (1978) to vary from 0.05 to 2.1 µg/L. Dissolved Zn, Cd, Cr, Pb, Hg and As levels at Netserk F-40 and Isserk F-27 were also measured by Beak (1978), although the analytical detection limits for the elements studied were generally much higher than the values normally observed in unpolluted seawater. In some cases high trace metal levels were thought to be due to sample contamination.

1.5.2.2 Trace Metals in the Sediments of the Beaufort Sea Shelf

Data for the trace metal content of the sediments of the Beaufort Sea shelf, together with comparative data from other areas, are summarized in Figure 1.5-3. These data are expressed in units of µg/g (ppm by weight) on a dry weight basis for analyses completed with whole sediment samples. The analysis of trace metals in marine sediments does not pose many of the problems of seawater analyses since the average concentration of metals is about three orders of magnitude greater (usually in the ppm range).

In general there appears to be a high correlation between sediment grain size and sediment trace metal composition. Sediments composed primarily of sand-

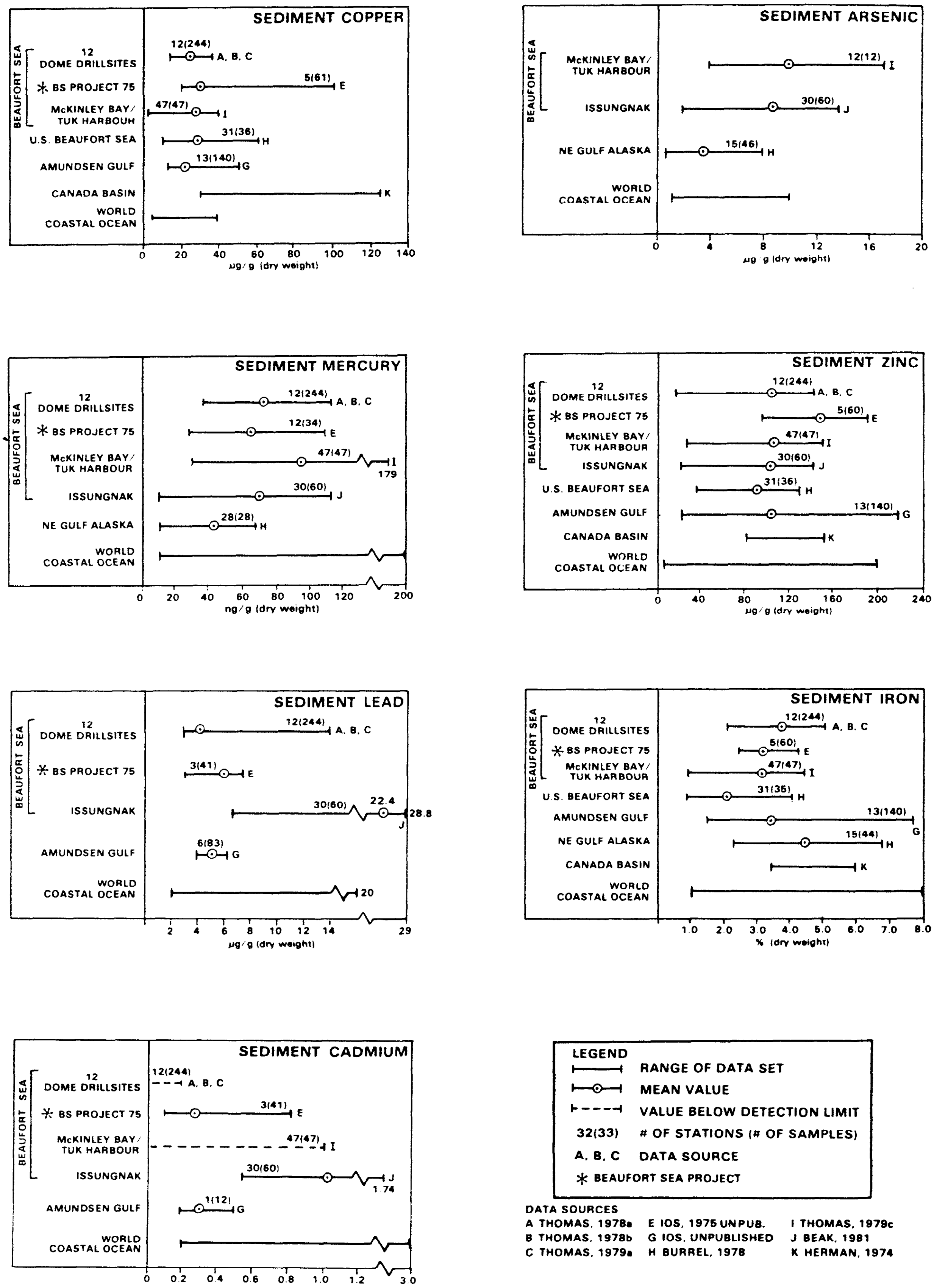


FIGURE 1.5.3 *Summary of trace metal levels in Beaufort Sea sediments and those of other areas (continued on next page).*

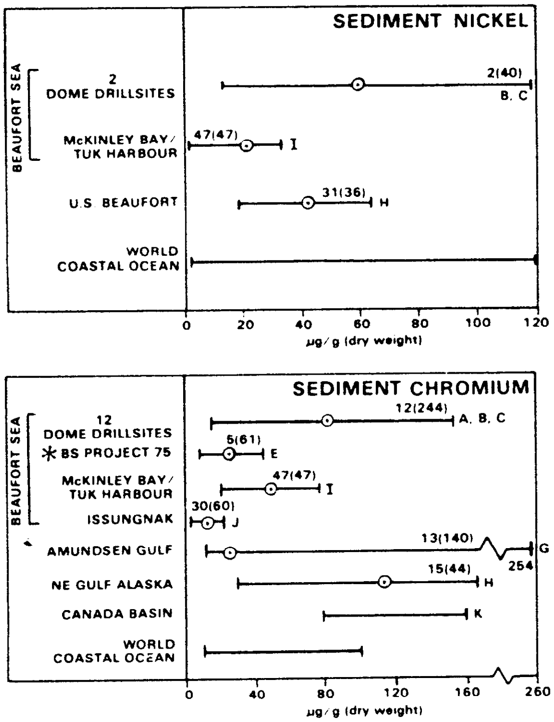


FIGURE 1.5-3 *Cont'd.*

sized particles usually contain relatively low concentrations of iron and trace metals when compared to sediments consisting of silt or clay-sized particles which are usually rich in iron and other metals. There is a strong regional variation in the sediment grain-size distribution in the Beaufort Sea (Pelletier, 1976), and similar regional variation in the distribution of heavy metals in surficial sediments. Concentrations of Fe, Cu, Zn, Cd, Ni, Cr, Pb and Hg may differ by an order of magnitude or more in shelf sediments.

Thomas (1978a) reported that Fe, Cu, Zn, Cd, Ni, Cr, Pb and Hg concentrations at twelve Dome Petroleum drillsites were 2.08-5.12, 14.0-40.0, 77.0-142.0, 0.2-2.7, 16.0-119.0, 13.0-156.0, 3.0-14.0, and 0.016-0.106 µg/g, respectively. These levels are consistent with values currently accepted as the baseline for unpolluted world coastal sediments. The Institute of Ocean Sciences (unpublished data) found similar ranges for Cu, Cd, Pb and Hg in samples collected during the Beaufort Sea Project in 1975. Macdonald and Macdonald (unpublished data) also determined the Fe, Mn, Zn, Cu, Cr, Pb and Cd content of five sediment cores (about 50 cm in length) from the Beaufort Sea shelf. In general the metals were uniformly distributed throughout the cores, although there may have been a slight decrease in trace metal concentration with depth. This suggests that, over the last 250 years, the input of trace metals into Beaufort shelf sediments has been approximately constant. A similar examination of sediment cores from Amundsen Gulf in 1977 by Macdonald and Macdonald (unpublished data) also indicated a relatively uniform metal distribution along the sediment core and trace metal concentrations similar to those found in Beaufort Sea surficial sediments.

1.5.2.3 Trace Metals in the Biota of the Beaufort Sea Shelf

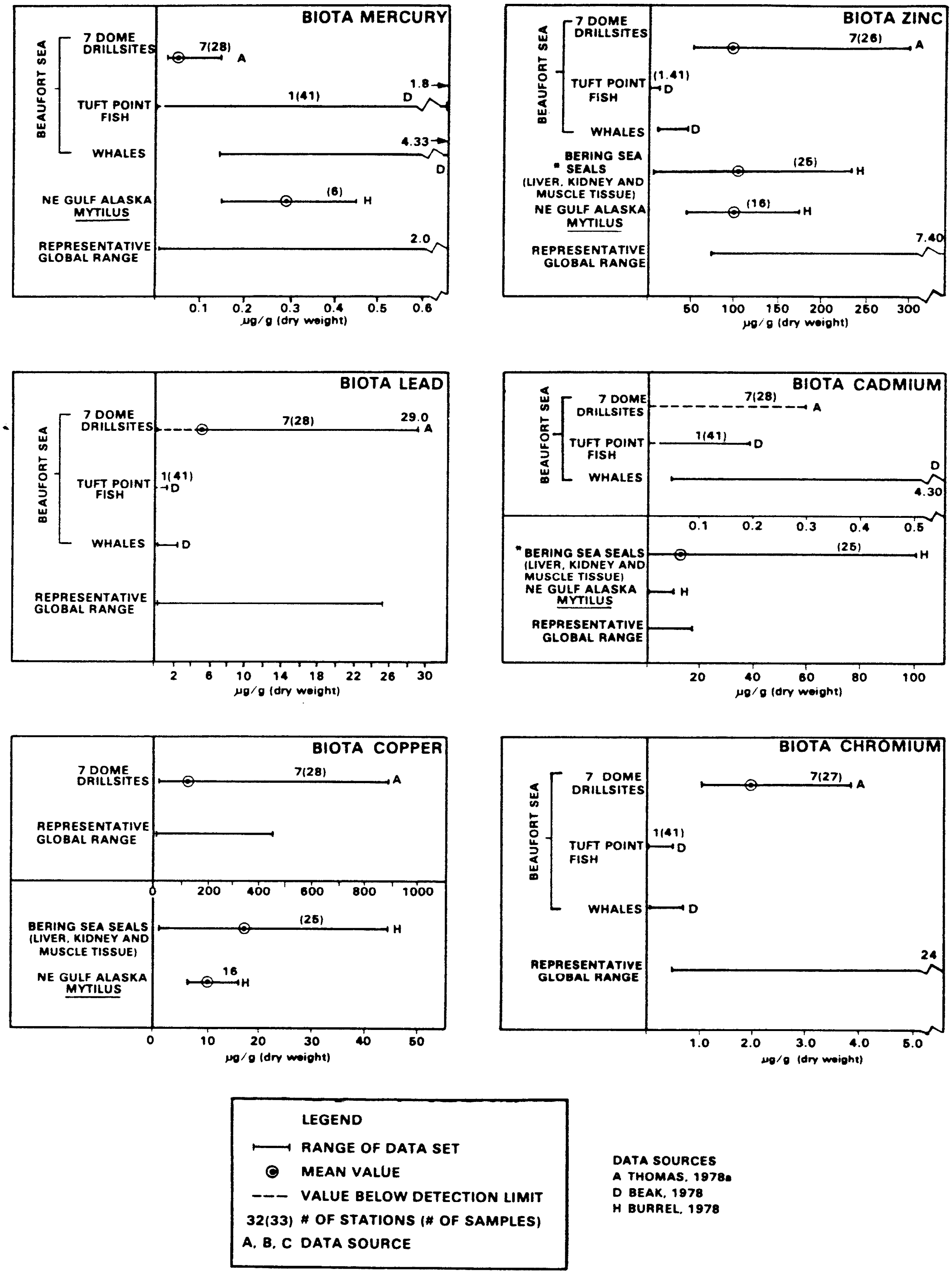
Data describing the trace metal levels in biota from the Beaufort Sea, together with comparative data from other areas, are summarized in Figure 1.5-4. Concentrations are expressed in µg/g (ppm by weight) on a dry weight basis. Residual trace metal data are usually difficult to interpret and compare from region to region because of the wide natural variations that commonly occur due to factors such as size, sex, age, species, the developmental stage of the organism and the method of sampling and preservation. For this reason, interpretation of the trace metal content of organisms is usually only qualitative. Nevertheless, these data indicate that concentrations of trace metals observed in Beaufort Sea fauna are consistent with background levels reported from other regions. In addition, there has been no evidence of significant bioaccumulation of metals in organisms exposed to drilling wastes.

1.5.3 HYDROCARBONS

Some of the hydrocarbons found in petroleum can also be of marine or terrestrial biogenic origin, and be of marine or terrestrial biogenic origin, and may biota. The following summarizes available data on specific groups of hydrocarbons which have been documented in seawater, sediments and organisms of the Beaufort Sea.

1.5.3.1 Low Molecular Weight Hydrocarbons (LMWHC) in Seawater

Low molecular weight hydrocarbons (LMWHC's) can be defined in several ways according to operational or analytical needs. The term can refer to those hydrocarbons (C_1-C_4) which exist as a gas at standard temperature and pressure. In addition, LMWHC's have been arbitrarily defined as those organic compounds containing between one and 10 carbon atoms, thus distinguishing them from the high molecular weight hydrocarbons which contain greater than ten hydrocarbon atoms. The latter definition for LMWHC compounds corresponds closely to those carbon compounds which have an appreciable vapour pressure under common environmental conditions.
Macdonald (1976) measured concentrations of low molecular weight hydrocarbons in the Beaufort Sea during 1974 and 1975. The concentrations of methane, propane and n-butane during 1974 were 72.0 to



DATA SOURCES
A THOMAS, 1978a
D BEAK, 1978
H BURREL, 1978

FIGURE 1.5-4 *Trace metal levels in biota from the Beaufort Sea and other areas.*

617.0, 0.02 to 0.92 and 0.012 to 0.254 nanolitres/litre (nL/L) of seawater, respectively, while concentrations in 1975 were 15.0 to 1154.0, 0.11 to 0.90, and 0.11 to 0.90 nL/L of seawater, respectively. The concentrations of methane were considered high for marine waters. Profiles of dissolved methane with depth indicated that concentrations were highest in a zone within about 10 m of the bottom, suggesting that the sediments were the methane source. This is supported by recent work by Kvenvolden et al. (1980) which showed that methane concentrations in the interstitial waters of Bering Sea sediments were much more abundant than other LMWHC gases and increased in concentration with depth into the cores. Since high ethane, propane and n-butane were not found in conjunction with the high methane concentrations in the Beaufort Sea, petrogenic contamination by seeps or hydrocarbon exploration-related activites were considered unlikely. LMWHC concentrations measured in near-bottom waters of the Chukchi Sea (Cline, 1977) are similar to those documented in the Beaufort Sea by Macdonald (1976). The former author reported relatively high methane levels but very low concentrations of ethane, ethene, propane, propene and n-butane.

1.5.3.2 Polycyclic Aromatic Hydrocarbons (PAH) in Seawater

Polycyclic aromatic hydrocarbons (PAH's) are a class of organic compounds containing hydrogen and carbon combined in two or more condensed aromatic rings. The concentrations of PAH in the waters of the southern Beaufort Sea vary from 13.0 to 45.0 ng/L (chrysene equivalents), and inversely with salinity (Wong et al., 1976). PAH concentrations in nearshore waters are much more variable than PAH in deeper waters, possibly due to the influence of the Mackenzie River which flows through regions with known fossil fuel deposits and natural seepages. Wong et al. (1976) reported a PAH level of 16.0 ng/L, which is comparable to concentrations found in uncontaminated oceanic waters at Ocean Weather Station P (50°N, 145°W) in the northeast Pacific Ocean (Institute of Ocean Sciences, 1977).

1.5.3.3 Non-Polar Hydrocarbons in Marine Sediments

Wong et al. (1976) reported that the distribution of n-paraffins in marine sediments of the southern Beaufort Sea was characteristic of sediments containing both marine and terrestrial biological and detrital materials. All sediments contained a series of n-paraffins (n-C_{17} to n-C_{32}), the isoprenoids pristane and phytane, and an unresolved group of non-polar hydrocarbons (envelope). The concentration of the n-paraffins was 2.6 to 23.6μg/g, while levels of the unresolved envelope hydrocarbons varied from 28.3 to 136.7μg//g. Peake et al. (1972b) also reported a range of 1.23 to 9.40μg/g for n-paraffins in ten Beaufort Sea sediments. By comparison, Brown et al. (1972) documented that the range of total n-paraffins in Saanich Inlet (British Columbia) surface sediments was 2.3 to 32.7μg/g. Wong et al. (1976) also noted that an odd-carbon predominance, which is characteristic of terrestrial plant material, was evident in most marine sediments of the southern Beaufort Sea, suggesting an influx of detritus from the Mackenzie River.

1.5.3.4 Polycyclic Aromatic Hydrocarbons in Sediments

Wong et al. (1976) reported that total PAH (defined as the sum of chrysene, benzanthracene, perylene, phenanthrene, and pyrene, and certain isomers) in marine sediments from the Beaufort Sea ranged from 236.0 to 984.0 and 97.0 to 1,341.0μg/kg wet weight during 1974 and 1975, respectively. Total UV-PAH (defined as the sum of pyrene, benz(a)pyrene, perylene and coronene) was 0.4 to 20.0μg/kg dry weight for nearshore sediments and about 300.0 μg/kg dry weight for benthic sediments. In a subsequent study Stitch and Dunn (1980) measured about 0.5 to 3.3 μg/kg dry weight benze(a)pyrene in about 20 sediment samples from the southern Beaufort Sea.

On a world-wide basis background levels for PAH in sediments appear to be in the range from a few tens to approximately 500.0μg/kg (dry weight). The total PAH content of northwest Atlantic sediments greater than 1,000 km offshore was 18.0 to 97.0μg/kg (Windsor and Hites, 1979), while total PAH in Amazon River sediments was about 500.0μg/kg (Laflamme and Hites, 1978) and about 100.0μg/kg in the sediments of King Edward Cove on the mid Antarctic island of South Georgia (Platt and Mackie, 1979). In an unpolluted Ontario lake, eighteen PAHs were found at concentrations ranging from 6.0 to 38.0μg/kg (Brown and Starnes, 1978), and 5.0μg/kg of benz(a)pyrene were reported on the west coast of Greenland (Mallet et al., 1963).

Consequently, the sediments of the Beaufort Sea appear to have an elevated PAH baseline relative to global background levels. In fact, southern Beaufort Sea sediment PAH is even higher than the 800.0 μg/kg (dry weight) found at Buzzards Bay, U.S.A., shallow area near large sources of PAH from the heavily industrialized northern seaboard of the United States. The most likely source of the high natural baseline level of PAH in the southern Beaufort Sea is the Mackenzie River which flows through regions with known fossil fuel deposits, natural seepages, and burned-over areas.

1.5.3.5 Polycyclic Aromatic Hydrocarbons in Marine Organisms

Total PAH (defined as the sum of chrysene, benzanthracene, perylene, phenanthrene and pyrene and certain isomers) in the tissue of southern Beaufort Sea fish (pomfret, least cisco and Arctic cisco) averaged 21.0μg/kg wet weight and ranged from 9.0 to 31.0μg/kg wet weight (Wong et al., 1976). It is difficult to compare these baseline data with those from other areas because of the differences in age, species, migration patterns, food habits, analytical techniques and chemical compounds involved. However, total PAH in fish caught from waters near Ocean Weather Station P was 20.0 to 82.0μg/kg wet weight for salmon and 184.0μg/kg wet weight for tuna. Sullivan (1974) gives a range of 0 to 230μg/g wet weight for benz(a)pyrene in shrimp, molluscs and oysters.

1.5.3.6 Non-Polar Hydrocarbons in Fish

Fish (flesh) samples from the southern Beaufort Sea show percentages of unresolved total hydrocarbons of 23% to 67%, compared with 12 to 16% for northeast Pacific Ocean fish and over 80% for Sargasso Sea fish (Wong et al., 1976). These characteristics can be used as a measure of petroleum contamination, since northeast Pacific fish are considered uncontaminated and Sargasso Sea fish as contaminated. Therefore, southern Beaufort Sea fish may be considered marginally contaminated by petroleum hydrocarbons, although the small number of samples analyzed, biological variability and the analytical uncertainties associated with this unresolved hydrocarbon envelope technique limit interpretation of these data. However, in absolute units, reported concentrations of non-polar hydrocarbons in Beaufort Sea fish are 1.11 to 7.8μg/g wet weight (Wong et al., 1976), compared with 0.4 to 11.8μg/g wet weight for a variety of fish including flounder, dogfish, cod and herring from Atlantic waters (Clark and MacLeod, 1977).

1.5.3.7 Non-Polar Hydrocarbons in Marine Plankton

Wong et al. (1976) found that most of the mixed zooplankton samples from the southern Beaufort Sea contained n-alkanes from C_{16} to C_{38}. The gas chromatographic pattern showed maximum n-paraffin content at C_{26}, a slight predominance of odd-carbon number paraffins and a significant envelope of unresolved hydrocarbons. Total hydrocarbons and unresolved hydrocarbons ranged from 1.6 to 203.0μg/g wet weight and 0.0 to 7.3μg/g wet weight, respectively. The authors were unable to conclude whether or not the insignificant odd-even predominance and envelope of unresolved hydrocarbons, two factors normally identifying the presence of petroleum hydrocarbons, were indicative of hydrocarbons incorporated into the plankton biomass, or an artifact of the sampling technique which included collection of both living and non-living particles. Data from studies conducted in Massachusetts, Scotland and the British Isles indicate n-paraffin concentrations in mixed plankton from 0.3 to 159.0μg/g wet weight (Clark and MacLeod, 1977).

1.5.4 NUTRIENTS

The available data for the reactive nutrient (nitrate, phosphate and silicate) content of southern Beaufort Sea waters, together with comparative data from other western Arctic waters, are summarized in Figure 1.5-5. The spatial distribution of nutrients in the southern Beaufort Sea is dominated by the outflowing Mackenzie River which appears to contain higher concentrations of silicate and nitrate, but lower concentrations of phosphate, than Arctic Ocean water. Considerable local variability in the surface nutrient concentrations may occur in areas of ice-melt, since meltwaters generally contain virtually no nitrate, phosphate and silicate. Mechanisms of nutrient regeneration and replenishment in this region are described in Section 3.5.2.

1.5.4.1 Silicate

Wong et al. (1980) found that silicate concentrations in the surface (0-5 m) waters of the Beaufort Sea ranged from 2.0 to 39.0μg-at Si/L. Silicate levels varied inversely with salinity due to dilution of silicate-enriched Mackenzie runoff (30μg-at Si/L with depleted Beaufort Sea shelf surface water (2 μg-at Si/L). A similar decrease in surface silicate concentrations with distance from shore has been documented in the western Beaufort Sea, where Alaskan North Slope rivers contribute relatively high levels (4.2 - 12.4μg-at Si/L) of silicate to nearshore areas (Hufford, 1974). The relatively warm waters of the Bering Sea also contribute silicate to Alaskan coastal waters, increasing concentrations 2.0 to 3.0 μg/-at/L above those in surrounding waters. Below approximately 45 m, silicate concentrations in the southeast Beaufort increased to above 30.0μg-at Si/L, and then decreased with depth into the Atlantic water mass below 200 metres. A similar vertical distribution of silicate was observed in Amundsen Gulf (Macdonald et al., 1978), where the range of values was 2.0 to 35.0μg-at Si/L. Grainger (1974) reported a range of 10.0 to 33.0μg-at Si/L for the southern Beaufort Sea, while on the U.S. Beaufort shelf, Hufford (1974) found that silicate varied from 2.0 to 40.0 μg-at Si/L, with lowest concentrations occuring in the brackish surface layer.

Gudkovich (1956) reported that silicate levels at stations between 75° and 80°N in the Eurasian Arctic were 11.0 to 18.0μg-at Si/L in the upper 50 m during

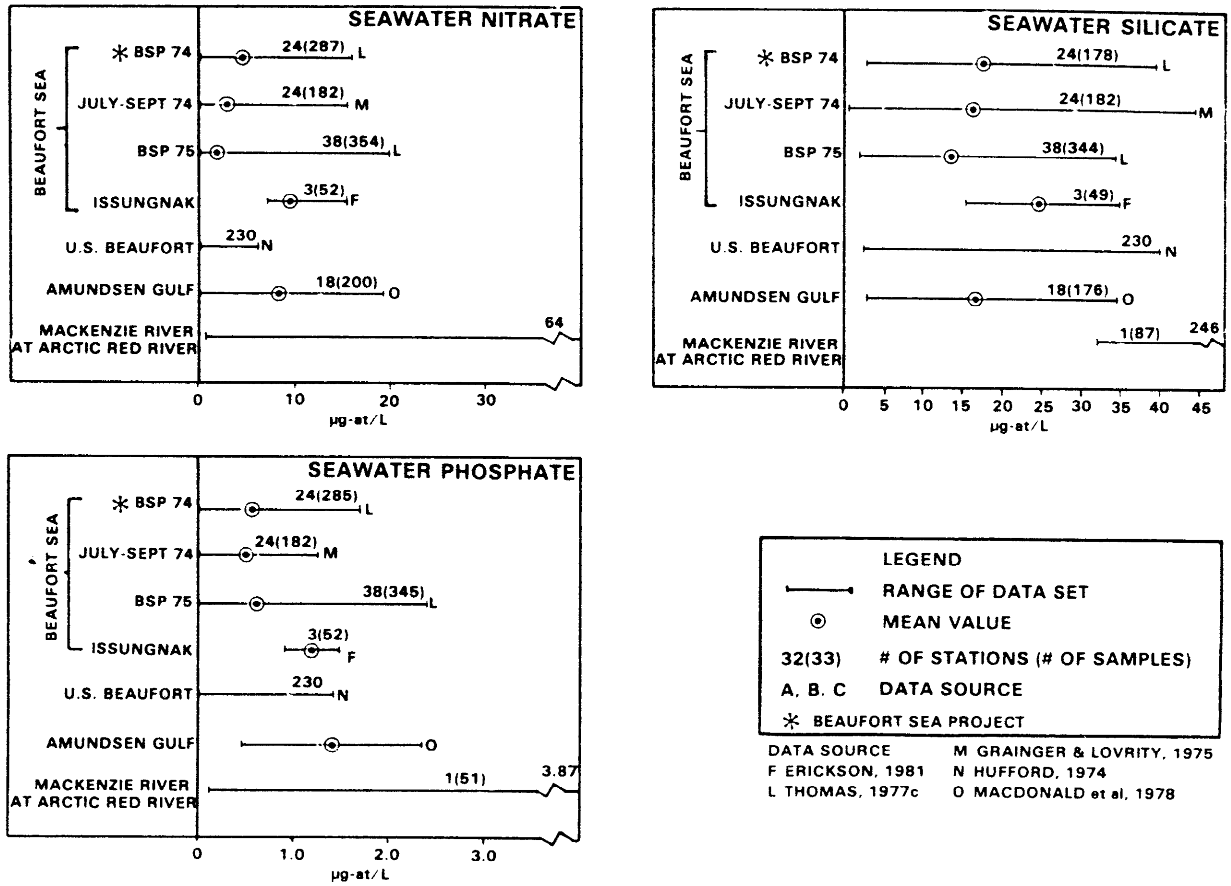


FIGURE 1.5-5 *Summary of nutrient concentrations in Beaufort Sea waters and other areas.*

April. English (1961) reported a range of 3.0 to 9.0 µg-at Si/L from Drifting Ice Station Alpha, while Kinney et al. (1970) measured values of 5.0 to 10.0 µg-at Si/L in the upper 50 m of Amerasian Basin waters. In the latter investigation, the highest values (27.0-57.0µg-at Si/L) occurred at depths between 150 and 180 m. By comparison, Reeder et al. (1972) provided a range of 5.0 to 127.0µg-at Si/L for the fresh waters of the Mackenzie River drainage basin.

1.5.4.2 Phosphate

Wong et al. (1980) found that phosphate concentrations in the surface waters of the southern Beaufort Sea ranged from 0.01 to 2.3µg-at P/L. An analysis of salinity versus phosphate levels indicated that phosphate must be almost absent in Mackenzie River water, although this is not consistent with the data of Grainger (1974) which show a surface phosphate distribution with the greatest levels immediately off the Mackenzie Delta, and progressively lower concentrations in seaward directions. Reeder et al. (1972) found phosphate levels of less than 0.10µg-at P/L at a single station in the Mackenzie River, but a range of 0.10 to 0.95µg-at P/L for 101 stations elsewhere in the Mackenzie drainage basin. In coastal waters of the western (U.S.) Beaufort Sea, surface phosphate concentrations increased with increasing distance seaward (Hufford, 1974), largely due to unmeasurable phosphate levels in Alaskan North Slope rivers.

These divergent observations cannot be resolved with the existing level of information on the seasonal and spatial differences in phosphate concentrations. Surface concentrations of phosphate seldom exceed 1.0µg-at P/L. As in the case of silicate, phosphate concentrations in the Beaufort Sea increase markedly in the 50 to 200 m depth region, reaching levels in excess of 2.0µg-at P/L, and then decreasing with depth in the Atlantic water mass below 200 metres. Similar vertical distributions have been observed in Amundsen Gulf (Macdonald et al., 1978) where concentrations range from 0.45 to 2.26µg-at P/L, as well as in the U.S. Beaufort Sea where values range from 0.0 to 1.4µg-at P/L (Hufford, 1974).

1.5.4.3 Nitrate

Wong et al. (1980) found that nitrate was almost totally depleted from surface waters of the Beaufort Sea during their 1975 studies. As with silicate and phosphate, nitrate increased sharply to about 15.0 µg-at N/L below 50 m, and then decreased with depth in the waters of Atlantic origin (200-900 m).

Similar vertical distributions of nitrate were observed in Amundsen Gulf and the western Beaufort Sea. In the Alaskan Beaufort, surface nitrate levels decreased with increasing distance from shore (Hufford, 1974), while Grainger (1974) documented a similar relationship in the southeast Beaufort Sea and attributed this to the importance of the Mackenzie River as a source of nitrates. The latter hypothesis is supported by the data of Reeder et al. (1972) who reported nitrate concentrations from 0.2 to 12.4μg-at N/L in the Mackenzie drainage basin, and a level of 4.5μg-at N/L for the Mackenzie River where it enters the Delta (Macdonald et al., 1978; Hufford, 1974).

1.5.4.4 Temporal and Spatial Variability in Nutrient Levels

Large variations in the distribution of nutrients can occur in the southern Beaufort Sea as a result of annual differences in river flow patterns. An example is the difference in the distribution of nitrate between 1974 and 1975. In 1974, the ice pack was much closer to shore than in 1975. As a result, Mackenzie River runoff tended to pile up between the ice edge and the shoreline. This limited phytoplankton productivity and reduced the demand on nitrate. On the other hand, in 1975 the ice edge was farther offshore, the surface waters were less turbid, and phytoplankton productivity depleted nitrate from the surface waters.

Hufford (1974) indicated that nutrients may be transported by upwelling onto the Alaskan portion of the Beaufort Sea shelf. Although direct measurement of similar transport onto the shelf of the southern Beaufort Sea has not been reported, upwelling along the Tuktoyaktuk Peninsula has been observed (Herlinveaux and de Lange Boom, 1975). This upwelling may occasionally cause large scale variations in the distribution of nutrients in surface waters. This and other mechanisms of nutrient replenishment and regeneration are discussed in Section 3.5.2.

1.6 THE SHORES

This section summarizes the physical character of shorelines in the southern Beaufort and northeast Chukchi seas as well as the coastal processes which affect these shores, such as wave action, runoff and other erosional forces. A much more comprehensive treatment of the subject is provided in Woodward-Clyde (1981), a supporting document to the Environmental Impact Statement. The information provided here has been divided into separate descriptions for the Chukchi Sea, the Alaskan Beaufort Sea, the Canadian Beaufort Sea and Amundsen Gulf.

The information regarding shoreline processes and coastal geomorphology for Alaskan Arctic coasts (Northeast Chukchi Sea and Alaskan Beaufort Sea coastlines) varies significantly within the region. For the Alaskan Beaufort Sea numerous recent studies provide a substantial data base for descriptions (Woodward-Clyde, 1981; Owens et al., 1981), but to the south, along the shores of the Chukchi Sea, the quality of the information base becomes more limited. Site-specific studies provide information on some areas, but overall the character of the coastal processes is not well understood.

The available information base for much of the Canadian Beaufort Sea is generally very good (Woodward-Clyde, 1981; Worbets, 1979). By comparison, that for Amundsen Gulf is limited. Recent (1981) low altitude video-tape surveys of the Amundsen Gulf coasts provide detailed information on the shore zone character, but not on the coastal processes of the region.

1.6.1 CHUKCHI SEA

The Chukchi shoreline is bordered by relatively high (up to 5 m) barrier islands which are interspersed with eroding tundra cliffs (Area B in Figure 1.6-1). Relief is generally low in the coastal zone, but tends to be higher within Kotzebue Sound which is a large structural embayment. Pleistocene marine deposits are common on low-lying coastal areas and, to the south of Cape Lisburne, some sedimentary bedrock crops out locally in the shore zone. Long, continuous barriers are the dominant feature of the shore zone. Where tundra cliffs are high (up to 10 m), they are generally fronted by barriers and lagoons. The barriers are stable, but are subject to reworking and to changes during storm events. The high tundra cliffs are retreating at rates of about 0.5 m/yr, but where low tundra cliffs (less than 3 m) occur in lagoon environments these may be extremely unstable, with erosion rates greater than 1 m/yr.

The open water season on the Chukchi coast varies from as little as 50 days each year at Barrow to 135 days per year in Kotzebue Sound to the south. In bad ice years the coast north of Icy Cape may be icebound throughout the normal open water season. Fetch distances are generally less than 500 km and wave energy levels are low, except during periods of late summer-fall storms. These storms occur at a time when fetch distances are usually at a maximum. The head of Kotzebue Sound is a very sheltered, low energy, embayed coast. This region as a whole is predominantly a micro-tidal, wave-dominated environment, with the effects of storm events becoming more significant toward the north.

1.6.2 ALASKAN BEAUFORT SEA

The Alaskan Beaufort Sea coast is characterized by

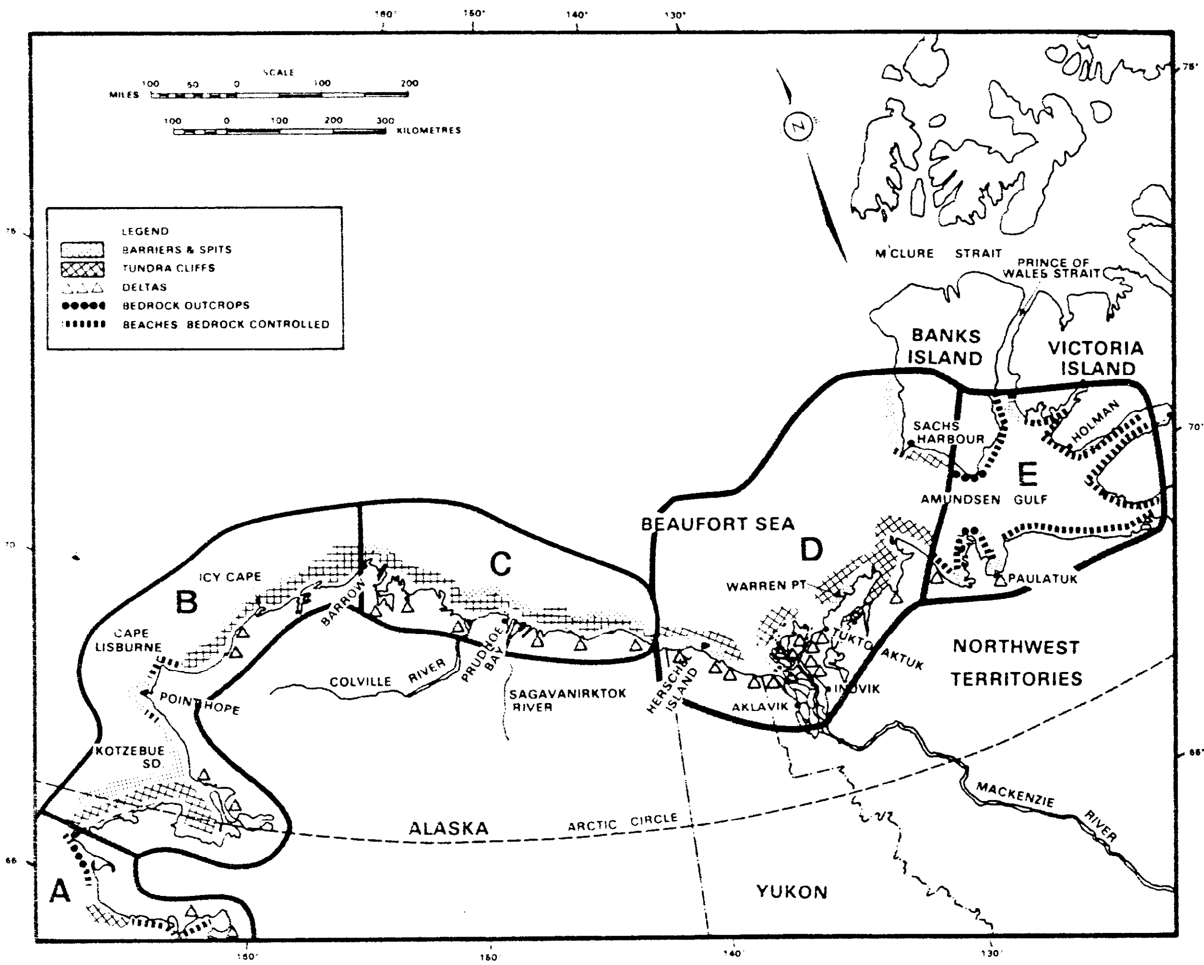


FIGURE 1.6-1 *Simplified shore zones of the Beaufort and Northeast Chukchi seas.*

low (less than 3 m) offshore barrier islands and low ice-rich tundra cliffs (Area C in Figure 1.6-1). The coastal zone is a plain of ice-bonded Pleistocene alluvial and marine deposits. The discontinuous offshore barrier islands are separated from the mainland coast by wide shallow lagoons. Virtually the entire mainland shoreline is characterized by ice-rich tundra cliffs, but this continuity is interrupted by the presence of numerous major braided river deltas. The barrier islands are highly unstable, migrating up to 40 m/yr to the west, and 1 to 2 m/yr landward. The ice-rich mainland shores are extremely unstable, with rates of retreat in the order of 1 to 2 m/yr. Locally, individual erosion rates of over 10 m/yr have been recorded. Delta coasts may show annual changes owing to shifts in the distributary channels and to thaw-lake coalescence.

The open water season on the Beaufort Sea coast varies between 90 and 120 days. There are significant annual variations, and in bad ice years the ice cover may remain virtually complete along most sections of shoreline. Maximum fetch distances are generally less than 300 km, extending to the edge of the polar pack to the north, but may be as much as 1,000 km parallel to the shoreline during relatively ice-free years. This elongated east-west fetch window results in a large component of alongshore wave energy that runs parallel to the coast. Wave energy levels are generally low except during major autumn storms, making this a micro-tidal, storm-dominated coast. Sediment transport occurs during the periods of storm wave activity as a series of major pulses (Owens et al., 1981). These aperiodic changes dominate the development of recurve ridges and of the barrier island morphology. Thermal erosion of ice-rich tundra cliffs is a significant process on mainland coasts and takes place throughout the open water season. Fluvial processes dominate the major deltas of the Colville, Kuparuk and Sagavanirktok rivers. Meteorologically-induced storm surges of up to 3 m above normal high water are common and, when these coincide with high waves, the effects on shore zone morphology can be significant.

1.6.3 CANADIAN BEAUFORT SEA

The coastal geology and process characteristics of the Canadian Beaufort Sea are very diverse. Wave energy at the shoreline varies both seasonally and from year to year and shoreline changes are rapid in many areas owing to the unresistant nature of the shore zone materials. This is a storm wave environment in which the littoral processes are generally dominated by the effects of aperiodic high energy events. In addition, the effects of fluvial, thermo-erosional, and ice pressure processes are also significant on many sections of coast.

The southern Beaufort Sea coast is characterized by a series of barrier beaches, ice-rich or unconsolidated coastal cliffs, and deltas (Area D in Figure 1.6-1) (Plates 1.6-1, 2 and 3). This region is part of the Arctic Coastal Plain and backshore relief is low (less than 50 m) in all areas. Barriers and spits have developed as a function of the availability of sediment from local sources. Ice-rich tundra cliffs generally supply only small volumes of sediment to the shore zone so that beach development in areas of low tundra cliffs is generally poor, despite high local rates of coastal retreat. Unconsolidated sediment cliffs of higher relief (greater than 5 m) that are exposed at the coast undergo slower rates of retreat but supply larger volumes of material for reworking by littoral processes. Beach development is more significant on these sections of coast, as for example on the east side of Warren Point on the Tuktoyaktuk Peninsula. The Mackenzie River has an extensive Delta. Braided deltas are very common on the Yukon coast. Few sections of shoreline within this area could be regarded as stable. In particular, the ice-rich tundra cliffs and the low barriers are subject to large-scale changes during the open water season. Coastal erosion rates of greater than 10 m during a single storm event have been recorded at one site, and elsewhere annual erosion rates (during the short open water season) are frequently in the order of 1 m/yr.

The southern Beaufort Sea is a micro-tidal, storm-wave environment, but fluvial, thermo-erosional and ice pressure processes play an important role in developing shore zone morphology. Wave energy levels are highest on east facing sections of the Yukon coast which are exposed to the dominant winds and which have maximum fetch distances. The open water season is generally in the order of 100 days. Fetch distances are ice-limited, reaching a maximum of 500 km to the edge of the polar pack. Although wave generation is ice and fetch-limited, occasional high energy levels occur during periods of storm wave activity on exposed coasts in the open water season. Storm surges, up to 2 or 3 m, are important on low-lying coasts and can cause extensive inundation of backshore areas.

1.6.4 AMUNDSEN GULF

The coastal environments of Amundsen Gulf are significantly different from those of the Canadian Beaufort Sea (Area E in Figure 1.6-1). Sedimentary and Precambrian rocks are exposed on, or underlie, most coastal areas. The shore zone configuration is inherited primarily from pre-glacial and Pleistocene erosion processes, and Prince of Wales Strait and Dolphin and Union straits are former valleys of a river system which drained toward the west into the Arctic Ocean basin during Tertiary times. Relief is higher than on the Arctic Coastal Plain and, although there are thick deposits of surficial sediments in many coastal areas, there are relatively few sections where ice-rich cliffs are exposed at the shore zone. Relief is extremely varied, and backshore elevations up to 500 m occur in some sections (Plate 1.6-4). The shore zone is predominantly continuous sand or gravel beaches, although backshore cliffs can occur in areas of high relief. The coast has only recently (1981) been surveyed completely at a reconnaissance level, and mapping of the shore zone character is as yet incomplete.

Amundsen Gulf is a micro-tidal, wave-dominated environment, with a secondary ice-dominanted component. Due to the presence of ice-rich cliffs in the southern Parry Peninsula, this area is also characterized by thermokarst erosion. The open water season generally ranges between 45 and 60 days, and fetch areas are generally less than 500 km during relatively ice-free years. Storms produce high wave energy levels on exposed coasts during the open water season. Although this coast can be regarded as one of low wave energy levels, intertidal beach sediments are generally reworked every year by normal wave processes during the short open water season. On some sections of coast, particularly in the southeast of the gulf, ice plays a dominant role in the reworking of beach sediments.

PLATE 1.6-1 *The Yukon coastal plain at Clarence Lagoon showing a barrier spit and low relief. Courtesy: Woodward-Clyde Consultants.*

PLATE 1.6-2 *Herschel Island showing the Unconsolidated Coastal Cliffs Characteristic of this Area. Courtesy: Woodward-Clyde Consultants.*

PLATE 1.6-3 *Barrier beach coastline and pingos near Tuktoyaktuk. Courtesy: Woodward-Clyde Consultants.*

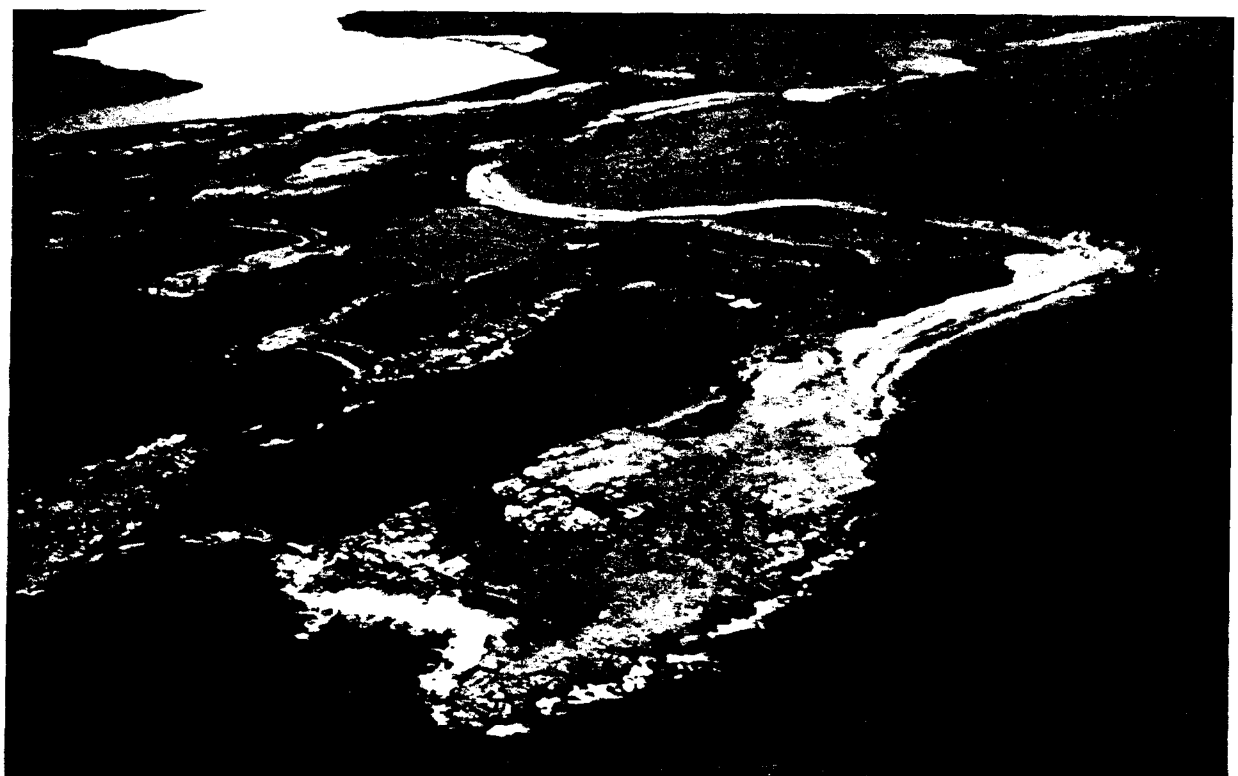


PLATE 1.6-4 *The rocky shores and gravel beaches typical of eastern Cape Parry-Amundsen Gulf. Courtesy: Woodward-Clyde Consultants.*

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CHAPTER 2 TERRESTRIAL PHYSICAL ENVIRONMENT

This chapter of Volume 3A summarizes existing information on the physical environment of the onshore or coastal zone of the Beaufort Sea. The region encompasses the coastal area extending from the Yukon North Slope through the Mackenzie Delta, Tuktoyaktuk Peninsula, Anderson Plain, to Cape Parry (Figure 2-1). Separate sections provide an overview of the climate and weather, geology, soils and hydrology of this region. Further information on the physical environment of the coastal zone is provided in various supporting documents as well as the literature reviewed during preparation of this overview.

Information presented here and in Chapter 4 of this volume (Terrestrial Plants and Animals) forms part of the background for assessment of the potential impacts of shorebased facilities and activities associated with hydrocarbon production and transportation in the Beaufort Sea region (Volume 4). Since the proposed pipeline corridor extends into the Beaufort Sea coastal region, there is a necessary duplication of some of the information presented in the following sections and in Volume 3C, describing the environmental setting of the Mackenzie Valley Corridor.

2.1 ATMOSPHERIC ENVIRONMENT

The following summarizes information on the climate, weather and air quality of coastal areas adjacent to the Beaufort Sea. The annual variability in weather conditions is also described, while a more detailed treatment of the offshore climate is provided in Section 1.2. Burns (1973, 1974) provides a major source of information on the climate of the Mackenzie Delta and Beaufort Sea coast. Also, specific information on weather parameters is available from seven active and one abandoned meteorological station in the region, and is published in various Ministry of Transport and Environment Canada reports. The location, climatic data measured, and period of

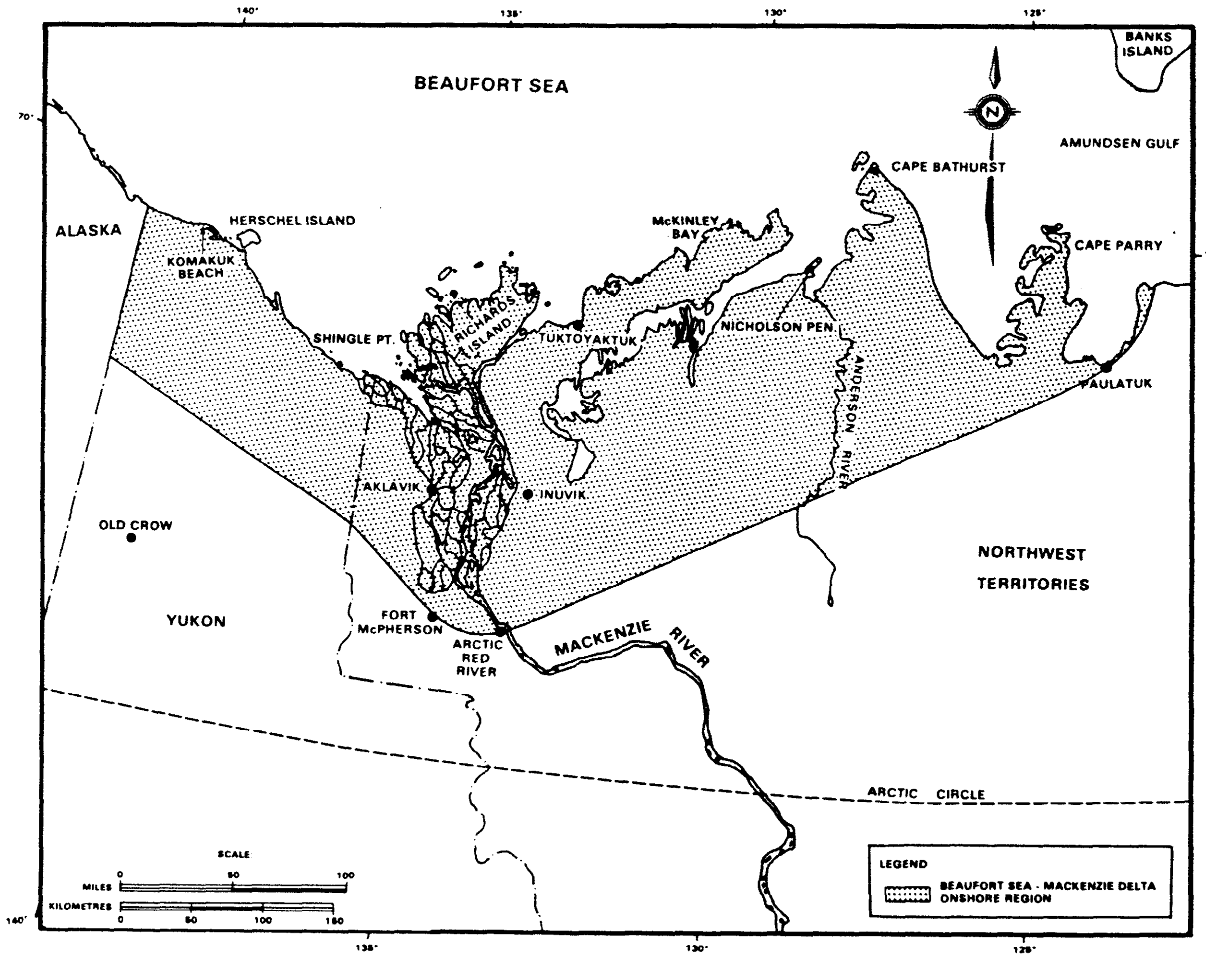


FIGURE 2-1 *Approximate boundary of the onshore or coastal zone of the Beaufort Sea-Mackenzie Delta region described in Volume 3A.*

record at each of these stations are summarized in Table 2.1-1.

2.1.1 SYNOPTIC CLIMATOLOGY

The normal upper level airflow over the region is westerly in summer and northwesterly in winter. Severe weather is often associated with abnormal departures from this pattern caused by major shifts in the circulation patterns of the upper atmosphere. For example, such shifts may result in southerly flows which introduce warm moist air into the region, producing record high temperatures and increased instability. On the other hand, persistant blocking of circulation patterns may prevent surface lows from entering the region, resulting in long periods of drought and, in winter, stagnation of cold Arctic air with accompanying record low temperatures.

2.1.1.1 Winter

In winter, a semipermanent upper air ridge over Alaska results in a relatively strong mean northwesterly flow of air aloft. At the surface, the Northwest Territories and the Polar Basin are a region of continuous snow and ice cover. As a consequence, Arctic air predominates throughout the winter (December-March) and results in an anticyclonic circulation pattern or atmospheric high at the surface.

The cold dome of continental Arctic air over the region acts as an effective barrier against any penetration by maritime air masses. Migrating frontal lows are forced to follow trajectories around the edge of the continental Arctic air mass well to the north of the Beaufort Sea coastal zone. Low pressure centres which originate in the Aleutians migrate across the Beaufort Sea between 73°N and 75°N latitude. These systems produce blizzards along the coast and within the Mackenzie Delta. They occur primarily in January and March, but may also occur in other months of the winter.

The high pressure systems which are dominant in the region from November to March originate over the polar ice pack in the Beaufort Sea or in northern Alaska. Their primary trajectory is southeastward along the Mackenzie Valley. In February, these systems tend to stagnate over the valley resulting in prolonged cold spells.

2.1.1.2 Spring

Spring in the Mackenzie Delta and Coastal Plain begins with the gradual eastward shift of the dominant high pressure system, from over the Mackenzie

TABLE 2.1-1

METEOROLOGICAL STATIONS IN THE BEAUFORT SEA COASTAL PLAIN AND MACKENZIE DELTA REGIONS

Station (Lat./Long./Elev.)	Period of Record: Temperature	Precipitation	Wind	Synoptic	Hourly	Sunshine	Radiation
Northwest Territories							
Aklavik (68°14'N 138°00'W 9 m)	1926-1962*	1926-1962*	1944-1960*	1926-1960*		1956-1960*	1948-1960*
Cape Parry A** (70°10'N 124°41'W 16 m)	1955-1981	1955-1981		1955-1981	1955-1981		
Fort McPherson (67°26'N 134°53'W 100 m)	1892-1981	1892-1981		1909-1937*			
Inuvik A** (68°18'N 133°29'W 62 m)	1957-1981	1957-1981	1957-1981	1960-1981	1961-1981	1960-1981	1960-1981
Nicholson Peninsula (69°54'N 128°58'W 98 m)	1957-1981	1957-1981					
Tuktoyaktuk (69°27'N 133°99'W 18 m)	1957-1981	1957-1981		1957-1981			
Yukon Territory							
Komakuk Beach (69°35'N 140°11'W 9 m)	1958-1981	1958-1981					
Shingle Point (68°57'N 137°13'W 54 m)	1957-1981	1957-1981					

* No longer in operation
** Airport

Valley to the region lying between approximately 107°W and 103°W longitude. High pressure systems still originate in the north and follow southeastward trajectories. However, whereas in February these systems tend to stagnate over the Mackenzie Valley, by March they begin to move to the east of the Valley over Great Bear and Great Slave lakes.

The eastward displacement of high pressure centres allows more frequent penetrations of frontal lows, bringing maritime Arctic and maritime polar air masses to the region and resulting in a general increase in instability. The continental Arctic air mass begins to retreat northward along the Mackenzie Valley, while increased solar heating and lower albedos begin to warm the southern portions of the Arctic air. The progression of spring is gradual from south to north and does not reach the Mackenzie Delta until late April or early May.

In May frontal lows from northern Alaska begin to follow trajectories through the northern Yukon and down the Mackenzie Valley, resulting in increased precipitation.

2.1.1.3 Summer

The semipermanent upper level ridge which lies over Alaska in winter shifts eastward to over the Yukon in the summer. The strong northwesterly flow of winter is replaced by weak westerlies. This produces a surface trough along the length of the Mackenzie Valley and the Coastal Plain.

With the break-up of the pack ice along the coast, the climate of the Coastal Plain becomes more maritime and the source region of the Arctic air mass is reduced to the area covered by the polar ice pack. Outbreaks of Arctic air are modified during their passage over the open water between the polar pack and the coast; then cloudiness and stable air become dominant features of the coastal climate. However, as the maritime air penetrates into the Mackenzie Delta it is further warmed and becomes unstable, resulting in more frequent precipitation.

From May to July frontal lows follow a trajectory from northern Alaska, through the northern Yukon, and southeastward along the Mackenzie Valley. Cyclonic activity in the region usually reaches a peak in July and August, so that in August and September the region receives precipitation from storms which develop north of Alaska and travel along the coast between 70°N and 72°N latitude.

2.1.1.4 Autumn

The autumn season, from September to December, is the reverse of the spring season. The summertime upper level ridge over the Yukon gradually begins to shift westward back to its winter position over Alaska. Airflows aloft change from relatively weak westerlies to a strong northwest flow by the end of the fall.

At the surface, outbreaks of cold Arctic air become more frequent and colder, and penetrate further south along the Mackenzie Valley. As freeze-up begins along the coast in late September, steaming of open waterbodies introduces moisture into the atmosphere and results in overcast skies and snow flurries. Also, cyclonic activity generally begins to decline from the July peak. Major snowfalls along the coast and within the Delta tend to accompany low pressure centres which travel eastward between 70°N and 72°N latitude in September, but they usually occur less often after October as these storm trajectories shift to higher latitudes between 73°N and 75°N.

Beginning in November, high pressure systems originating in either northern Alaska or over the Beaufort Sea travel southeastward along the Mackenzie Valley. By December, anticyclonic circulation is re-established as Arctic air once again dominates the region.

2.1.2 ATMOSPHERIC INVERSIONS

Atmospheric inversions are important when considering the dispersion of air pollutants. Cold Arctic air masses increase in temperature with height, generally within 1,000 m above the land surface. These air temperature increases or inversions result from the negative radiation balance over snow and ice surfaces which are present at high latitudes during much of the year. Low sun angle, high albedoes, and short days combine to limit daytime heating at the surface, while subsidence and warm air advection aloft help to maintain and intensify inversions.

Table 2.1-2 shows the frequency of surface-based inversions found at Inuvik (Burns, 1973). Low-level inversions also occur in which temperatures initially decrease with height for the first few hundred metres and are capped by a shallow inversion layer. These are common in the afternoon in this region. Although there are no statistics on their frequency of occurrence, it may be assumed that some nighttime (1100 GMT) surface-based inversions are transformed into low-level inversions by afternoon heating, and are not accounted for in the statistics for 2300 GMT provided in Table 2.1-2. Therefore, the percentage of time that afternoon surface-based inversions occur should not be used as a direct measure of the pollution potential associated with temperature inversions.

The mixing height concept has been developed as a better means of determining air pollution dispersal potential. The mixing heights presented in Table 2.1-

TABLE 2.1-2

SEASONAL DIFFERENCES IN THE FREQUENCY OF SURFACE-BASED TEMPERATURE INVERSIONS (%) OBSERVED AT INUVIK AIRPORT, N.W.T. (Source: Burns, 1973)

Months	Time of Day (GMT)	Frequency of Inversions (%)
Dec-Feb	2300	58
	1100	67
Mar-May	2300	3
	1100	60
June-Aug	2300	0
	1100	61
Sept-Nov	2300	25
	1100	46

3 are a measure of the maximum depth of vertical mixing which occurs at the earth's surface as a result of daytime heating. The concept, as defined by Holzworth (1967), is based on the principal that solar heating at the surface results in convection, vigorous vertical mixing and the establishment of a dry adiabatic lapse rate (that is, a decrease of temperature with height at a rate of 0.98°C/100 m). The maximum (afternoon) mixing height is determined from a graph of temperature versus height by extending the maximum surface temperature at the dry adiabatic lapse rate from the surface to the point at which it intersects the vertical temperature profile observed at 1200 GMT. The mean mixing layer wind speed (Table 2.1-3) is the vertically averaged wind speed between the surface and the top of the mixing layer as

TABLE 2.1-3

MEAN MAXIMUM AFTERNOON MIXING HEIGHTS (m), MEAN MIXING LAYER WIND SPEEDS (km/h) AND MEAN MAXIMUM VENTILATION COEFFICIENTS ((m²/s)/10) FOUND AT INUVIK, N.W.T.

Month	Mean Maximum Afternoon Mixing Height (m)	Mean Mixing Layer Wind Speed (km/h)	Mean Maximum Ventilation Coefficient ((m²/s)/10)
Jan	119	9.4	39
Feb	162	9.0	48
Mar	288	12.6	107
Apr	445	14.8	187
May	836	17.3	407
June	1221	16.9	559
July	1460	17.6	716
Aug	1042	15.8	477
Sept	675	16.6	308
Oct	280	12.2	104
Nov	159	11.2	71
Dec	159	8.3	45
Annual	621	14.0	280

(Source: Portelli, 1977)

defined by the mixing height. The mean maximum ventilation coefficient (Table 2.1-3) is the product of the maximum mixing height and the mean mixing layer wind speed. As a measure of the ability of the atmosphere to disperse pollutants, the ventilation coefficient is more dependent upon the mixing height than upon the wind speed. Consequently, the pollution potential may be considered inversely proportional to the maximum afternoon mixing height, while pollution episodes would occur as often as surface-based and low-level inversions occur.

For Inuvik, Table 2.1-2 shows that nighttime (1100 GMT) surface-based inversions occur often throughout the year, ranging from a low of 46% of all the days during the period September through November, to a high of 67% during December to February. Afternoon (2300 GMT) surface heating tends to eliminate most surface inversions which occur from March to August. However, only 13% of all nighttime inversions occurring during December to February are eliminated by afternoon heating. A similar trend is evident for afternoon mixing heights (Table 2.1-3). Afternoon mixing improves markedly in April and remains good throughout the summer until September. By November, mean maximum afternoon mixing heights are less than 200 m above the surface and remain low until February. Although surface-based and low-level inversions occur frequently throughout the year, their pollution potential is minimized by higher mixing heights and wind speeds during the months of March through September. On the other hand, based on the ventilation coefficients shown in Table 2.1-3, the period from October through April would be when most potential pollution-producing episodes could occur at Inuvik.

2.1.3 DAYLIGHT REGIME

The duration of daylight varies with latitude and season (Figure 2.1-1) and the more northerly the location, the more variable is the duration of daylight hours. In the coastal Beaufort region, daylight hours vary from zero during December and early January to 24 hours in June and July.

However, the absence of sunlight during the winter does not imply total darkness, since an evening twilight exists during some months, and light from the moon reflects off the snow and ice.

2.1.4 AIR QUALITY

In 1972 and 1973 Slaney (1974) measured dustfall, suspended particulate matter, and various other airborne pollutants at sites on Richards Island and at Inuvik (Table 2.1-4). None of the atmospheric con-

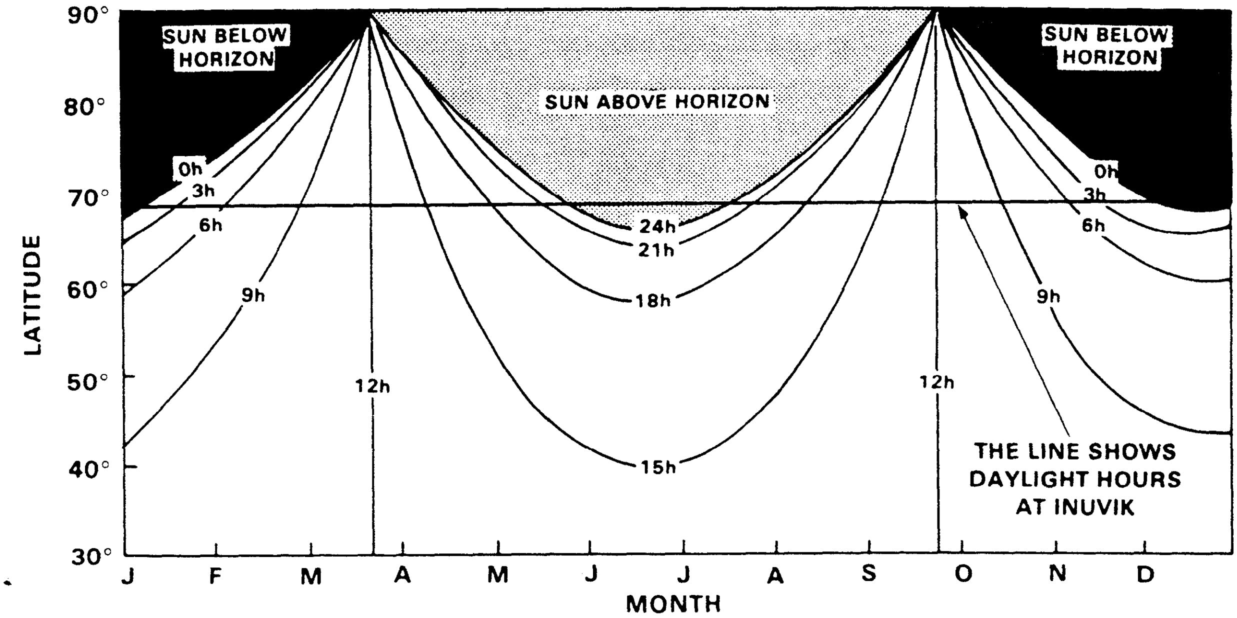


FIGURE 2.1-1 *Duration of daylight. In the coastal Beaufort region, daylight hours vary from zero during December and early January to 24 hours in June and July. (Source: Burns, 1973).*

taminants measured were present at harmful concentrations and all were well below accepted limits. However, because of more industry and people, dustfall, sulphur dioxide and hydrocarbon levels were higher at Inuvik than on Richards Island. These concentrations should not be considered as representative of those for the region. According to Eley (1974) and Benson (1969), low-lying areas may be more susceptible to ice fog and air pollution episodes due to cold air drainage or temperature inversions. On the other hand, slopes and wind-swept hilltops are less likely to experience these conditions.

TABLE 2.1-4

AIR QUALITY PARAMETERS MEASURED AT INUVIK AND RICHARDS ISLAND DURING 1972-1973
(Source: Slaney, 1974)

Air Quality Parameter	Richards Island	Inuvik
Dustfall	0 007-1.52 tonnes/sq.km/month[1]	0 69-10 16 tonnes/sq km/month[1]
SO_2	0 000008 ppm[2]	0 00002 ppm[2]
H_2S	< 0 0003-0 036 ppm	—
Ozone	< 0.0003-0.017 ppm	—
NO_2	0.0002-0.006 ppm	—
Hydrocarbons	0.3-2 4 ppm	4 1 ppm

[1]Based on weighing of insoluable solids only
[2]Based on multiplying sulphation index by 0 03

Since June of 1977, the Atmospheric Environment Service of Environment Canada has systematically collected precipitates for chemical analysis at various locations in Canada. Inuvik was chosen as one of the initial CANSAP (Canadian Network for Sampling Precipitation) sites, although it has been operated only sporadically. Table 2.1-5 shows the precipitation data collected at Inuvik up to June 1980.

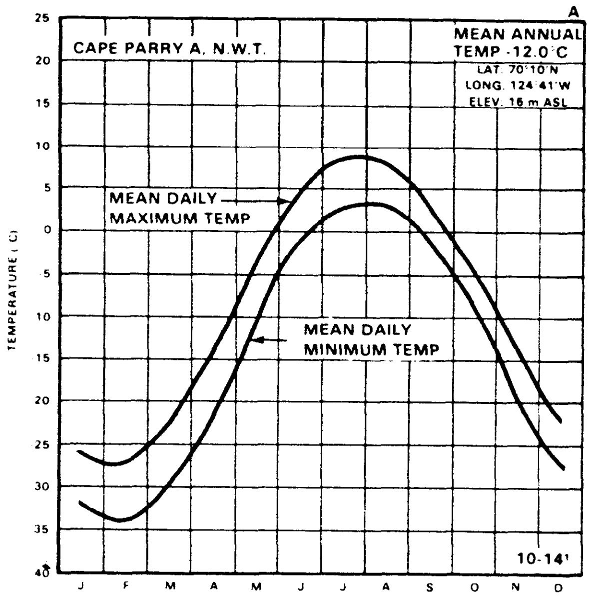
Precipitate analysis has shown that ion concentrations vary depending upon previous weather, wind directions and precipitation. Consequently, the analysis of bulk precipitates on a monthly basis may not be appropriate for northern locations; hence conclusions drawn from the existing data set for Inuvik may be in doubt.

2.1.5 WEATHER OF THE COASTAL BEAUFORT SEA REGION

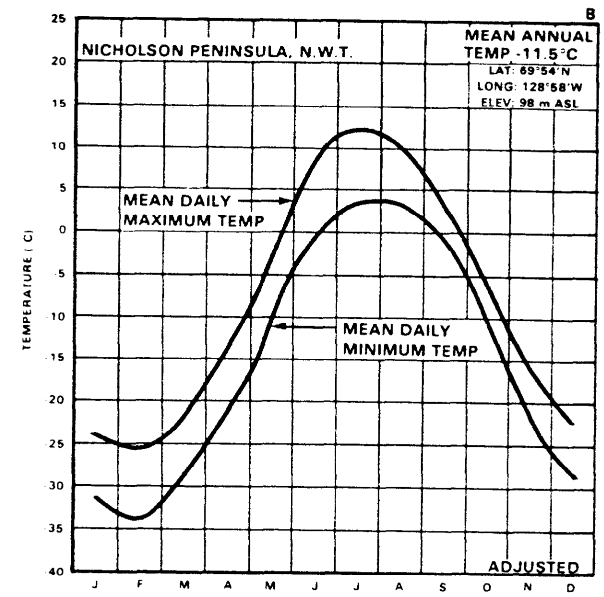
2.1.5.1 Temperature

The annual variation in mean daily temperatures along the Beaufort coast is less than at inland stations such as Inuvik. Mean daily temperatures range from -30.4°C to 5.7°C at Cape Parry, and from -29.4°C to 13.3°C at Inuvik (Atmospheric Environment Service, 1975a). Winter minima and summer maxima are less extreme in coastal areas owing to the moderating influence of the nearby Beaufort Sea, and the heavier cloud cover in the summer which reduces daytime air temperatures. Diurnal variations in air temperature are also less along the coast, partly for the same reasons, but also because of the higher wind speeds on the exposed coast.

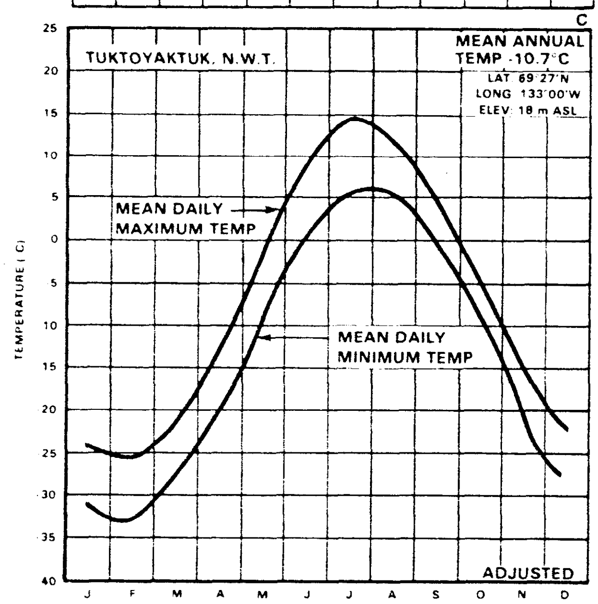
Annual cycles in mean daily air temperatures (averaged on a monthly basis) and monthly extremes at eight locations in the coastal Beaufort region are summarized in Figure 2.1-2a through 2.1-2h. January is usually the coldest month while July is the warmest. Cold air advected from the Beaufort Sea and increased cloud cover help to moderate fall temperatures. By the last week in October all lakes and channels are usually frozen over and mean daily temperatures average less than -18°C. Inuvik does



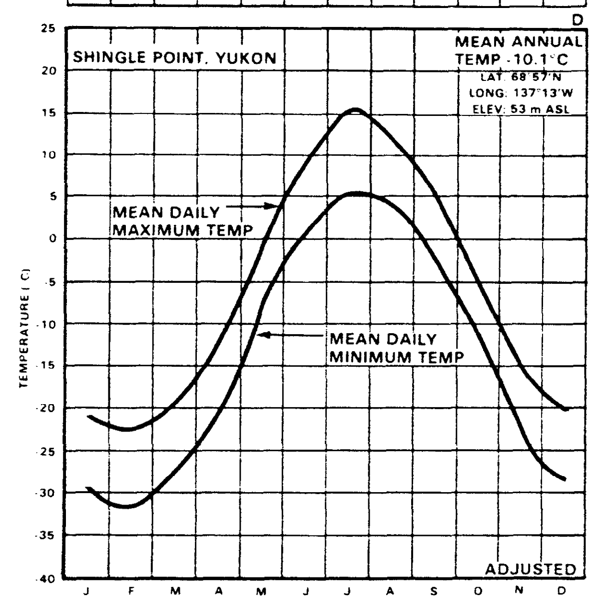
A	-28.5	-30.4	-26.1	-17.4	-6.1	1.7	5.7	5.3	0.8	-6.5	-18.2	-24.5
B	-2.8	-8.3	-5.0	2.8	11.1	16.7	23.3	21.1	18.3	5.6	3.3	-3.9
C	-42.2	-47.2	-42.8	-38.3	-27.8	-10.6	-3.3	-3.9	-8.3	-22.2	-36.7	-40.6



A	-27.7	-29.3	-25.1	-17.6	-5.5	4.1	7.8	6.8	0.8	-7.3	-19.4	-25.6
B	-3.3	-6.7	5.6	6.1	17.2	24.4	27.2	26.1	17.8	8.9	7.8	-2.8
C	-43.9	-46.7	-43.3	-39.4	-26.7	-12.2	-7.8	-4.4	-11.7	-26.7	-39.4	-42.2



A	-27.2	-29.2	-24.9	-16.9	-4.6	4.7	10.3	8.7	2.3	-6.9	-19.3	-25.2
B	-3.9	-2.8	1.1	5.6	18.9	27.2	27.8	30.0	21.7	10.0	6.1	-2.2
C	-45.0	-50.0	-41.7	-38.3	-27.2	-11.1	-2.2	-1.7	-10.6	-31.1	-38.9	-43.9

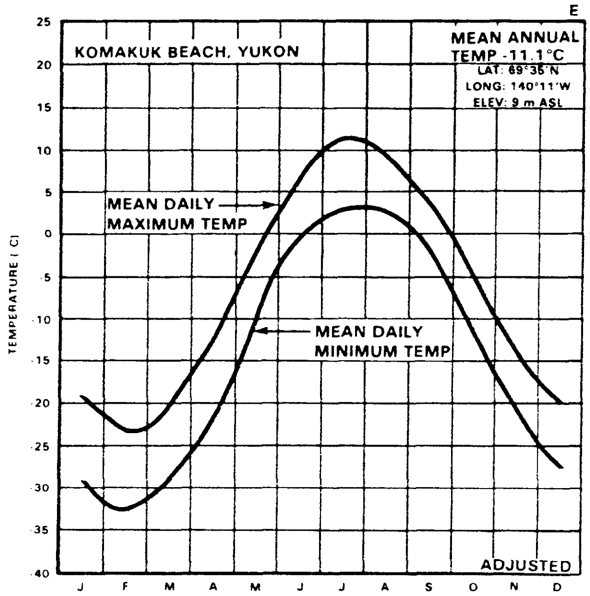


A	-24.9	-27.3	-23.5	-16.3	-4.2	5.0	10.6	8.2	1.7	-7.9	-18.9	-24.1
B	1.7	0.6	5.0	8.9	20.0	28.3	27.8	28.9	18.3	15.0	7.8	1.7
C	-51.1	-52.2	-42.2	-38.9	-30.6	-8.9	-6.7	-5.6	-13.3	-30.0	-42.8	-47.2

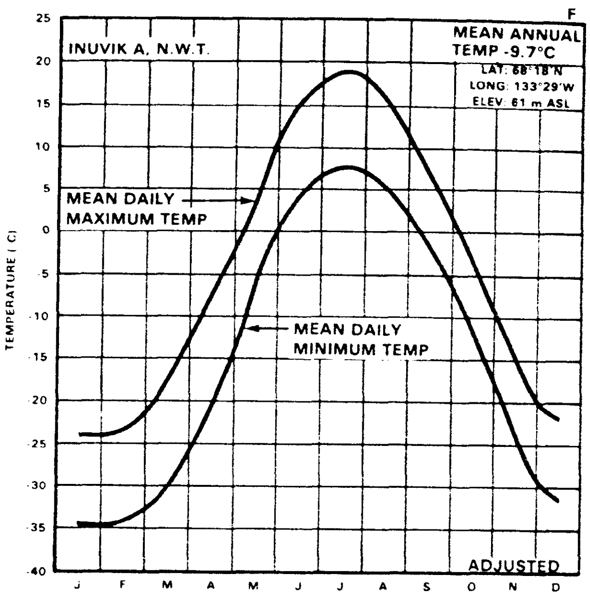
LEGEND

A MEAN DAILY TEMP (°C)
B EXTREME MAX. TEMP. (°C)
C EXTREME MIN. TEMP (°C)

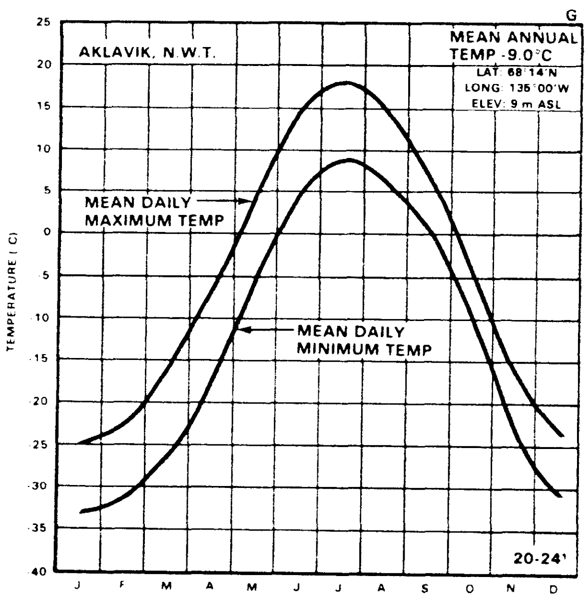
FIGURE 2.1-2 *(This figure is continued on the next page). Annual cycles in mean daily temperatures and monthly extremes at locations in the coastal Beaufort region. January is usually the coldest month and July is the warmest. By the end of October, all lakes and channels are frozen over and mean daily temperatures average less than -18° C. (Source: Atmospheric Environment Service, 1975a).*



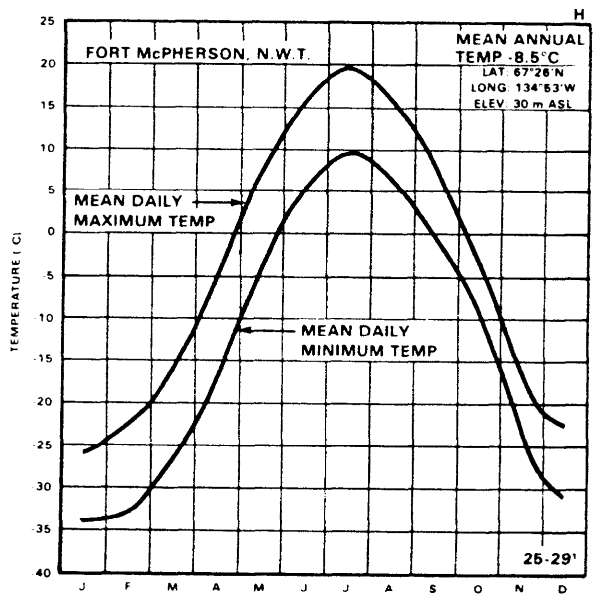
	J	F	M	A	M	J	J	A	S	O	N	D
A	-24.3	-27.9	-24.7	-17.6	-5.1	2.9	7.3	5.9	0.8	-8.4	-17.6	-23.9
B	8.3	-0.6	2.8	7.8	15.0	25.6	27.2	25.6	23.3	13.3	8.3	7.2
C	-46.7	-47.8	-47.8	-35.6	-25.0	-9.4	-5.6	-7.8	-17.8	-29.4	-38.9	-47.8



	J	F	M	A	M	J	J	A	S	O	N	D
A	-29.3	-29.4	-23.8	-14.6	-0.8	9.8	13.3	10.3	2.7	-7.2	-20.6	-27.1
B	1.7	2.8	6.1	13.3	23.3	31.7	31.1	29.4	25.6	15.0	10.6	-0.6
C	-51.7	-56.7	-50.6	-43.9	-27.8	-6.1	-3.3	-6.1	-18.9	-35.0	-46.1	-50.0



	J	F	M	A	M	J	J	A	S	O	N	D
A	-28.6	-27.4	-22.3	-12.7	-0.4	9.6	13.8	10.8	3.6	-7.1	-19.5	-27.3
B	6.7	9.4	9.4	13.9	25.0	30.0	33.9	31.1	24.4	12.8	6.7	10.0
C	-50.6	-52.2	-48.9	-42.2	-25.6	-6.7	-1.1	-3.9	-11.1	-30.0	-45.6	-47.8



	J	F	M	A	M	J	J	A	S	O	N	D
A	-29.4	-27.9	-21.5	-11.1	1.4	11.5	14.8	11.4	3.5	-7.0	-20.3	-26.9
B	8.9	10.0	9.4	16.7	28.3	31.1	32.2	33.3	27.2	17.2	8.9	8.3
C	-55.6	-55.0	-48.9	-44.4	-25.6	-6.7	0.0	-6.7	-15.0	-37.2	-46.7	-50.0

LEGEND

- A MEAN DAILY TEMP (°C)
- B EXTREME MAX. TEMP. (°C)
- C EXTREME MIN. TEMP (°C)

FIGURE 2.1-2 *(cont'd)*

TABLE 2.1-5

CANSAP PRECIPITATION DATA SUMMARY
(SOURCE: ATMOSPHERIC ENVIRONMENT SERVICE, 1977-80)

Station:	**Inuvik**															
Year:	**1977**					**1978**					**1979**			**1980**		
Month:	**June**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**June**	**July**	**Sept.**	**Oct**	**Feb.**	**Nov.**	**Jan.**	**Feb.**	**Apr.**	**May**	**June**
Sampling Period (Days)	8	19	31	28	32	31	31	30	32	30	34	32	29	31	31	30
Catch of Collector (mm)	18	5	2	2	3	15	6	14	15	3	9	7	3	15	4	3
Catch of Standard (mm)	65	5	4	4	12	40	24	34	32	4	15	10	6	31	17	4
pH	5.5	7.1	—	6.9	6.6	7.7	7.5	6.9	6.7	6.5	6.9	7.0	6.7	6.5	7.1	7.5
Conductance (μ s/cm)	4.8	—	—	—	—	56.0	97.0	47.6	17.7	21.6	24.2	21.1	25.4	10.5	50.9	59.0
Acidity (μ g/L)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sulfate (SO_4^*)(mg/L)	.6	—	1.1	1.9	—	1.1	1.7	.8	.9	3.5	.5	2.2	3.3	.4	3.2	2.8
Nitrate (NO_3-)(mg/L)	.35	—	.35	.58	—	.41	.96	.13	.12	.58	.04	BD*	.66	.22	.62	.55
Chloride (Cl-)(mg/L)	.13	—	1.89	2.61	—	.30	.62	1.70	.59	1.67	1.67	3.20	1.80	.16	4.48	2.61
Ammonium (NH_4^+)(mg/L)	.02	.01	.25	.35	—	.04	.13	.12	.13	.06	.22	.01	.26	.07	.67	.57
Sodium (Na+)(mg/L)	.1	—	.8	2.0	—	.2	—	1.0	.4	1.5	1.5	1.7	1.1	.3	3.5	2.2
Potassium (K+)(mg/L)	.06	.96	1.80	1.60	—	.15	—	BD*	.08	.32	.87	.35	.68	.12	1.63	1.30
Magnesium (Mg++)(mg/L)	.02	.46	.70	.65	—	2.00	—	2.20	.65	.27	.80	.50	.40	.33	.68	1.02
Calcium (Ca++)(mg/L)	.15	1.40	2.3	1.80	—	8.30	—	4.55	1.65	1.40	2.30	1.56	1.84	1.07	3.00	5.86

*BD = Values that were below detectable limits.

not experience monthly mean daily temperatures above zero again until June.

Extremely low temperatures are likely to occur more often and are lower at Inuvik than at Cape Parry. Computed return periods for annual extreme maximum and minimum temperatures are presented in Table 2.1-6. Since the period of record for both locations is relatively short, for example, 11 years at Inuvik and 12 years at Cape Parry, little confidence should be placed on return periods greater than 20 years. These figures indicate that in any given year extreme minimum temperatures may reach -45°C and -53°C with a probability of 10% at Cape Parry and Inuvik, respectively. Within the Delta, temperatures below -40°C may be expected to occur between the end of November and mid February. The highest probability of temperatures below -40 °C occurs from late December to early February. However, extreme minimum temperatures of less than -40°C are unlikely to persist beyond six consecutive days anywhere in the region.

The mean annual number of frost-free days varies from about 12 to 50 days on the coast compared to approximately 70 days at Aklavik and 50 days at Inuvik (Figure 2.1-3). The mean date of last frost varies from June 10 to July 10 in the region (Figure 2.1-4), while the mean date of first frost varies from July 30 to August 30 (Figure 2.1-5).

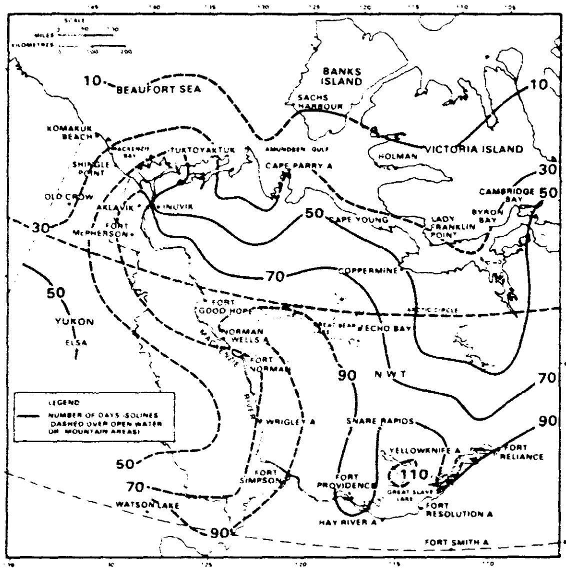


FIGURE 2.1-3 *Mean annual frost free days. On the coast, there are from 12 to 50 frost-free days. (Source: Burns, 1973).*

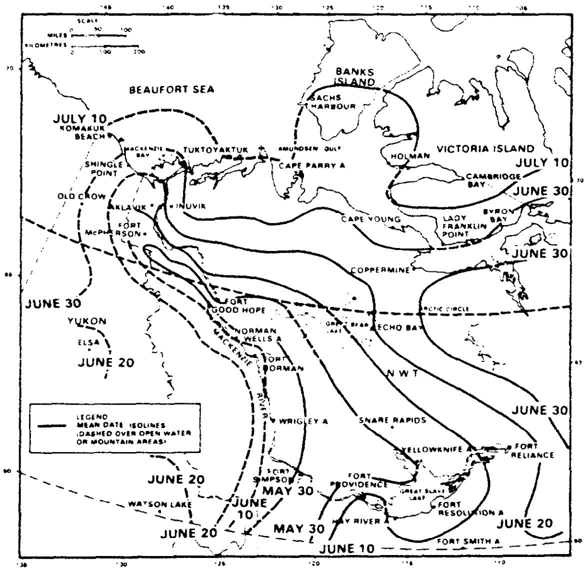


FIGURE 2.1-4 *Mean date of last frost (spring). In the coastal region, the mean date of last frost varies from June 10 to July 10. (Source: Burns, 1973).*

TABLE 2.1-6

EXTREME MAXIMUM AND MINIMUM TEMPERATURES (°C) AND ASSOCIATED RETURN PERIODS
(Source: Burns, 1973)

A. MAXIMUM TEMPERATURES

	Return Period (years)							
Station	**1.1**	**2**	**5**	**10**	**20**	**30**	**40**	**50**
Cape Parry A	16	19	21	23	24			
Nicholson Peninsula	22	24	26	27	28			
Tuktoyaktuk	23	25	27	28	29			
Shingle Point	26	26[1]	27	28				
Komakuk Beach	21	23	26	27				
Inuvik	27	29	30	31	32			
Aklavik	26	28	29	30	31	32	32	32
Fort McPherson	29	31	32	33	33	34	34	34

B. MINIMUM TEMPERATURES

	Return Period (years)							
Station	**1.1**	**2**	**5**	**10**	**20**	**30**	**40**	**50**
Cape Parry A	-40	-42	-43	-45	-46			
Nicholson Peninsula	-41	-43	-45	-46	-47			
Tuktoyaktuk	-42	-44	-46	-46	-47			
Shingle Point	-42	-46	-49	-52	-54			
Komaluk Beach	-41	-44	-47	-49	-51			
Inuvik A	-47	-49	-52	-53	-54			
Aklavik	-43	-46	-48	-50	-52	-52	-53	-53
Fort McPherson	-44	-48	-51	-53	-55	-56	-57	-57

[1] Most instances of the same temperature occurring in successive return periods are a result of converting fahrenheit to celsius. However, in some cases, temperatures in Burns (1973) had the same temperature in successive return periods.

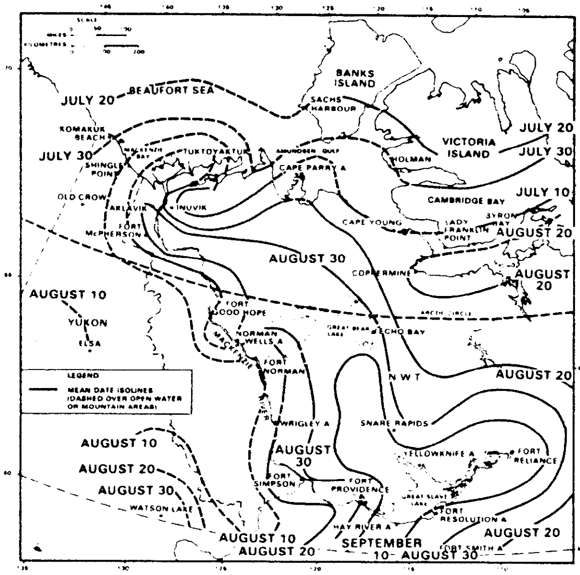


FIGURE 2.1-5 *Mean date of first frost (autumn). In the Beaufort coastal region, the mean date of first frost varies from July 30 to August 30. (Source: Burns, 1973).*

2.1.5.2 Wind

Burns (1973) provides a summary of wind data recorded at Inuvik and Cape Parry. Observed winds are often influenced by local topography and vegetation cover, and may not be applicable to other locations. Consequently, the wind patterns observed at these two locations may not apply to other areas along the Beaufort coast.

Figure 2.1-6 shows monthly mean hourly and extreme high hourly wind speeds recorded at Inuvik and Cape Parry, while the average seasonal wind directions for these two stations are indicated in Figures 2.1-7 and 2.1-8, respectively. These data show that winds are strongest along the coast and decrease with distance southward from the coast. The highest mean monthly hourly wind speeds at Cape Parry occur during the fall (October), while at Inuvik they occur during the summer (June). However, extreme high hourly wind speeds at both locations occur during the winter and are greater along the coast.

Figure 2.1-7 shows seasonal wind direction frequency data for Cape Parry where an east and west direction is prominent, based on data from 1959 to 1972 (Atmospheric Environment Service, 1975c). As shown in this Figure, the westerly component becomes less pronounced during the summer. At Inuvik (Figure 2.1-8), the wind regime is more varied. The easterly component is infrequent in summer and is constant throughout the rest of the year. Northeasterly, northerly and northwesterly winds tend to be most frequent in the summer and least common in winter, while westerlies remain more or less constant through the year.

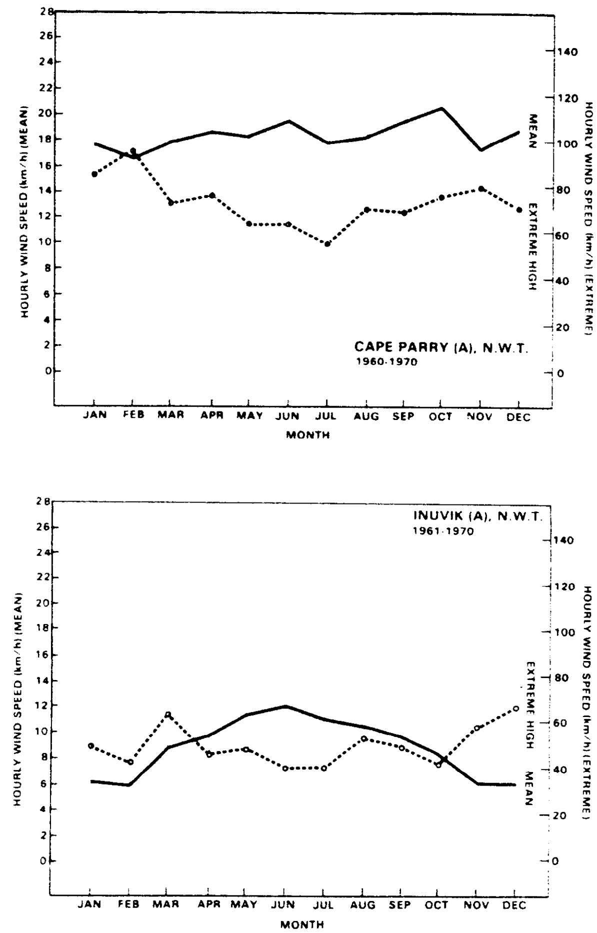


FIGURE 2.1-6 *Mean hourly and extreme high hourly wind speeds at Cape Parry and Inuvik. Winds are generally stronger along the coast (at Cape Parry) than inland (at Inuvik). Extreme winds occur at both locations during the winter. (Source: Burns, 1973).*

The frequency of occurrence and duration of calms differs significantly between the coast and the Delta with calm conditions prevailing from one third to two thirds as frequently at Cape Parry as at Inuvik.

Cape Parry, and probably the entire coastal region, is much windier than inland on the Delta. Strong winds occur during winter and are likely to be strongest and last longer along the coast than within the Mackenzie Delta. For example, winds in excess of 64 km/h (40 mph) generally persist for less than 4 hours at Inuvik, but may last up to 13 hours at Cape Parry (Burns, 1973).

Table 2.1-7 shows return periods for computed maximum hourly wind speeds at Cape Parry and Inuvik. These data indicate that wind speeds are higher along the coast. However, relatively short periods of wind records at both locations (11 years at Inuvik, 12 years at Cape Parry), and the site-specific nature of the wind data, limit their applicability to the region in general.

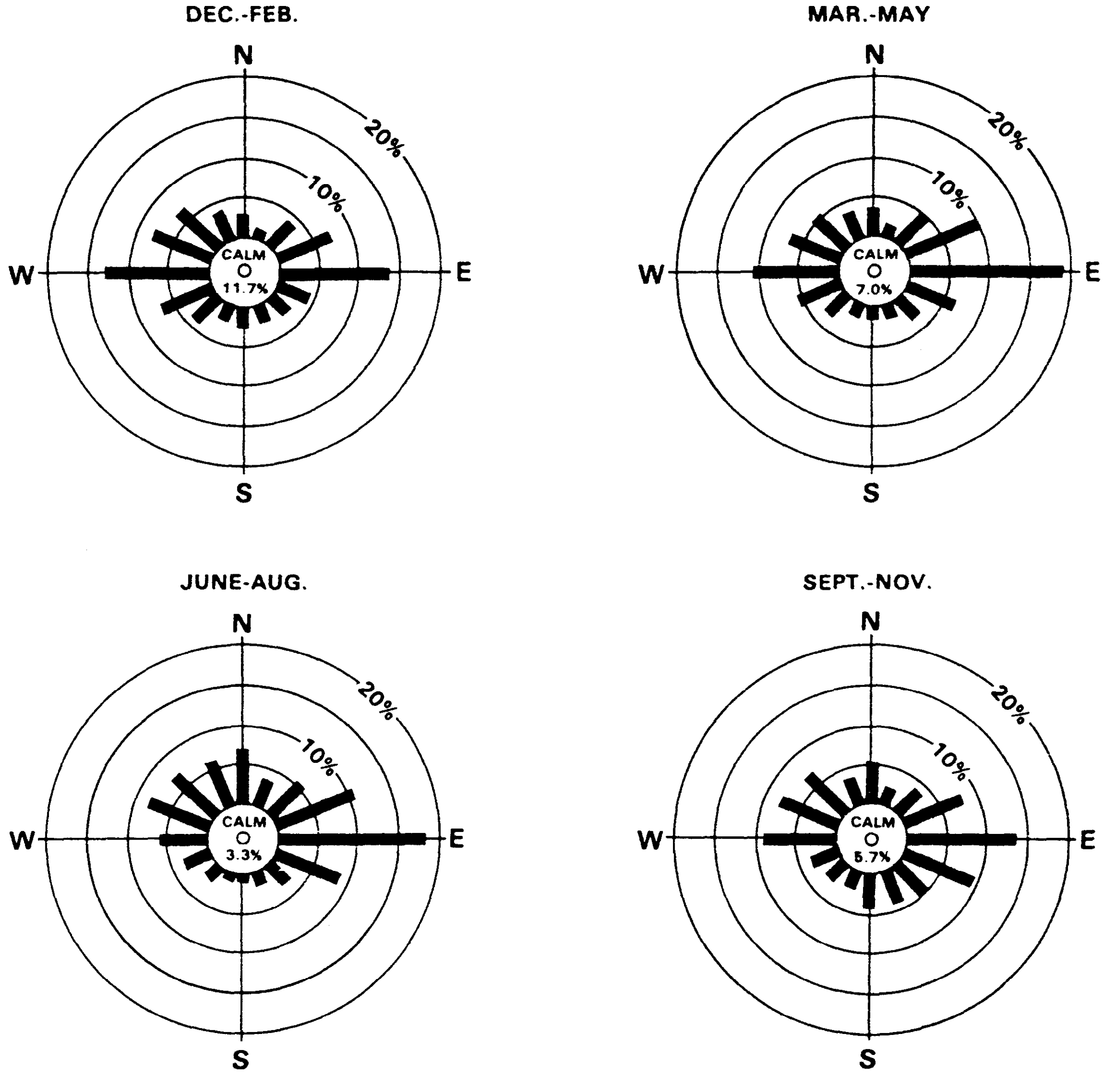


FIGURE 2.1-7 *Average seasonal wind direction frequency (in percent) observed at Cape Parry. Dominant winds are from both the east and west with the westerly component being less pronounced in summer. (Source: Atmospheric Environment Service, 1975c).*

TABLE 2.1-7

EXTREME HOURLY WIND SPEED (km/h) AND ASSOCIATED RETURN PERIOD FOR CAPE PARRY AND INUVIK (Source: Burns, 1973)

Station	Return Period (years) 1.1	2	5	10	20
Cape Parry A	58	67	77	83	90
Inuvik A	32	43	54	61	67

2.1.5.3 Precipitation

Precipitation along the Beaufort Sea coast and within the Mackenzie Delta region is extremely variable. For any given month precipitation may range from zero to almost double the mean monthly average (Burns, 1974). It is least along the Beaufort Sea Coastal Plain and increases inland from the coast (Table 2.1-8) where it also occurs more often and is more intense. In general, coastal stations record measurable amounts of precipitation on 40 to 100 days per year, while precipitation occurs on about 90 to 130 days within the Delta (Table 2.1-9).

At the stations analyzed, precipitation is more frequent during the summer and autumn before landfast ice forms along the coast. Inuvik is an exception to this trend, with more precipitation generally occurring during the autumn and winter. The higher frequency in summer and autumn, for most stations, is associated with the open water along the coast. There are many days with small amounts of precipitation, but relatively few days with precipitation in excess of 2.5 mm.

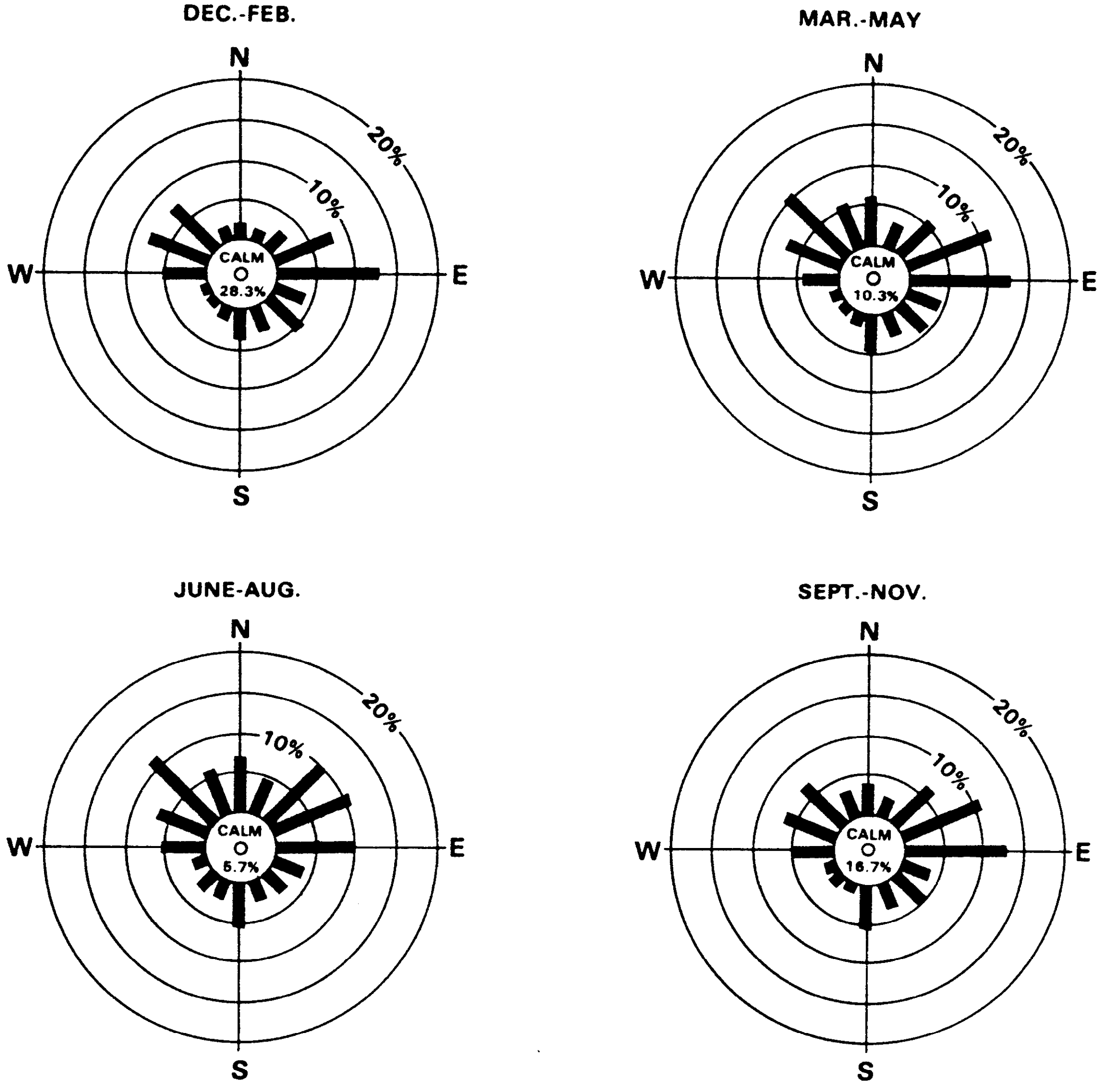


FIGURE 2.1-8 *Average seasonal wind direction frequency (in percent) observed at Inuvik. Easterly winds are most frequent except in summer. Southwest winds are least frequent year-round. (Source: Atmospheric Environment Service, 1975c).*

TABLE 2.1-8

MEAN MONTHLY RAINFALL (mm)
(Source: Atmospheric Environment Service, 1975b)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Cape Parry A	4.6	5.3	6.4	10.2	7.9	14.2	18.0	31.0	26.2	21.3	81.	6.4	159.6
Nicholson Penin.	2.3	2.3	3.3	3.6	4.6	10.7	20.8	31.8	15.0	10.9	4.1	3.0	112.4
Tuktoyaktuk	5.1	5.3	3.6	4.8	7.1	13.5	22.1	28.7	14.0	12.7	5.1	7.6	129.6
Shingle Point	9.4	3.0	6.9	8.9	8.4	19.3	39.1	39.4	21.1	24.1	8.9	4.1	192.6
Komakuk Beach	4.8	2.3	3.0	2.5	3.8	11.4	28.2	31.0	13.0	15.2	5.8	3.6	124.6
Inuvik A	20.3	10.2	16.5	14.0	17.5	13.0	34.3	46.2	21.1	33.8	14.7	18.5	260.1
Aklavik	11.9	10.7	11.2	8.1	8.1	18.3	33.8	36.1	20.1	32.3	21.1	24.4	236.1
Fort McPherson	20.6	19.6	25.7	23.4	14.5	22.9	26.4	43.4	31.8	47.8	35.6	25.9	337.6

TABLE 2.1-9

NUMBER OF DAYS WITH MEASURABLE PRECIPITATION IN THE BEAUFORT SEA COASTAL REGION AND MACKENZIE DELTA (Source: Atmospheric Environment Service, 1975b)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Mean Annual Total
Cape Parry A	6	5	6	7	7	5	8	10	13	15	10	7	99
Nicholson Penin.	2	2	2	2	2	4	6	9	7	5	2	2	45
Tuktoyaktuk	3	3	3	3	3	4	7	8	6	7	3	4	54
Shingle Point	2	1	3	3	3	5	9	8	6	8	4	3	55
Komakuk Beach	2	2	2	1	2	2	6	6	5	5	2	2	37
Inuvik A	12	11	12	10	7	6	10	10	10	14	11	15	128
Aklavik	8	7	8	7	5	6	9	12	11	11	10	109	103
Fort McPherson	7	7	7	5	4	6	8	10	8	10	9	7	88

Mean monthly precipitation at coastal locations exhibits a skewed annual distribution. Approximately 70 to 80% of the mean annual precipitation occurs during the months from June to October (Figure 2.1-9). In contrast, within the Mackenzie Delta only 50 to 60% of the annual total precipitation is received during this period. The bulk of the precipitation at all coastal and inland locations occurs in the form of rain. A major difference between the coast and the Delta is the comparatively low snowfall at the coast during the winter. Mean monthly snowfall along the coast during the winter and spring varies from 2 to 12 cm, compared with 12 to 22 cm per month at Inuvik and 12 to 36 cm per month at Fort McPherson.

Table 2.1-10 shows the computed return periods for extreme 24 hour precipitation for various locations throughout the region (Burns, 1974). However, due to the relatively short period of record at some locations these values should only be regarded as estimates.

(a) Rainfall

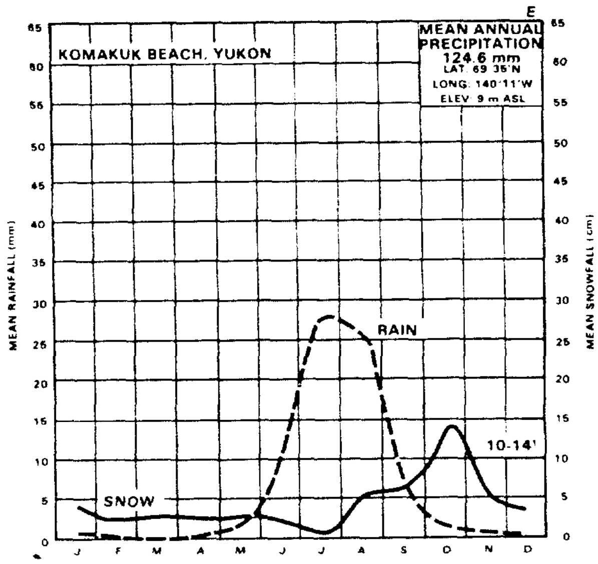
It normally rains in this region from May to October, with peak rainfall occurring during July and August. However, under certain meteorological conditions, rain may fall in winter, and has been recorded during all months of the year. Large variations in annual rainfall are common, the largest occurring during July and August. These are also the months when extreme 24 hour rainfalls are most likely to occur.

Convective activity in the Beaufort Sea Coastal Plain is relatively light and most rainfall is associated with large baroclinic disturbances. Thunderstorms seldom occur. During the years 1960-70, only 10 and 15

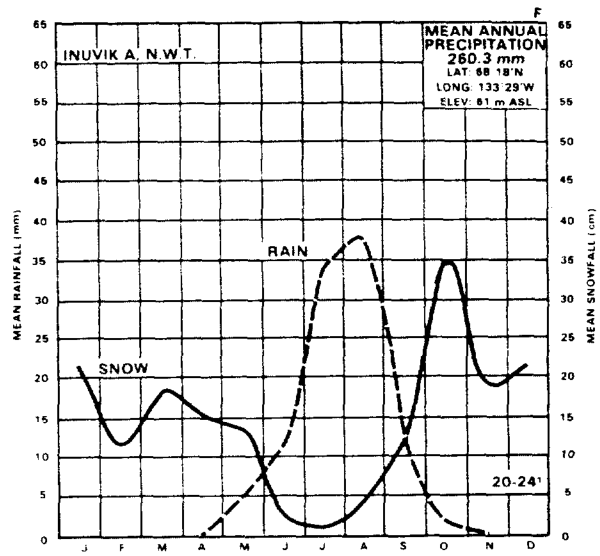
TABLE 2.1-10

EXTREME 24-HOUR PRECIPITATION (mm.) AND ASSOCIATED RETURN PERIODS FOR THE BEAUFORT SEA COAST AND MACKENZIE DELTA (Source: Burns, 1974)

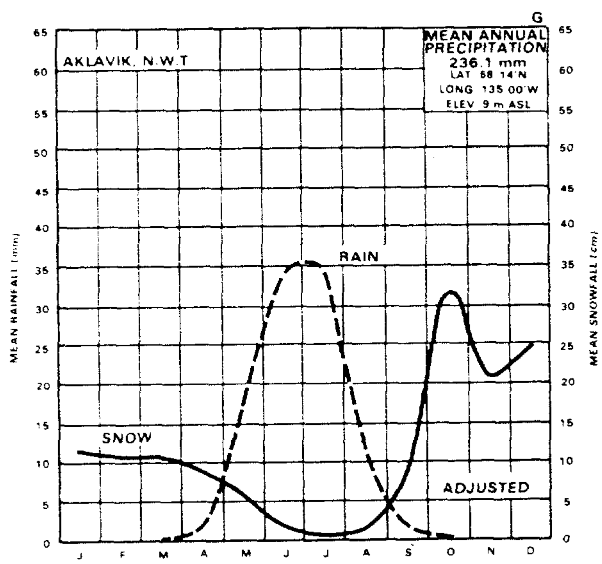
Station	Return Period (years)							
	1.1	2	5	10	20	30	40	50
Cape Parry A	10.2	17.8	27.9	33.0	38.1			
Tuktoyaktuk	7.6	15.2	22.9	27.9	33.0			
Inuvik A	12.7	20.3	30.5	35.6	40.6			
Aklavik	5.1	17.8	30.5	38.1	48.3	50.8	55.9	55.9
Fort McPherson	2.5	22.9	38.1	50.8	61.0	66.0	71.1	73.7



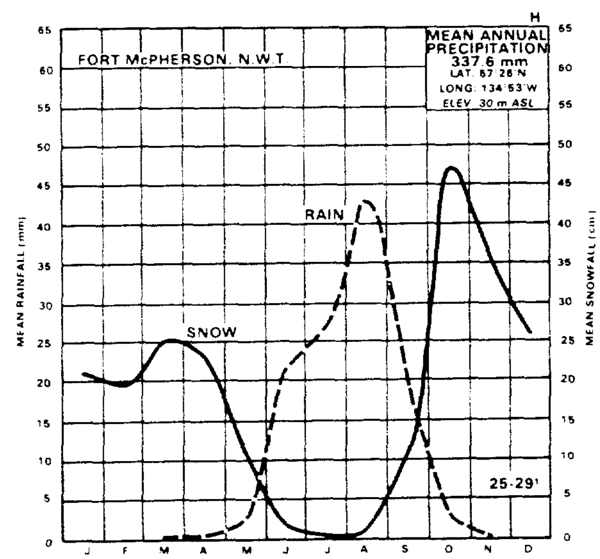
A	4.8	2.3	3.0	2.5	3.8	11.4	28.2	31.0	13.0	15.2	5.8	3.6
B	1.3	0.0	0.0	0.0	T	28.7	44.5	44.5	10.4	4.3	6.9	0.0
C	10.2	3.0	2.5	12.4	7.6	6.9	1.5	15.2	7.6	7.6	7.6	10.2



A	20.3	10.4	16.5	14.0	17.5	13.0	34.3	46.2	21.1	33.8	14.7	18.5
B	1.5	T	T	0.3	19.3	18.0	22.1	33.0	9.7	13.2	0.8	0.0
C	11.4	13.7	13.0	17.8	24.9	10.2	1.3	22.6	12.2	13.5	10.4	12.2



A	11.9	10.7	11.2	8.1	8.1	18.3	33.8	36.1	20.1	32.3	21.1	24.1
B	0.0	0.0	T	0.8	50.8	29.7	40.9	44.2	14.7	6.9	T	0.0
C	20.3	25.4	25.4	25.4	10.7	20.8	1.0	14.5	16.0	18.8	20.8	15.2

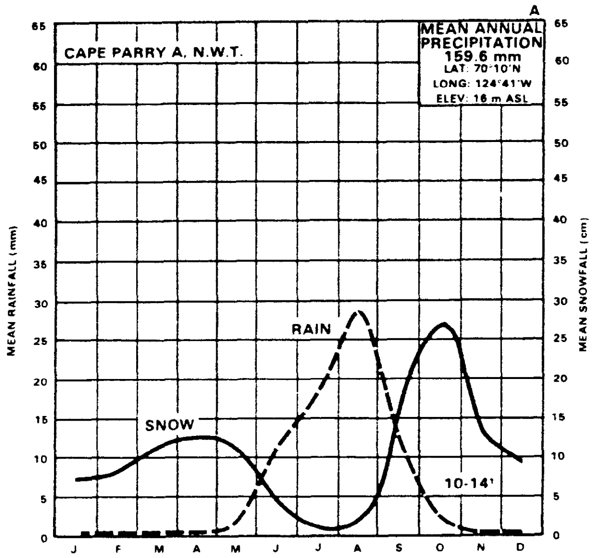


A	20.6	19.6	25.7	23.4	14.5	22.9	26.4	43.4	31.8	47.8	35.6	25.9
B	0.0	0.0	T	5.1	18.5	37.3	66.0	50.8	28.2	9.9	T	3.8
C	17.8	15.2	15.2	22.9	24.1	5.1	T	10.7	27.2	35.6	17.8	20.3

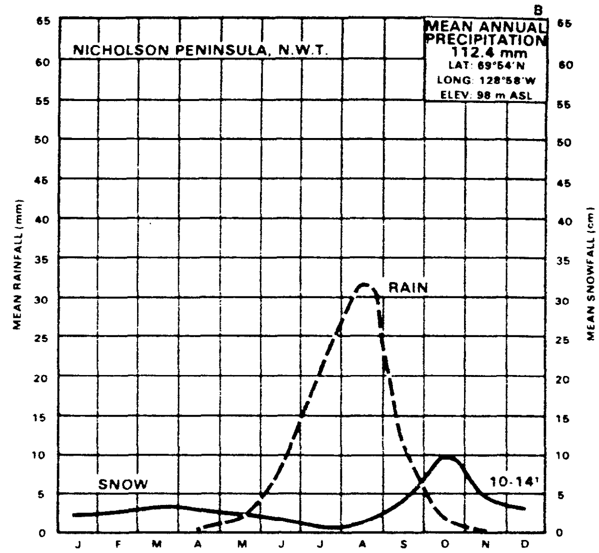
LEGEND

- **A** MEAN MONTHLY TOTAL PRECIPITATION (mm)
- **B** GREATEST 24-HOUR RAINFALL (mm)
- **C** GREATEST 24-HOUR SNOWFALL (cm)

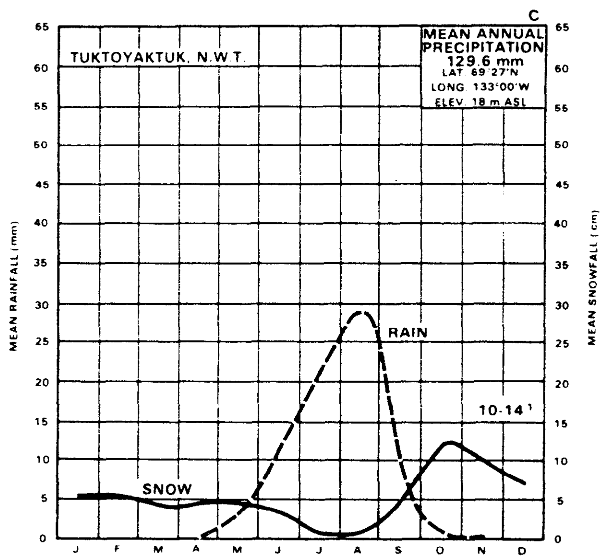
FIGURE 2.1-9 *(This figure is continued on the next page). Annual cycles in mean daily precipitation and monthly extremes at eight locations in the coastal Beaufort region. Most precipitation at all stations falls as rain. A major difference between the coast (Komakuk Beach, Shingle Point, Tuktoyaktuk, Nicholson Peninsula and Cape Parry) and the Delta (Fort McPherson, Aklavik and Inuvik) is the comparatively low snow-fall during the winter at the coast. (Source: Atmospheric Environment Service, 1975b).*



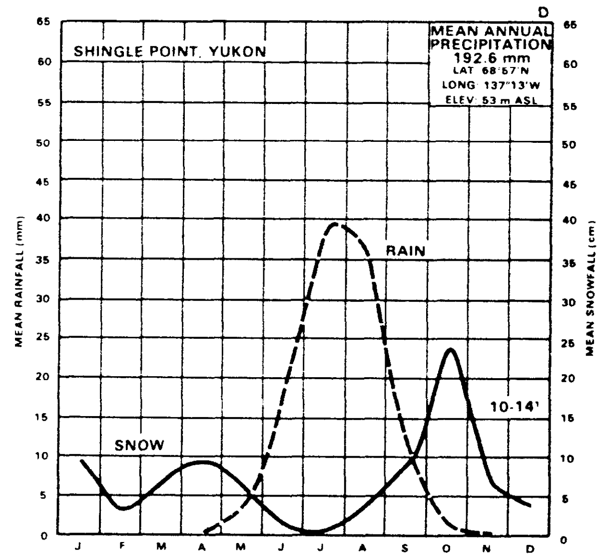
A	4 6	5.3	6 4	10.2	7.9	14.2	18 0	31 0	26.2	21.3	8.1	6.4
B	0.5	T	T	T	6.4	27 4	28.4	31.2	14.0	10.2	0.3	T
C	5 6	10.9	6.9	13.2	12 7	5 6	8.1	4.3	9 9	14 0	10.2	5.1



A	2 3	2.3	3.3	3 6	4.6	10.7	20 8	31.8	15.0	10.9	4 1	3.0
B	0 0	0 0	0.0	T	7.6	18.3	27 9	20.3	11.9	8 4	0 0	0.0
C	5.1	5 1	5.1	5 1	2.5	10.2	1.3	7.6	7 6	6.9	8 1	2.8



A	5 1	5.3	3 6	4 8	7 1	13.5	22 1	28.7	14.0	12.7	5 1	7 6
B	0 0	0 0	0.0	T	12 4	19 1	20 3	29.5	12 7	2 8	1 0	0.0
C	10.2	7 6	6 4	8.9	5 1	11 4	4.1	3 6	12.7	6 4	7 6	6 6



A	9 4	3 0	6 9	8 9	8 4	19 3	39 1	39.4	21 1	24.1	8.9	4 1
B	0 0	0 0	0 0	T	7 6	12.7	27 9	33.5	22.9	12 7	0 0	0 0
C	15 2	5.1	10.2	14 0	12 7	2 5	0.0	7.6	12.7	14.0	17.8	7.8

LEGEND

- **A** MEAN MONTHLY TOTAL PRECIPITATION (mm)
- **B** GREATEST 24-HOUR RAINFALL (mm)
- **C** GREATEST 24-HOUR SNOWFALL (cm)

FIGURE 2.1-9 *(cont'd)*

hours of thunderstorm activity were recorded at Cape Parry and Inuvik, respectively, mostly in June. In general, most rainfall occurs as weak showers on most days with measurable precipitation. On the other hand, the passage of intense frontal low pressure systems may produce heavy downpours on only two or three days of the month which account for as much as 75% of the monthly total precipitation.

Figure 2.1-9 shows the mean monthly rainfall recorded at stations in this region. Rainfall occurs more frequently in the Delta than along the coast (Table 2.1-11) and the extreme 24 hour rainfall is also higher within the Delta than along the coast. In general, the duration of rainfall is less than 6 hours, with the majority of events lasting less than 24 hours (Burns, 1974).

Considerable rain usually falls on the coast around the end of May. May and October are the transition months during which most falls of both rain and snow are usually recorded. Freezing rain, therefore, is most likely to occur in these months, and is more frequent along the coast than within the Delta. There is little difference in the number of hours of freezing rain along the coast during the spring and fall. However, within the Delta, freezing precipitation occurs most often in the autumn. Table 2.1-12 contains the computed estimates of expected ice accretion (build-up) on surfaces for Cape Parry and Inuvik for 10 and 20 year return periods.

Rainfall generally ends by early November, and, except for infrequent warm spells in January which may produce some freezing rain, only trace amounts of rain are likely to fall during November through April. The greatest rainfall recorded at Inuvik during the month of January was 1.5 mm (Figure 2.1-9).

TABLE 2.1-11

NUMBER OF DAYS WITH MEASURABLE RAINFALL
(Source: Atmospheric Environment Service, 1975b)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Cape Parry A	*	0	0	0	1	4	7	9	6	*	*	0	27
Nicholson Penin.	0	0	0	0	1	3	6	9	4	*	0	0	23
Tuktoyaktuk	0	0	0	0	1	3	7	8	4	*	*	0	23
Shingle Point	0	0	0	0	1	4	9	8	3	*	0	0	25
Komakuk Beach	*	0	0	0	*	2	6	5	3	*	*	0	16
Inuvik A	*	0	0	*	2	6	10	10	6	1	*	0	35
Aklavik	0	0	0	*	1	6	9	12	7	1	0	0	36
Fort McPherson	0	0	0	*	1	6	8	9	6	*	0	0	30

* Rain recorded in the general area but this particular station was not manned at the time.

TABLE 2.1-12

ICE ACCRETION EPISODES AND ASSOCIATED RETURN PERIODS
(Source: Chaine et al., 1974)

Station	**Cape Parry**		**Inuvik**	
Return Period (years)	**10**	**20**	**10**	**20**
Ice accretion on horizontal surfaces (cm.)	.61	1.19	.38	.71
Ice accretion on vertical surfaces (cm.)	1.14	2.21	.41	.79

(b) Snowfall

Although snowfall occurs only on rare occasions during June, July and August, it may occur in any month of the year throughout the region. Most snow tends to fall beginning from late September through early November, with a secondary maximum snowfall occurring in March through April. Extreme variations in the timing and amount of snowfall are common. For example, extreme 24 hour accumulations are most likely to occur in October, however, unusually heavy snowfalls may also occur at other times of the year. Occasional intrusions of moist maritime air, in conjunction with temperatures of a few degrees below freezing, may produce record, or near-record, 24 hour snowfalls in April and May. Rare and unusual meteorological conditions associated with shifts in the upper-level airflow may also produce near record snowfalls mixed with rain in the month of August. On one occasion, Inuvik recorded 22.6 cm of snow in August, which is only slightly less than the all-time record at Inuvik of 24.9 cm. However, such summertime snowstorms are so rare that they do not significantly affect the mean monthly snowfall norms for August, although they remain important in relation to structural snow loading. Snow falls on about 31 to 99 days of the year at most locations on the Delta, with a minimum of about 23 days at some coastal locations (Table 2.1-13). Snowfalls are most frequent in the months of October to December. The majority of snowstorms last less than 24 hours, but may extend up to 72 hours.

TABLE 2.1-13

NUMBER OF DAYS WITH MEASURABLE SNOWFALL

Source: Canadian Normals, vol. 2-SI, Precipitation, 1941-70, 1975

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Aklavik	8	7	8	7	4	1	.	.	4	11	10	9	69
Cape Parry A	7	6	8	8	7	2	1	1	9	16	11	9	85
Fort McPherson	7	7	7	5	3	.	0	.	3	9	9	7	57
Inuvik A	12	11	12	10	6	1	.	1	6	14	11	15	99
Komakuk Beach	2	2	2	1	2	1	.	2	2	5	2	2	23
Nicholson Penin.	2	2	2	2	2	1	.	.	3	5	2	2	23
Shingle Point	2	1	3	3	2	1	0	1	3	8	4	3	31
Tuktoyaktuk	3	3	3	3	3	1	.	.	2	6	3	4	31

The earliest date for the establishment of first snow cover to a depth of at least 2.5 cm on the Delta and coastal regions is about August 31. The mean date of first snow cover varies from September 25 to 30 on the coast, up to approximately October 10 at Inuvik. The latest date for the establishment of snow cover ranges from September 30 around the Tuktoyaktuk Peninsula and Inuvik, to as late as October 20 to 25 at Shingle Point. Continuous snow cover (that is, months with no breaks in cover) generally lasts from November through April on the Delta, and from November to May along the Coastal Plain. The latest recorded date for snow cover on the Delta is roughly June 10, while along the coast the latest date ranges from June 20 to 25. There are approximately 250 days of continuous snow cover in the region (Burns, 1976).

2.1.5.4 Visibility

The factors which reduce visibility along the Beaufort Sea coast and within the Mackenzie Delta vary with season and location. The main phenomena are advection fog, ice fog, steam fog, ice crystal haze, blowing snow, and a condition peculiar to Arctic environments called whiteouts (Burns, 1974).

In summer, warm moist air flowing over coastal waters containing ice results in the formation of advection fog. Although the fog generally occurs at the edges of ice floes, light onshore winds may advect the fog over the adjacent land. Most fog along the coast occurs in August, with a maximum of 6 to 8 days of fog in August at Cape Parry. The Delta, on the other hand, experiences a maximum of only two to three days of fog per month in the period from October to February.

Ice fog is relatively uncommon in this region because its formation relies on the sublimation of moisture on airbourne particles (mostly hydrocarbons) in cold air below -30°C. Due to the naturally low moisture content of cold air masses and the dirth of human activity in the area, ice fog is insignificant.

Steam fog is a winter phenomenon associated with open leads or tidal cracks in the ice cover along the coast and in leads of larger rivers. The fog forms when moisture from the open water condenses in the cold air, and is usually observed from October through April when mean monthly temperatures are well below freezing.

Ice crystal haze is normally associated with the clear skies and low temperatures of Arctic high pressure systems. Although such haze may extend over wide areas, it usually does not lower the visibility below 3 km.

Blowing snow is the most common form of visual obstruction in the winter and occurs when winds blow over powder snow. According to Burns (1974), "powder-fine snow will start to drift with wind speeds of 9 to 20 mph [14.4 to 32.0 km/h] and about 50% of blowing snow occurs with wind speeds of 21 to 29 mph [33.6 to 46.4 km/h]. Winds in excess of 30 mph [48 km/h] usually produce visibilities of less than 0.5 mile [0.8 km] and in extreme cases near zero with fresh snowfalls." The higher wind speeds along

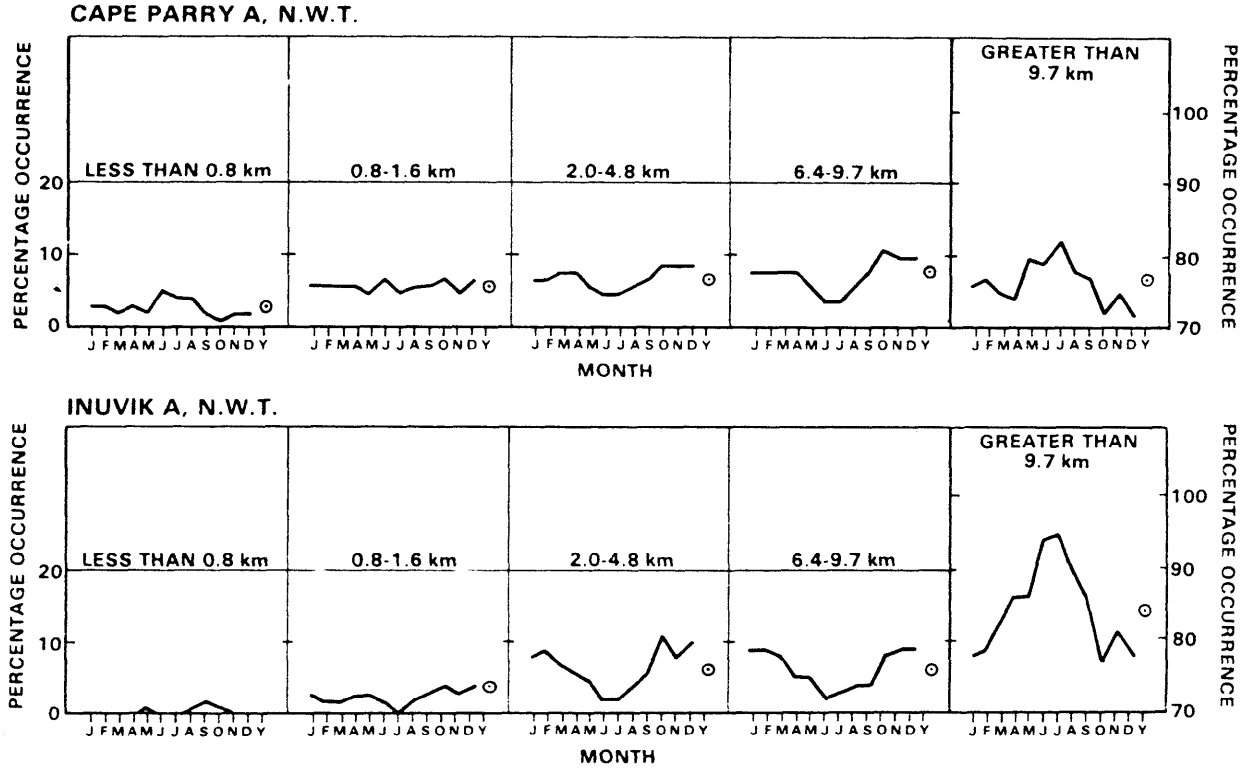


FIGURE 2.1-10 *Percentage occurrence of specific visibility classes. Visibility is usually much less at coastal locations then within the Delta, however, everywhere in the region the visibility is poorest in both the spring and fall. (Source: Burns, 1974).*

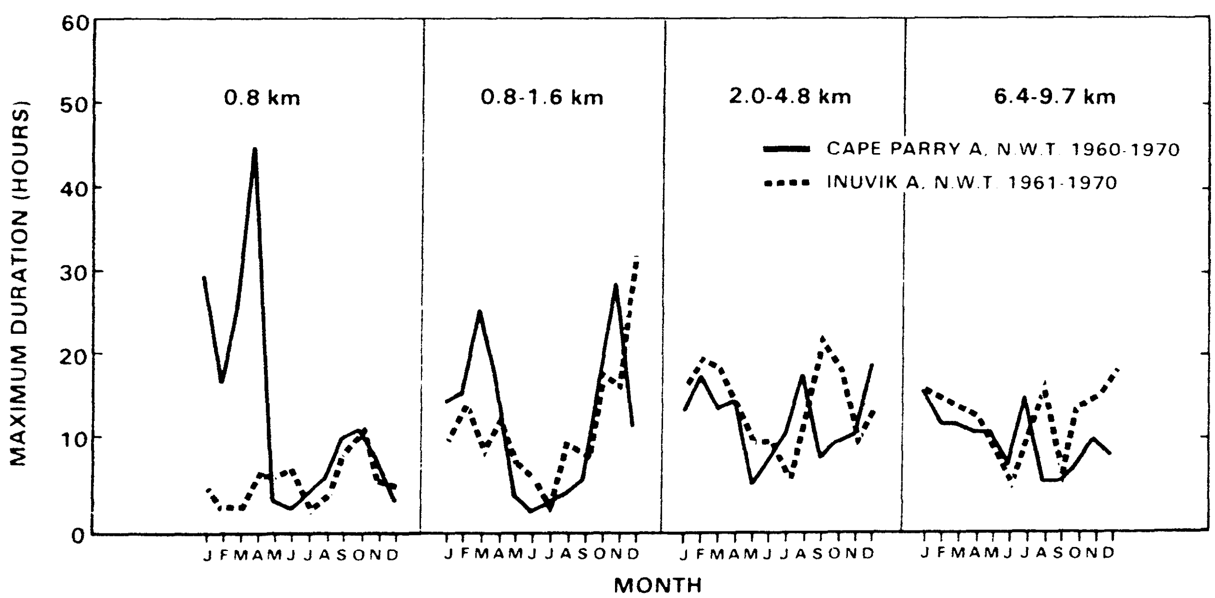


FIGURE 2.1-11 *Maximum duration of specific visibility classes. The persistence of limited visibility is greatest during the fall and winter and least during the summer. (Source: Burns, 1974).*

the coast, coupled with the presence of a thin layer of powder snow on landfast ice, produces blowing snow approximately 10 to 15% of the time at Cape Parry from November to April, as compared with only 1 to 2% of the time at Inuvik for the same period. Powder-fine snow will begin to drift at wind speeds of 9 mph (14.5 km/h) (Burns, 1974). Using Burn's graph for the maximum duration of hourly wind speeds (Burns, 1973), the maximum duration for blowing snow at Cape Parry would be expected to be roughly 55 hours in January, compared to approximately 95 hours at Inuvik in January.

An Arctic whiteout is the optical phenomenon in which perspective and orientation are lost. A whiteout occurs when light is diffusely scattered during multiple reflections between a uniform low-overcast sky and an unbroken snow cover beneath it. The condition is accentuated by a low sun angle. Under these conditions, white objects and surface irregularities become invisible, while perception of distance to dark objects becomes uncertain. Whiteout usually occurs most often in later winter, early spring and autumn.

Figure 2.1-10 shows the percentage frequency of occurrence of specific visibility classes, while Figure 2.1-11 shows the maximum duration of each class at Cape Parry and Inuvik (Burns, 1974). They indicate that visibility is poorest in the spring and fall along the coast and within the Delta, but that visibility is usually much less at coastal locations than within the Delta. The persistence of limited visibility is greatest during the fall and winter and least during the summer.

2.2 COASTAL GEOLOGY

This section summarizes the general geology and terrain conditions of the Beaufort Sea coastal zone. The relief and topography, bedrock and surficial

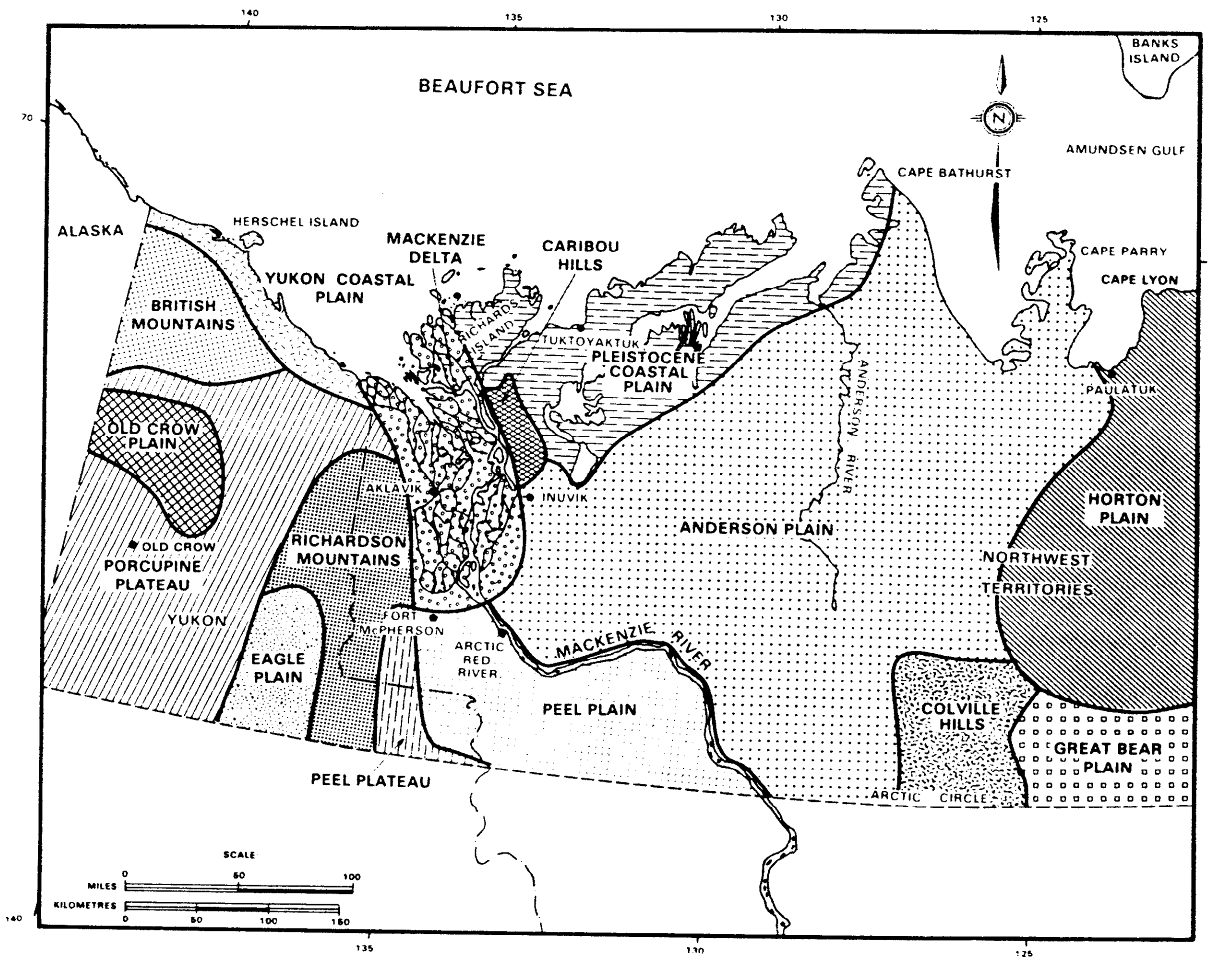


FIGURE 2.2-1 *Physiographic divisions of the onshore Beaufort area. (after: Bostock, 1969; Fyles et al., 1972) This section on coastal geology is limited to descriptions of the Yukon Coastal Plain, the Mackenzie Delta, the Pleistocene Coastal Plain and the northern part of the Anderson Plain.*

geology, permafrost and ground ice conditions, and terrain stability and sensitivity are described for the Yukon Coastal Plain and adjacent areas, the Mackenzie Delta, and the Pleistocene Coastal Plain-Anderson Plain (Figure 2.2-1). A discussion of surficial deposits along the coastal zone of the Beaufort Sea is provided in Section 2.3 of this volume. To assist the reader a glossary of common geological terms and a geological time chart are provided in Tables 2.2-1 and 2.2-2, respectively.

2.2.1 YUKON COASTAL PLAIN

The Yukon Coastal Plain is bounded on the north by the Beaufort Sea and on the south by the North Slope watershed (Figure 2.2-1). The plain extends eastward from the Alaska - Yukon border for a distance of approximately 130 km to the western edge of the Mackenzie Delta, and is 10 to 25 km wide. The geology and terrain of the Yukon Coastal Plain and adjacent areas is described in detail by Hughes (1972) and Rampton (1974, in press).

2.2.1.1 Topography and Relief

Physiographically, this region encompasses the Yukon Coastal Plain proper, as well as the northern parts of both the British and Richardson mountains (Bostock, 1969). Elevations range from sea level along the Beaufort Sea coastline in the north, to about 1,500 m above sea level (asl) in the Richardson Mountains and 1,750 m asl in the British Mountains. Slopes of less than 10° are characteristic of the Coastal Plain, except locally on eroded banks, while slopes of up to 30° occur in the more rugged sections of the British Mountains. On the other hand, slopes of 5° or less are typical of the pediment-erosion surface which lies between the Coastal Plain and the edge of the mountains.

2.2.1.2 Bedrock Geology

The Yukon Coastal Plain and its adjacent erosion surface are underlain by sandstones and shales of Tertiary to Quaternary age (Douglas, 1969) (Figure 2.2-2). On the Coastal Plain, these bedrock strata are overlain by a relatively thick layer of more recent sediments, while shallower overburden occurs on the pediments (Section 2.2.1.3). The Richardson Mountains consist of sandstone, shale, conglomerate and carbonate rocks of Palaeozoic and Mesozoic age, while the portion of the British Mountains situated within this physiographic division is formed of argillite and sandstone of the Helikian (Precambrian) Neruopuk Formation (Bamber et al., 1963).

2.2.1.3 Surficial Geology

The Yukon Coastal Plain and its adjacent areas may be further subdivided into three sections: a coastal plain, erosion surface-pediment areas, and mountains and foothills (Rampton, 1974).

(a) Coastal Plain

The Coastal Plain is narrow, generally only up to about 15 km wide, and is covered by 30 m to 60 m of surficial deposits (Rampton, 1975). Depending on location, the origin of these deposits may be predominantly preglacial, marine, alluvial, lacustrine or glacial (Figure 2.2-3).

The area between the Alaska-Yukon boundary and Herschel Island has not been glaciated (Hughes, 1972). In the western portion of this region (west of Herschel Island) lacustrine and glaciomarine silts and clays are dominant, although relatively small alluvial fans are also present in some areas. However, further to the east, extensive alluvial fans, consisting of sand and gravel up to 10 m thick, occur almost continuously along the coast. Some of these fans are also veneered by fine-grained and organic deposits up to 3 m thick (Rampton, 1974).

Unlike the Herschel Island-Alaska-Yukon boundary region, the area east of Herschel Island has been glaciated, with the terrain east of King Point having been glaciated twice (Hughes, 1972). Outwash and rolling moraine (till) plains are the dominant near-surface deposits in this area. In most instances, the surficial glacial deposits are veneered by postglacial lacustrine and organic sediments, and are underlain by a succession of preglacial fine-grained marine, deltaic and alluvial sediments. The latter deposits are often severely contorted by glacial ice thrusting and are of either early Wisconsin or preglacial age (Mackay et al., 1972).

(b) Pediment-Erosion Surface Areas

These areas are located between the Coastal Plain and Richardson and British mountain foothills, and frequently extend up the river valleys for a considerable distance into the mountains. Hughes (1972) reported that pediment surfaces are found in the glaciated as well as the unglaciated areas.

In the glaciated areas, till and glaciofluvial outwash are the dominant deposits (Rampton, 1974). These materials are underlain by either fine-grained marine, deltaic or alluvial material or by glaciolacustrine clay. The depth to bedrock generally ranges from 1 to 2 m down to about 10 m. On the other hand, the unglaciated pediment surfaces, which often finger deep into the mountains, are coated by coarse colluvial bedrock debris and, in localized depressions, by organic material (Rampton, 1974). Depths to bedrock in most of the latter areas range from 1.5 to 5 metres.

(c) Foothills and Mountains

The foothills and northern edges of the Richardson

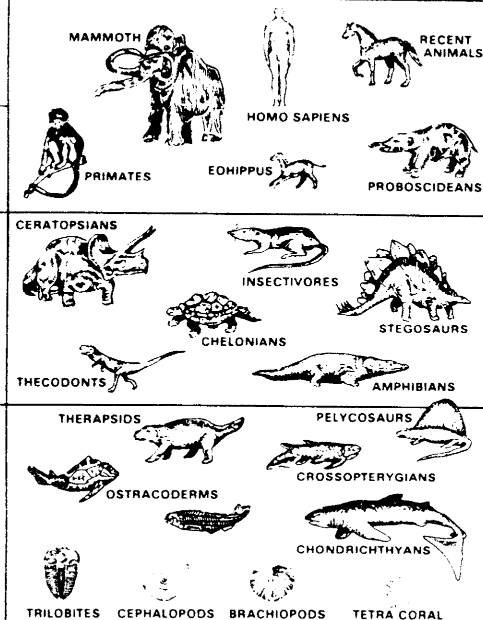
TABLE 2.2-1

GLOSSARY OF GEOLOGICAL TERMS

Active Layer Detachment Slide	A flow in which a thin unfrozen veneer of vegetation and mineral soil (the active layer) becomes detached and moves over a frozen planar inclined surface.
Alluvial	Pertaining to more or less stratified deposits of gravel, sand and silt moved by modern streams from higher to lower ground.
Argillite	A compact rock, generally of massive structure, derived from shale or lithified mud.
Colluvial	Pertaining to sediments deposited by any process of mass wasting or non-channelized flow on or at the base of steep slopes.
Conglomerate	A course grained, clastic sedimentary rock, comprising rounded to subangular fragments in a fine-grained matrix.
Cordilleran	Pertaining to, or originating in, the (Western) Cordillera.
Delta	A land form, generally triangular in shape, consisting of alluvial or glaciofluvial deposits.
Drumlin	An elongate or oval hill of glacial drift, commonly till, deposited by glacier ice and having its long axis parallel to the direction of ice movement.
Esker	A long, sinuous ridge of ice-contact sand and gravel, unrelated to the surrounding topography.
Glacial	Pertaining to, deposited by, or originating from a glacier.
Glaciofluvial	Pertaining to the meltwater streams flowing from glacier ice, and especially the deposits and landforms produced by such streams.
Glaciolacustrine	Pertaining to glacial lake conditions, as in glaciolacustrine deposits: sediments deposited in lakes marginal to a glacier.
Glaciomarine	Pertaining to glacial processes and deposition in a marine environment.
Ice, Aggradational	Additional newly formed or incorporated ground ice resulting from a raising of the permafrost table or lowering of its base.
Ice, Epigenetic	Ground ice that formed after the deposition of the earth material in which it occurs.
Ice, Ground	Ice in pores, cavities, voids or other openings in soil or rock, including massive ice.
Ice, Reticulate	Network of horizontal and vertical ice veins forming a three-dimensional rectangular or square latice, commonly found in frozen glaciolacustrine sediments.
Ice Vein	A seam or vein of ice occupying a crack that cuts across soil or rock layers.
Ice Wedge	A massive, generally wedge-shaped, body with its apex pointing downward, composed of foliated or layered vertically-oriented, ice.
Kame	A short irregular ridge, hill or mound of stratified drift deposited in contact with glacier ice by meltwater.
Lacustrine	Pertaining to, produced by, or formed in a lake; notably fine grained sediments deposited therein.
Laurentide	Pertaining to, or originating in, the Laurentian Shield.
Marine	Pertaining to, produced by, or formed in the sea; notably sediments deposited therein.
Moraine	An accumulation of earth materials carried by and finally deposited by a glacier.
Pediment	A plain of eroded bedrock, with or without a veneer of alluvial and colluvial material, developed between mountain and plain.
Permafrost	The thermal condition existing in soil or rock which remains at a temperature below 0° C for greater than one year.
Permafrost, Continuous	Permafrost occurring everywhere beneath the exposed ground surface throughout a geographic regional zone.
Permafrost, Discontinous	Permafrost occuring in some areas beneath the ground surface throughout a geographic regional zone where other areas are free of permafrost.
Physiographic	Pertaining to the study of the genesis and evolution of land forms.
Pingo	A conical mound or hill, occurring in the continuous and discontinuous permafrost zones, which has a cone of massive ground ice and exists for at least two winters.
Preglacial	Pertaining to, or occurring before a time of extensive glaciation.
Retrogressive-Thaw Flow Slide	A slide consisting of a steep head wall, which retreats in a retrogressive fashion through melting of ground ice, and a debris flow which slides down the head wall to its base.
Solifluction	The process of slow, gravitational, downslope movement, of saturated, non-frozen, earth material behaving as a viscous mass over a surface of frozen material.
Stratigraphy	The branch of geology that deals with the definition and description of major and minor natural divisions of rocks.
Talik	A layer or body of unfrozen ground within the permafrost.
Thermokarst (Topography)	The irregular topography resulting from the process of differential thaw settlement or caving due to melting of ground ice.

TABLE 2.2-2
GEOLOGICAL TIME SCALE

ERAS	PERIODS	EPOCH	MILLIONS OF YEARS AGO (APPROX.)	EARLIEST RECORD OF ANIMALS	EARLIEST RECORD OF PLANTS
CENOZOIC	QUATERNARY	RECENT PLEISTOCENE	0-1	MAMMOTH, HOMO SAPIENS, RECENT ANIMALS	
	TERTIARY	PLIOCENE MIOCENE OLIGOCENE EOCENE PALEOCENE	1-13 13-25 25-76 36-58 58-63	PRIMATES, EOHIPPUS, PROBOSCIDEANS	GRASSES AND CEREALS
MESOZOIC	CRETACEOUS		63-135	CERATOPSIANS, INSECTIVORES	FLOWERING PLANTS
	JURASSIC		135-181	CHELONIANS, STEGOSAURS	PINES AND CYPRUS
	TRIASSIC		181-230	THECODONTS, AMPHIBIANS	CYCADS AND GINKGOES
PALEOZOIC	PERMIAN		230-280	THERAPSIDS, PELYCOSAURS	
	PENNSYLVANIAN		280-310		CONIFERS
	MISSISSIPPIAN		310-345	CROSSOPTERYGIANS, OSTRACODERMS	VASCULAR PLANTS
	DEVONIAN		345-405		
	SILURIAN		405-425	CHONDRICHTHYANS	MOSSES SPORES GYMNOSPERMS
	ORDOVICIAN		425-500		
	CAMBRIAN		500-600	TRILOBITES CEPHALOPODS BRACHIOPODS TETRA CORAL	
PROTEROZOIC	PRECAMBRIAN			INVERTEBRATES FOSSILIZED REMAINS ONLY, WORMS, JELLYFISH, ALGAE	BACTERIA & ALGAE



and British mountains impinge into the southern part of the Yukon Coastal Plain physiographic division. Hughes (1972) reported that these areas were not glaciated and therefore colluvium is the most extensive surficial deposit. In areas of steeper terrain, the colluvial layer is generally shallow and discontinuous, but elsewhere may be up to 6 m thick (Rampton, 1974). The colluvium generally consists of fine-grained weathered bedrock debris. Alluvial floodplain and terrace deposits are associated with most of the streams which cross the Coastal Plain. Sand and gravel, occasionally with a veneer of fine-grained material, are the dominant materials in such areas.

2.2.1.4 Glacial History

The glacial history of the Yukon Coastal Plain and vicinity has been described by Hughes (1972) and Rampton (in press). The area was invaded twice by ice sheets moving toward the north and northwest. The first ice sheet was initially believed to be early or pre-Wisconsin age, but not dated as late Wisconsinan (Hughes et al., 1981), and at its maximum extent reached an elevation of about 900 metres along the eastern edge of the Richardson Mountains. It also covered the Yukon Coastal Plain northwest as far as the Firth River and Herschel Island (Hughes, 1972). The second ice sheet, now believed to be related to a late Wisconsinan still-stand or re-advance (Hughes et al., 1981), was less extensive and reached its limit at an elevation of only 90 m above sea level along the east side of the Richardson Mountains. This more recent ice sheet only extended onto the Coastal Plain for a short distance and as far west as King Point (Hughes, 1972).

2.2.1.5 Permafrost and Ground Ice

The Yukon Coastal Plain is located within the continuous permafrost zone (Brown, 1967). Permafrost is present throughout the region with talik zones occurring beneath the major river channels. There are no published data on permafrost thicknesses, although conditions similar to those encountered on Richards Island to the east may be anticipated (Judge et al, 1981). In the latter region frozen ground thicknesses are about 500 to 600 metres. Perennially frozen ground is also present beneath the adjacent Beaufort Sea (Mackay, 1972). Permafrost characteristics

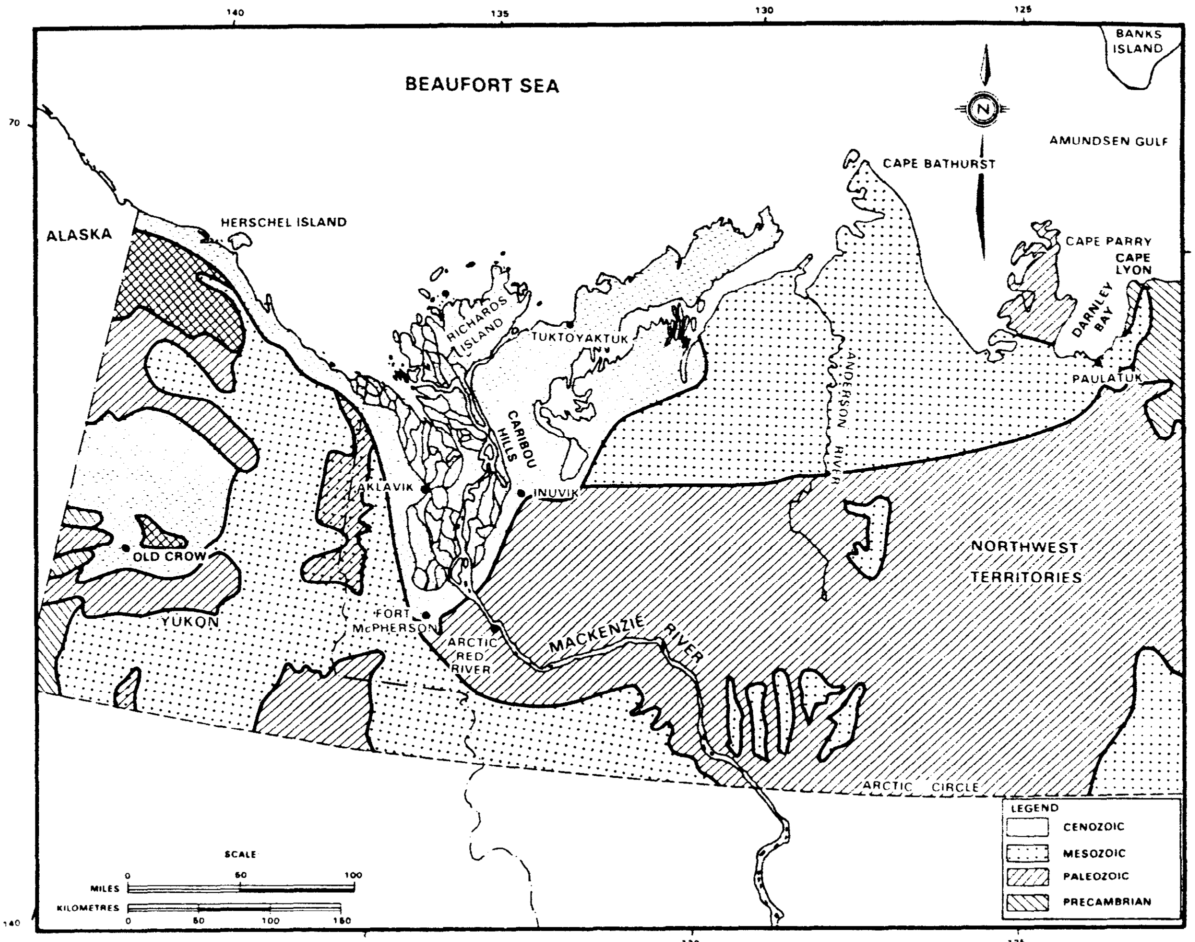


FIGURE 2.2-2 *Bedrock geology of the Beaufort onshore area. Recent bedrock (cenozoic) underlies most of the coastal region except toward the east where mesozoic and paleozic aged bedrock occurs.*

and the surficial geology of the Beaufort Sea are discussed in Section 1.4.

The permafrost and associated ground ice in some sections of the Yukon Coastal Plain are more than 40,000 years old (Mackay et al., 1972). In the glaciated eastern part of the region the preglacial sediments and associated ground ice have been glacially deformed (Mackay et al., 1972). Ground ice types and their distribution are described in detail by Rampton (1975). Ice wedges and segregated ice, both epigenetic and aggradational, are the most widespread and dominant ground ice features within the Coastal Plain. They commonly occur in all types of surficial material and may represent 20 to 50% of the excess ice volume (Rampton, 1974). Massive ice has not commonly been found in the coarser grained sediments. High excess ice content is characteristic of the fine-grained sediments underlying the pediments and of the colluvial deposits in the mountain and foothills areas (Rampton, 1974).

2.2.1.6 Terrain Stability and Sensitivity

Rampton (1975) reports that "much of the topography of the Yukon Coastal Plain ... and adjacent areas, where the unconsolidated sediments are thick, results in part from the formation and melting of segregated ice in the form of numerous ice lenses and massive ice." Generally, two types of stratigraphy and ground ice distribution are most susceptible to thermokarst subsidence: related erosion on slopes, and resultant instability. Poorly drained, fine-grained and organically-rich sediments characteristically have very high ice contents and may exhibit widespread and extensive subsidence. Active-layer detachment slides and retrogressive-thaw flow slides also commonly occur in these areas. Coarse-grained materials (sands and gravel) are the least susceptible to thermokarst subsidence and slope stability problems, except where massive excess ice is present, for example at the upper interface with finer sediments.

2.2.2 MACKENZIE DELTA

The coastal Beaufort region includes the entire Mackenzie Delta, both modern and Pleistocene (Mackay, 1963). Only the modern alluvial Delta is described here (Figure 2.2-1); the Pleistocene delta

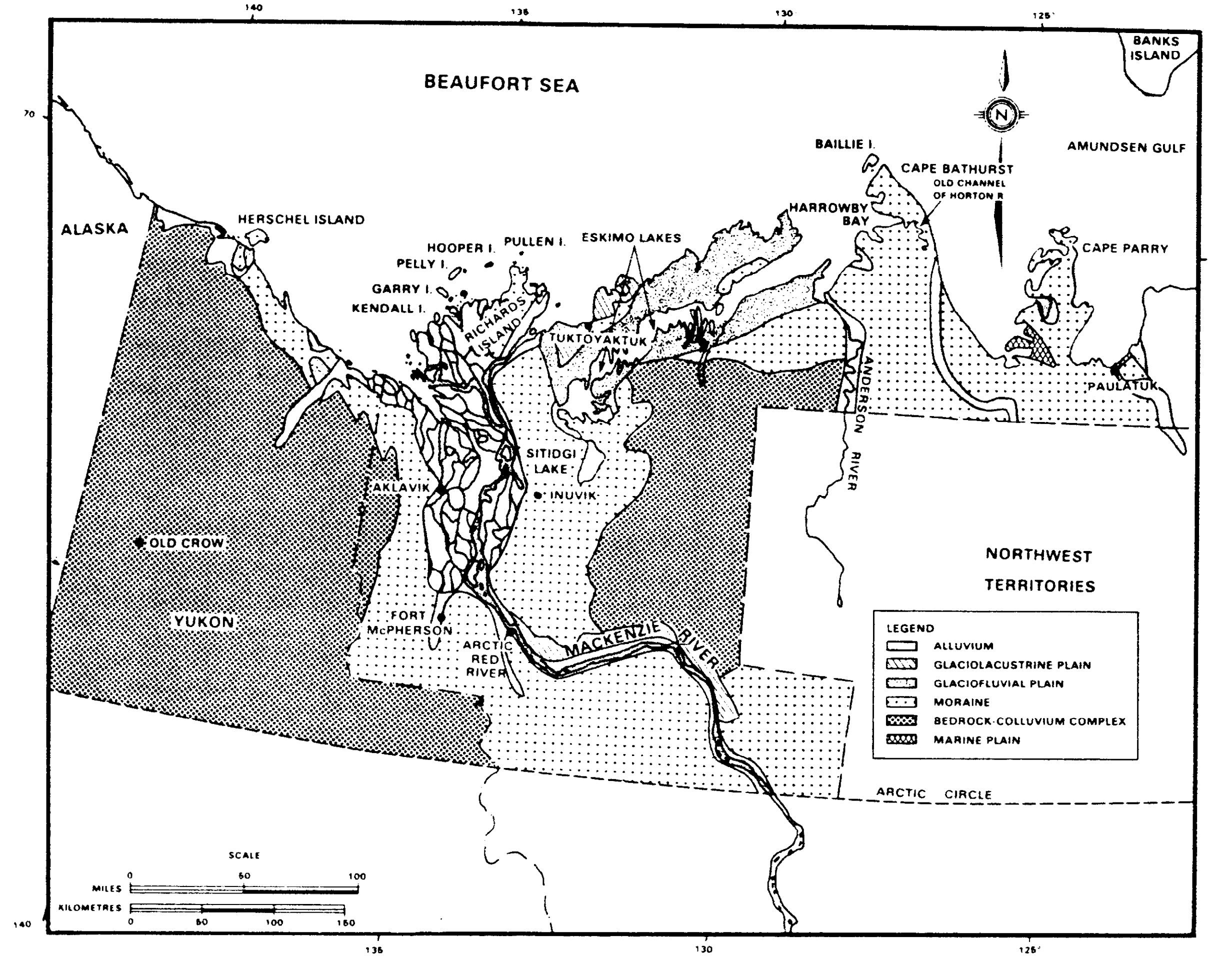


FIGURE 2.2-3 *Surficial geology of the Beaufort Sea coastal area (after: Hughes et al., 1973; Rutter et al., 1973, and Zoltai et al., 1979). Dominant deposits of the modern Mackenzie Delta are deltaic and alluvial silts and fine sands, frequently with a high organic content.*

forms part of the Pleistocene Coastal Plain and is discussed in Section 2.2.3. The geology of the Mackenzie Delta is also described in Volume 3C. The published and unpublished literature on the geology and terrain of the Mackenzie Delta is extensive. Prime sources of information are Mackay (1963) Fyles et al. (1972), and Rampton (1979a, b).

2.2.2.1 Topography and Relief

The topography of the modern Delta is level to depressional, and is characterized by numerous lakes. Its morphological features are described in detail by Mackay (1963). Elevations range from sea level along the northern edge of the Delta to 10 to 15 m above sea level in the vicinity of Fort McPherson and Arctic Red River (along its southern boundary). Slopes throughout the region are usually 10° or less, although they may be steeper in areas with eroding slopes.

2.2.2.2 Bedrock Geology

Bedrock in the Delta area, which is composed primarily of shales and sandstones of Tertiary age, is masked by a thick sequence of more recent, nonmarine sediments (Douglas, 1969). The depth to bedrock ranges from 70 m to greater than 150 m, with bedrock buried deeper towards the north (Johnston and Brown, 1965) (Figure 2.2-2).

2.2.2.3 Surficial Geology

Deltaic and alluvial silts and fine sands, frequently with a high organic content, are the dominant deposits of the modern Mackenzie Delta (Figure 2.2-3). In terrain depressions these materials are overlain by organic bog deposits, as well as organic-rich postglacial lacustrine silts and clays. Alluvial floodplain deposits and occasional terraces are characteristic of the major Mackenzie River channels.

Few data are available on the subsurface stratigraphy of the Delta despite the active hydrocarbon exploration which has taken place in some areas. Johnston and Brown (1965) report that a borehole near Inuvik intersected nearly 70 m of surficial material over bedrock, and this material consisted of 54 m of organic deltaic silt and sand, overlying 8 m of dense, silty, glaciomarine clay, and 7 m of pebbly clay. In another borehole near the seaward edge of the Delta more than 150 m of surficial material was encountered (Johnston and Brown, 1965).

2.2.2.4 Glacial History

Evidence of at least two glaciations of the Mackenzie Delta area exists in the form of "glacial limits" preserved along the eastern flank of the Richardson Mountains (Hughes, 1972). To the west of Aklavik a limit, now believed to be related to a minor readvance or still-stand is located at an elevation of about 90 m above sea level, while the limit of the Laurentide maximum occurs at about 900 m above sea level (Hughes et al., 1981). The direction of movement of both ice sheets was apparently to the north and northwest, parallel to the east edge of the Richardson Mountains (Mackay, 1963; Prest, 1970).

2.2.2.5 Permafrost and Ground Ice

The Permafrost Map of Canada (Brown, 1967) indicates that the modern Mackenzie Delta is located within the continuous permafrost zone. However, the area may more accurately be considered as an outlier of the discontinuous zone (Smith and Hwang, 1973). Due largely to the thermal influence of the numerous waterbodies within the Delta, the distribution of permafrost is physically discontinuous and is frequently absent beneath the larger river channels and lakes (Johnston and Brown, 1964). Permafrost thicknesses range from about 60 m in the "older" parts of the modern Delta to less than 20 m where frozen ground is actively aggrading in the vicinity of existing channels (Judge, 1973).

The distribution of ground ice in the modern deltaic silts and sand is variable. Although the coarser sediments may have a relatively low ice content, the silts, particularly where they have a high organic content, are ice-rich. Reticulate ice veins and wedges are the dominant ground ice types. The distribution of ground ice and its influence on topography are discussed in some detail by Rampton (1975). Pingos are present in some areas within the modern Delta, such as Ellis Island (Mackay, 1962; 1963); however, they are less numerous than within the Pleistocene Coastal Plain to the east (Plate 2.2-1).

2.2.2.6 Terrain Stability and Sensitivity

Local areas of instability, including thermokarst subsidence, slumps, solifluction and flow slides, occur throughout the modern Mackenzie Delta. Such areas occur frequently near channels and lakes, and are generally related to thermal erosion of ice-rich deltaic and lacustrine materials.

2.2.3 PLEISTOCENE COASTAL PLAIN - ANDERSON PLAIN

The region referred to as the Pleistocene Coastal Plain-Anderson Plain extends east from the edge of the modern Mackenzie Delta about 200 km to Cape Lyon north of the Horton plain, and inland from the Beaufort Sea coast about 60 to 70 km. It encompasses the Pleistocene Coastal Plain (which includes the Pleistocene Delta and Tuktoyaktuk Peninsula), the Caribou Hills and parts of the Anderson and Horton plains (Figure 2.2-1). The studies of Mackay (1963), Fyles et al. (1972) and Rampton (1974) are the main sources of geological information for this area. All three publications address geological conditions west of Cape Bathurst only. Published information on the geology of the extreme eastern section is sparse.

2.2.3.1 Topography and Relief

The physiography of the Pleistocene Coastal Plain-Anderson Plain region is highly variable. Elevations range from sea level along the Beaufort Sea and Amundsen Gulf coastlines to about 215 m above sea level in the Caribou Hills. Relief on Richards Island exceeds 100 m in some areas. Slopes throughout the region range from less than 5° on the Coastal Plain where terrain is unaffected by thermokarst processes, to greater than 30° in some sections of the steep scarp along the western edge of the Caribou Hills, adjacent to the Mackenzie Delta.

2.2.3.2 Bedrock Geology

The bedrock geology of the Pleistocene Coastal Plain-Anderson Plain region is shown in Figure 2.2-2 (Douglas, 1969). Sandstones and shales of Tertiary to Quaternary origin underlie most of the Coastal Plain, including the Tuktoyaktuk Peninsula and Richards Island. These strata are overlain by a thick, approximately 60 m, layer of more recent deposits. In the Caribou Hills, Tertiary sediments which are comprised of sands and gravels, are exposed at the surface or are located beneath a shallow veneer of colluvium or glacial deposits (Fyles et al., 1972). Upper Cretaceous shales are also exposed in the southern part of the Caribou Hills (Douglas, 1969).

Considerably older bedrock strata are present in two areas of the Anderson and Horton Plain physiographic regions (Douglas, 1969). At Cape Lyon and along the east side of Darnley Bay sandstones and carbonates of Neohelikian (Precambrian) age are the uppermost bedrock strata. Ordovician-Silurian carbonates underlie most of the Parry Peninsula (Douglas, 1969).

PLATE 2.2-1 *Pingos are present in some areas of the Mackenzie Delta and are particularly common and large near Tuktoyaktuk and along the peninsula (Courtesy, Hardy and Assoc.)*

2.2.3.3 Surficial Geology

(a) Pleistocene Coastal Plain

This physiographic division corresponds to the "Pleistocene Coast Lands" described by Mackay (1963), and encompasses Richards Island, the Tuktoyaktuk Peninsula and the offshore islands (including Garry, Pelly, Kendall, Pullen). Silts and sands of the Pleistocene Delta occur throughout this region, either at the surface or beneath more recent deposits. The deltaic sediments are generally greater than 30 m thick, and have been folded and faulted by glacial ice thrusting (Mackay et al., 1972). They are overlain by surficial deposits of both glacial and postglacial origin.

Hummocky moraine is the most extensive deposit of glacial origin within the Pleistocene Coastal Plain, although its composition may range from a practically stone-free clay to a gravel with very few fines (Rampton, 1975). The moraine stratum also varies in thickness. Where fine grain deposits predominate it is susceptible to thermokarst subsidence. These thermokarst depressions are generally filled with postglacial lacustrine and organic deposits.

Glaciofluvial outwash sediments, predominantly interbedded sands and gravels, are less widely distributed in the Pleistocene Coastal Plain, but are prevalent on the Tuktoyaktuk Peninsula and near Parsons and Eskimo lakes. In some areas, the outwash deposits are highly susceptible to thermokarst processes. Where massive amounts of ice occur at the boundary of the coarse outwash and more recent fine-grained deposits, subsidence has played a dominant role in the formation of the hummocky topography (Rampton, 1975). Eskers and kames are common in some areas of Richards Island, such as in the Ya-Ya esker complex.

Silts, clays and, to a lesser extent, fine sands of glaciolacustrine origin occur in the vicinity of the larger lakes (such as Eskimo, Parsons and Sitidgi), while postglacial deposits of lacustrine, alluvial, colluvial and organic origin are distributed throughout the Pleistocene Coastal Plain. Lacustrine silts and clays which frequently have a high organic content, as well as shallow organic bogs and fens, are present in most terrain depressions. Alluvial floodplain and terrace deposits are found in the major river and creek valleys. Colluvial slopewash is present on most slopes.

(b) Caribou Hills

Poorly consolidated Tertiary bedrock (sand and gravel, with some lignite) and Upper Cretaceous shales occur close to the surface throughout this physiographic division (Douglas, 1969). In most areas the bedrock is veneered by colluvial slopewash. Moraine (till) and glaciofluvial outwash deposits may be present locally, but are thin and not extensive (Fyles et al., 1972).

(c) Anderson Plain

The western part of the Anderson Plain, as far east as the Mason River, has been glaciated (Rampton, 1974), but in contrast to the Coastal Plain, glacial and overlying postglacial deposits are relatively thin. The transition between thick and thin overburden, in fact, constitutes the southern edge of the Anderson Plain. As a result, the Cretaceous shales which underlie the region are frequently exposed by river erosion. Fluted moraines are the most widespread surficial deposits in the western part of the Anderson Plain, although small lacustrine infilled depressions and isolated glaciofluvial outwash deposits are also occasionally present.

The peninsula south of Cape Bathurst in the eastern section of the Anderson Plain was not glaciated (Prest et al., 1968; Fyles et al., 1972). According to Rampton (1974), three types of terrain are dominant. The southern part, located south of the old channel of the Horton River, consists essentially of colluvium-veneered bedrock, while much of the northern section is a marine plain. The latter extends from north of Harrowby Bay to Baillie Island, and is underlain by brownish fine sand up to 12 m thick (Rampton, 1974). This sand is possibly a reworked marine deposit, and is underlain by interbedded sand and silt, marine clay and gravel. Glaciofluvial outwash terraces occur in the centre of the peninsula on either side of the Old Horton Channel.

The surficial geology of the extreme eastern section of the Anderson Plain is not well documented. According to Prest et al. (1968), this area has been glaciated and resembles the better documented western section of the physiographic division. Fluted moraine is the dominant landform, but isolated areas of outwash also occur. In addition, hummocky moraine underlays a significant portion of the Parry Peninsula (Prest et al., 1968).

(d) Horton Plain

The geology of this small area in the extreme eastern part of the onshore Beaufort region is relatively unknown. Fluted and drumlinoid moraines are the dominant landforms and depths to bedrock are generally shallow (Prest et al., 1968). A large alluvial fan is located at the mouth of the Brock River.

2.2.3.4 Glacial History

The Pleistocene Coastal Plain-Anderson Plain region and adjacent areas have a relatively complex glacial history. Existing evidence indicates that much of Richards Island, the northern part of the Tuktoyaktuk Peninsula, and the peninsula south of Cape Bathurst were not overridden by ice during the "classical" Wisconsin glaciation (Mackay et al., 1972). The remainder of the region was glaciated at least twice. On both occasions, Laurentide ice moved northward down the Mackenzie River Valley and spread out across the Coastal Plain. Tentative ice marginal limits are shown by Prest (1970) and Fyles et al. (1972). Ice flow directions in most of the region are apparent from patterns of drumlinoid ridges and flutings (Prest et al., 1968).

2.2.3.5 Permafrost and Ground Ice

The entire Pleistocene Coastal Plain-Anderson Plain region and vicinity are located within the continuous permafrost zone (Brown, 1967). With the exception of the major rivers and lakes, which may be underlain by talik zones, there are very few "windows" through the permafrost. The entire region is underlain by perennially frozen ground. Permafrost thickness ranges from about 650 m on Richards Island (Judge et al., 1981) to 140 m on the peninsula south of Cape Bathurst, and is approximately 100 m on the Anderson Plain (Taylor and Judge, 1974).

The distribution and influence of ground ice on present-day topography is described in detail by Rampton and Mackay (1971) and Rampton (1975). Ice wedges and vein ice occur within many fine-grained and organically-rich deposits such as in recent lake sediments. On the other hand, massive ice is most prevalent in areas underlain by coarser deposits, particularly where fine deposits overlie coarse granulated materials (Rampton, 1974). All types of ground ice and pingos are extensively developed within the Pleistocene Coastal Plain (Mackay, 1962; 1963), and thermokarst subsidence is the single most important factor influencing the topography.

The same general relationships between material type and ground ice occurrence, are found in the remainder of this portion of the onshore Beaufort area; namely, the Caribou Hills, Anderson Plain, and Horton Plain, except where coarse-grained outwash deposits occur. Massive ice is generally most common in areas where coarse-grained outwash deposits occur (Rampton, 1974).

2.2.3.6 Terrain Stability and Sensitivity

The relationships between landform, material type and segregated ground ice in the Pleistocene Coastal Plain-Anderson Plain region are generally the same as those previously described for the Yukon Coastal Plain (Section 2.2.1.6). Much of the topography in this region is the result of extensive wedge and vein ice melting in areas with poorly drained organically-rich deposits, or results from the melting of massive ice which underlies areas of coarse outwash. Active layer detachment and retrogressive-thaw flow slides are prevalent on the slopes in these areas. Both are induced by thermal erosion. These processes are usually less influential in areas with thinner surficial deposits. However, areas with ice-rich moraine and recent lacustrine sediments have also been affected by active layer detachment and retrogressive thaw flow slides following disturbance of the terrain.

2.2.4 SEISMICITY

Canada is divided into four seismic zones (Zones 0, 1, 2, 3), with Zone 0 being the least active and Zone 3 being the most active (National Building Code of Canada, 1980) (Figure 2.2-4). The parameter used to establish these seismic zones in "A_{100}", which is the

TABLE 2.2-3
DEFINITION OF SEISMIC ZONES

Seismic Zone	Range of Ratio of Horizontal Ground Acceleration to the Acceleration Due to Gravity		Acceleration Ratio A_{100}
0	Less than	0.01	0.00
1	Equal to or greater than	0.01	0.02
	to less than	0.03	
2	Equal to or greater than	0.03	0.04
	to less than	0.06	
3	Equal to or greater than	0.06	0.08

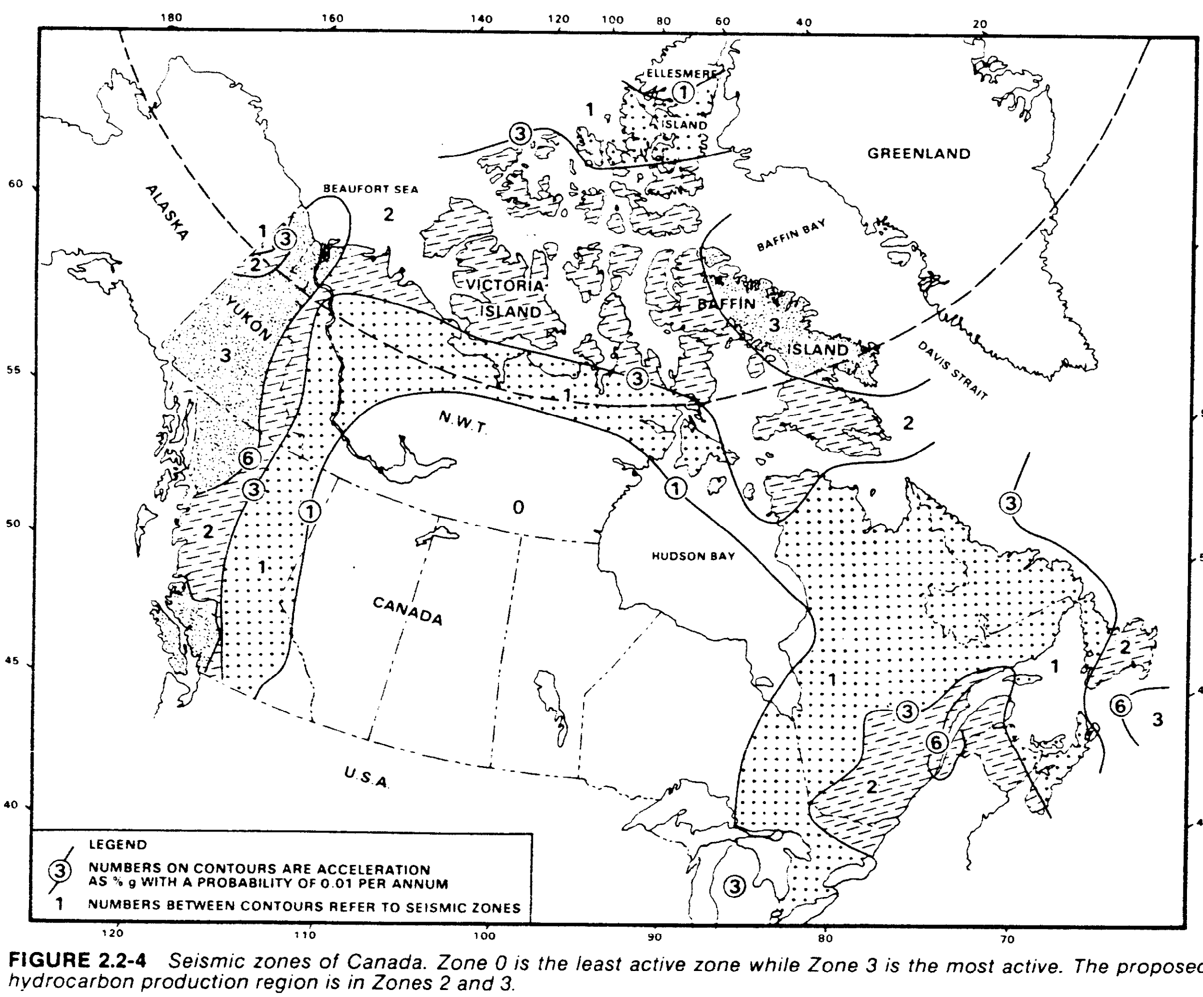


FIGURE 2.2-4 *Seismic zones of Canada. Zone 0 is the least active zone while Zone 3 is the most active. The proposed hydrocarbon production region is in Zones 2 and 3.*

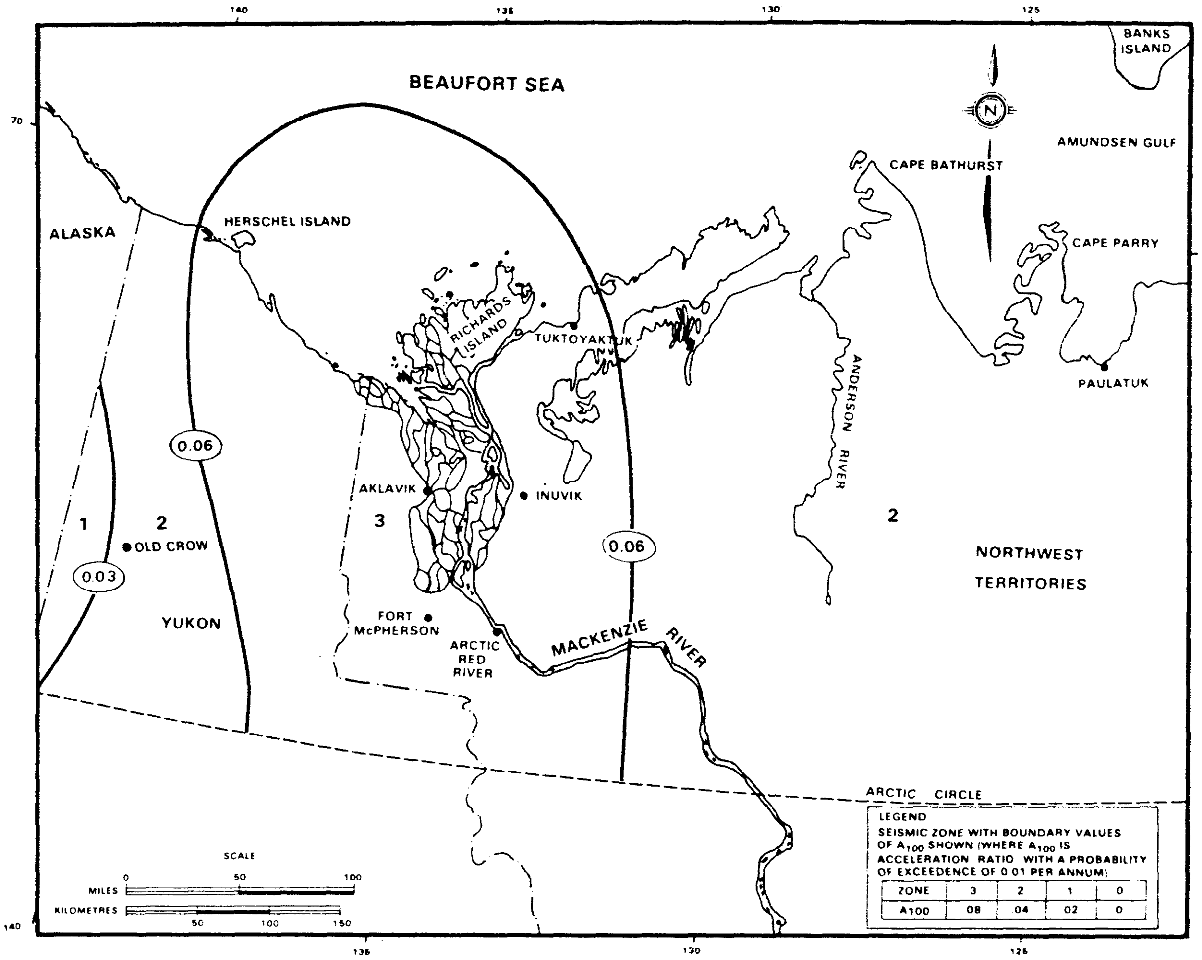


FIGURE 2.2-5 *Seismic zones of the Beaufort onshore region (Source. National Building Code of Canada, 1980). The values of A_{100} bordering the seismic zones show ground accelerations, as a fraction of the acceleration due to gravity, which have an annual probability of 1 in 100 of being equalled or exceeded.*

ratio of the ground acceleration to the acceleration due to gravity that has an annual probability of 1 in 100 of being equaled or exceeded. The zones are based on statistical analyses of earthquakes which have occurred throughout the country over the period 1899 to 1970. Table 2.2-3 provides additional information on zonal definitions.

The Beaufort Sea region lies within seismic Zones 2 and 3 (Figure 2.2-5). Historical earthquake data and the pattern and intensity of earthquakes in the region have been reviewed by Basham et al. (1977), Wetmiller and Forsyth (1978), Hasegawa et al. (1979) and Yorath and Norris (1975), while Stevens and Milne (1974) have discussed seismic risk in relation to pipeline corridors in adjacent areas of northwestern Canada and eastern Alaska (Figure 2.2-6).

Although tectonic forces characteristic of plate margins are not present in the Beaufort Sea or Mackenzie Valley, there has been considerable shallow seismicity noted in these areas. The occurence of numerous small magnitude, shallow-focus seismic events throughout the area suggests that deformation features from earlier periods are still reacting to present geological stresses (Hasegawa et al., 1979).

A strain release map based on earthquake data from 1899 to 1970 has been prepared by Stevens and Milne (1974) (Figure 2.2-7). The map indicates that release of strain has been highest in central Alaska and to a lesser extent, in the Richardson and Mackenzie mountains. There is less strain release indicated for the Beaufort Sea region. However, the authors caution that detailed and accurate seismic risk calculation is difficult because of the short history of reliable seismic data acquisition.

Four areas generate or have the potential to generate earthquakes in the Beaufort Sea coastal region. They are the Beaufort Sea Seismicity Cluster, the Eskimo Lakes Fault Zone, the Rapid Fault Array/Kaltag Fault, and the Martin Point seismicity Cluster (Yorath and Norris, 1975; Hasegawa et al., 1979). These are described in Section 1.4.8 of this volume.

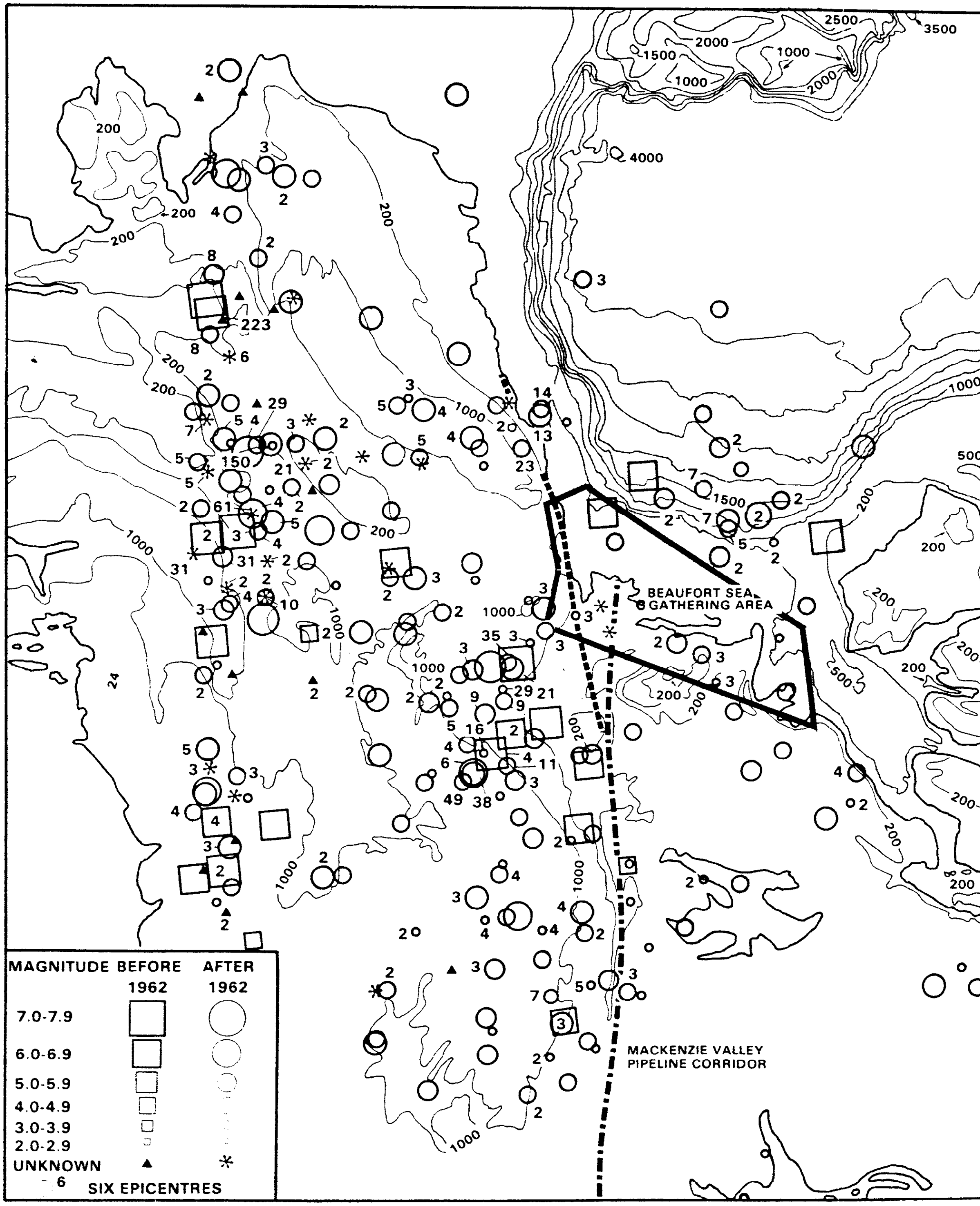


FIGURE 2.2-6 *Centres of known seismicity in the western Arctic (from Wetmiller and Forsyth, 1978; Hasegawa et al., 1979). The occurrence of numerous small magnitude, shallow focus seismic events suggests that deformation features from earlier periods are still reacting to present geological stresses.*

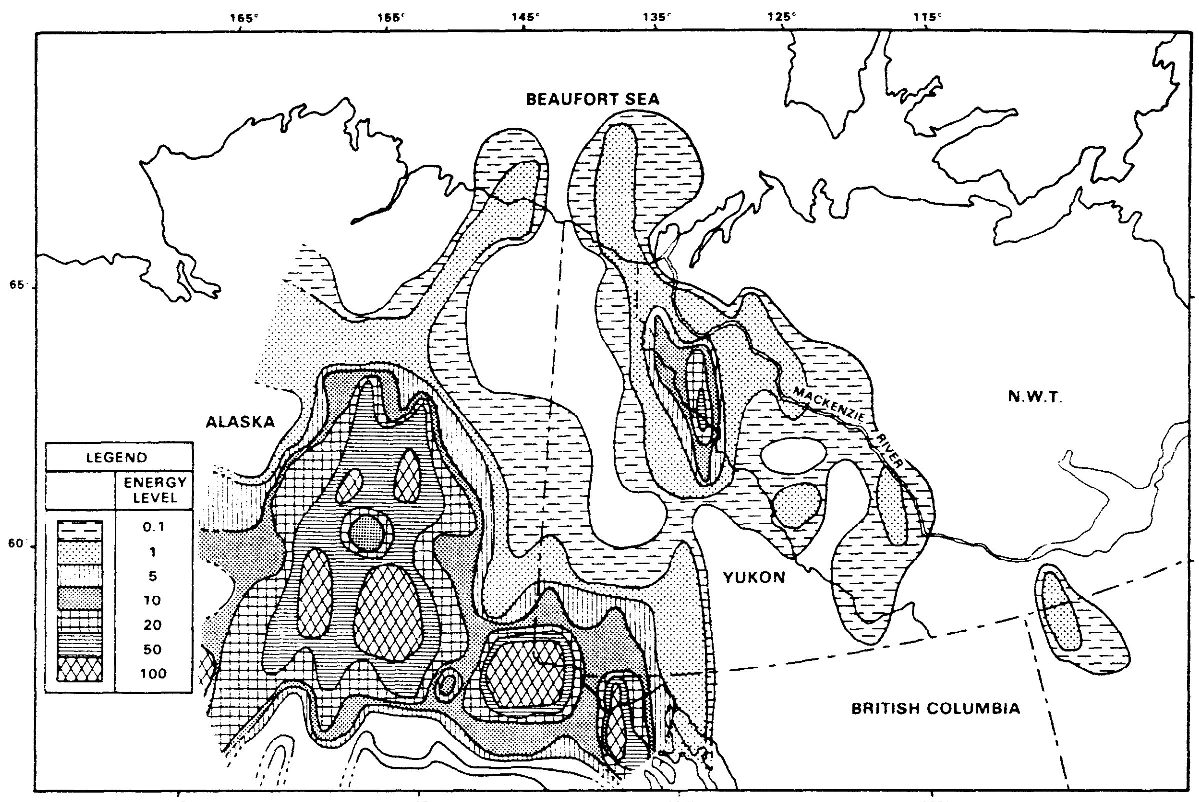


FIGURE 2.2-7 *Strain release map for the Yukon and adjacent areas of Alaska and the Northwest Territories, 1899-1970. This map indicates that release of strain has been highest in central Alaska and in the Richardson and Mackenzie Mountains west of the Mackenzie River. Less strain release is indicated for the Beaufort Sea region. (Source: Stevens and Milne, 1973).*

2.3 SOILS

This section describes the soils of the Arctic Coastal Plain which generally includes the Yukon Coastal Plain and the northern slope of the British and Richardson mountains, the modern Mackenzie Delta, and the Tuktoyaktuk Peninsula-Anderson Plain (Figure 2.3-1). Soils of the Beaufort Sea coastal region have been described by a large number of authors including Day and Rice (1964), Lambert (1968), Gill (1971), Hettinger et al. (1973), Tarnocai (1973), Janz (1974), Pettapiece and Zoltai (1974), Slaney (1974), Zoltai and Tarnocai (1974), Tarnocai and Zoltai (1978), Zoltai et al. (1979), Hardy Associates (1981), Cordes (in prep), Olsen et al. (in prep) and Tarnocai and Veldhuis (in prep).

The soil terminology and classification system used in this discussion are based on the system developed by the Canada Soil Survey Committee (1978). A list of common terms and their definitions is presented in Table 2.3-1.

Continuous permafrost exists in this region; nearly all its medium and fine textured soils have permafrost within 1 m of the surface and they are strongly cryoturbated. Cryosolic soils with near-surface permafrost are the dominant soils. They occur on most mineral and organic terrain, but may be absent from rapidly drained sites. Landform-soil-drainage relationships are summarized in Table 2.3-2, while more detailed soil descriptions are provided in Esso Resources (1982).

The major processes influencing soil development are cryoturbation and gleyzation resulting from near-surface permafrost. This is in marked contrast to how soils are normally formed in the freely drained soils of southern latitudes. In the north, coarse textured, freely drained soils do exhibit normal, though weakly expressed, processes of surface eluviation and subsurface accumulation. However, in fine textured soils with permafrost and impeded drainage, cryoturbation is the dominant soil development process.

Earth hummock-patterned ground features are the main surface indicators of permafrost related processes. Zoltai and Tarnocai (1974) have estimated that 90% of this northern region is covered by patterned ground features such as earth hummocks, circles, stripes and steps caused by cryopedological processes. Earth hummocks occur predominantly in association with fine textured till materials, while other patterned ground features such as polygons are associated with glaciofluvial deposits (Plate 2.3-1).

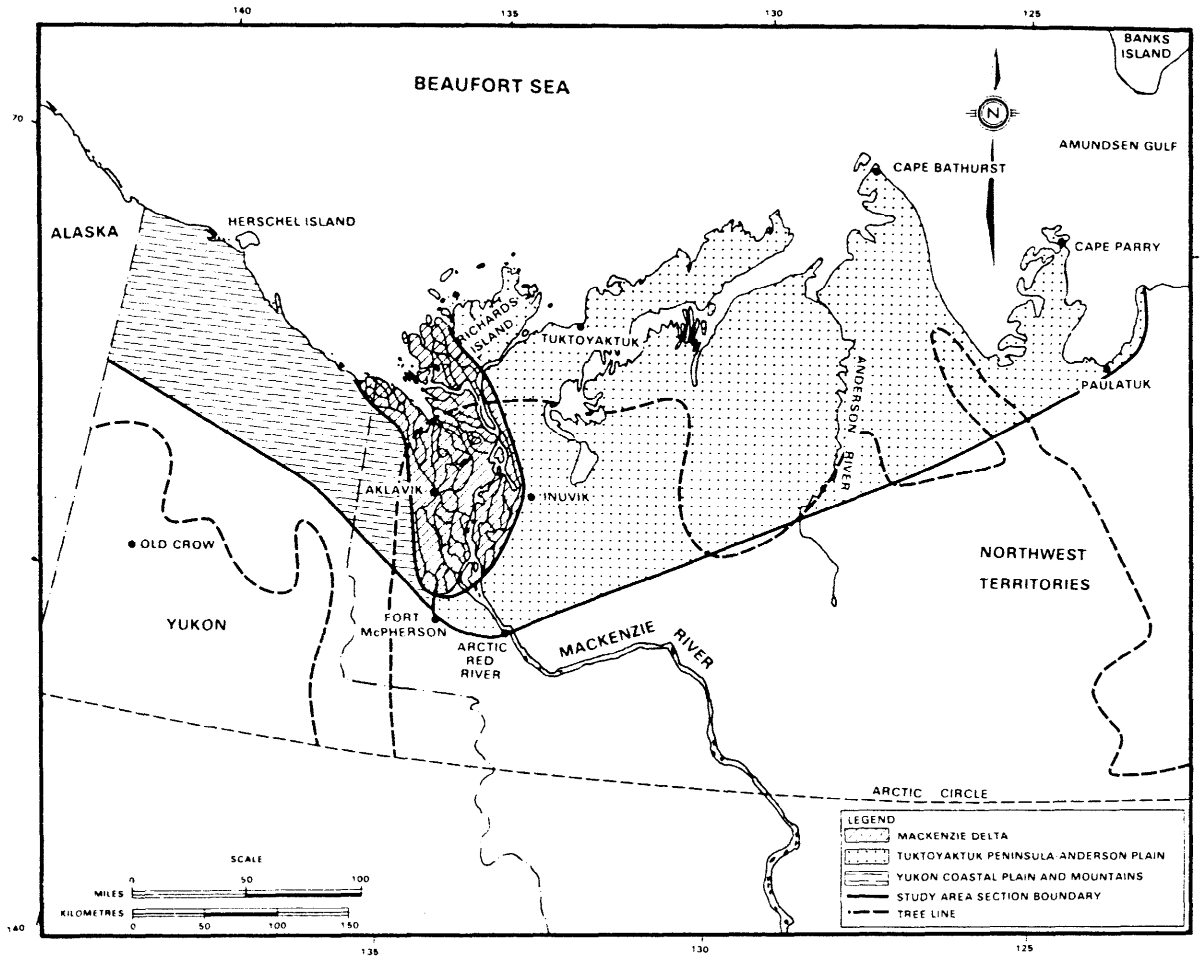


FIGURE 2.3-1 *Location map of the Beaufort Sea coastal region*

PLATE 2.3-1 *Polygonal features caused by permafrost related processes. This is typical of low-lying areas along the Tuktoyaktuk peninsula. (Photo courtesy, Hardy and Assoc.)*

TABLE 2.3-1 DEFINITION OF COMMON SOIL TERMS

BRUNISOL	Refers to soils which have developed under the influence of forest, alpine or tundra vegetation in a cool moist climate. Their common characteristic is a brownish mineral horizon near the surface which has developed in response to weak weathering processes. Soils classified as Eutric Brunisols usually occur on basic (or calcareous) parent materials while Dystric Brunisols usually occur on acidic parent materials.
COLLUVIUM	A hetergeneous mixture of material that has moved down a slope under the influence of gravity.
CRYOSOL	Refers to mineral and organic soils where permafrost remains close to the surface (within 1 or 2 m). An Organic Cryosol is composed of 30 percent or more organic matter. A Turbic Cryosol displays evidence of frost heave, while a Static Cryosol soil shows no evidence of frost heave.
CRYOTURBATION	Refers to the physical movement and disruption of the soil or active layer as a result of freezing and thawing processes in permafrost terrain.
ELUVIATION	The downward of lateral movement of soil material in soil water suspension or solution.
EOLIAN	Sand or silt or both deposited by wind.
FIBRIC	Refers to relatively undecomposed organic soils.
GLEYSOL	Refers to mineral soils which have features indicative of periodic or prolonged saturation with water. A Rego Gleysol lacks development horizons.
HUMIC	Refers to highly decomposed organic soils.
LUVISOL	Refers to mineral soils which display features indicative of moderate development and weathering. They generally have light colored horizons under the forest leaf-layers from which slicate clays have been removed through weathering processes and have moved downward and accumulated in a brownish-colored horizon.
MESIC	Refers to moderately decomposed organic soils.
ORTHIC	The normal or basic soil subgroup within a specific great group and soil order.
REGOSOL	Refers to mineral soils having little or no development. A Cumulic Regosol soil has layers that vary in color, texture, thickness, or organic matter that have resulted from intermittent deposition of waterborne materials.
THERMOKARST	Settling of the ground due to melting of ground ice.
TYPIC	Refers to the normal or basic soil subgroup within a specific great group.

Source: Canada Dept. of Agriculture (1976) and Canada Soil Survey Committee (1978).

TABLE 2.3-2
DOMINANT LANDFORMS AND ASSOCIATED SOIL TYPES OF THE BEAUFORT SEA COASTAL AREA.

Landform	Drainage	Soils
Moraine	Well to moderately well	Turbic Cryosols
	Imperfect to poor	Turbic Cryosols Static Cryosols
Lacustrine	Imperfect to poor	Static Cryosols Turbic Cryosols Organic Cryosols
Glaciofluvial	Rapid to well	Static Cryosols Regosols
	Moderately well to poor	Static Cryosols Turbic Cryosols
Alluvial	Well to moderately well	Cumulic Regosols Static Cryosols
	Imperfect to poor	Static Cryosols Turbic Cryosols
Colluvial-Bedrock	Well to moderately well	Static Cryosols Turbic Cryosols
	Imperfect to poor	Turbic Cryosols
Eolian	Rapid to well	Cumulic Regosols Static Cryosols

2.3.1 SOILS ON MINERAL PARENT MATERIALS

Over 90% of soils in this northern coastal region have developed on mineral parent materials. These materials are usually associated with reworked morainal landforms which occur on either side of the Mackenzie Delta. They also include glaciofluvial materials located mostly east of the Delta, alluvial materials of the Delta proper, colluvial and bedrock materials of the British and Richardson mountains and foothills, deposits of glacial and post-glacial lacustrine materials and minor amounts of eolian materials along the sea coast.

2.3.1.1 Morainal Deposits

Moraine deposits are the dominant surficial materials throughout this northern coastal region on either side of the Mackenzie Delta, and consist primarily of stony clays which have been reworked by thermokarst processes. They are exposed on the surface of uplands and slopes, but are overlain by post-glacial lacustrine and organic materials in most poorly drained thermokarst depressions (Rampton, 1974).

Stony clay upland and slope surfaces are subjected to cryoturbation, and are generally covered by earth hummocks. On level ground these hummocks are nearly circular in shape and range from 0.5 to 1 m in diameter, but on slopes they tend to be elongated. Hummock microrelief ranges from 10 to 50 cm, and hummock centre surfaces are often bare of vegetation. The development, age, morphology and movements of earth hummocks have been described in detail by Zoltai and Tarnocai (1974), Pettapiece (1974, 1975), Tarnocai and Zoltai (1978) and Mackay (1979).

The soils developed in this cryoturbated landscape are moderately well to poorly drained and are classified as Regosolic Turbic Cryosols, Orthic Turbic Cryosols, Brunisolic Turbic Cryosols and Gleysolic Turbic Cryosols. However, the predominant soils are the Orthic Turbic Cryosols (Esso Resources, 1982).

The dominant characteristics of soils associated with earth hummocks include high ice content, shallow active layers and disrupted horizons. High ice content is common in the subsoils of this region as discussed in Section 2.2. Active layer depths range from 10 cm in the interhummock depressions, to 70 cm in hummock centres. Soil horizons are usually broken and disrupted, and buried organic materials dated at 1,500 to 2,000 years old are distributed throughout the sides and lower parts of hummock cores (Pettapiece, 1974).

2.3.1.2 Glaciofluvial Deposits

Glaciofluvial deposits occur predominantly on the Tuktoyaktuk Peninsula, although some deposits are also scattered throughout the Yukon Coastal Plain. Most have been modified by thermokarst processes. The texture of glaciofluvial deposits is generally coarser than tills, consisting mainly of gravels and sands.

These deposits are not as susceptible to cryoturbation as till materials, and are mainly responsible for the production of a polygonal, instead of an earth hummock, dominated landscape. However, cryoturbation and resulting solifluction microtopography remain prevalent on slopes. Polygonal patterns occur

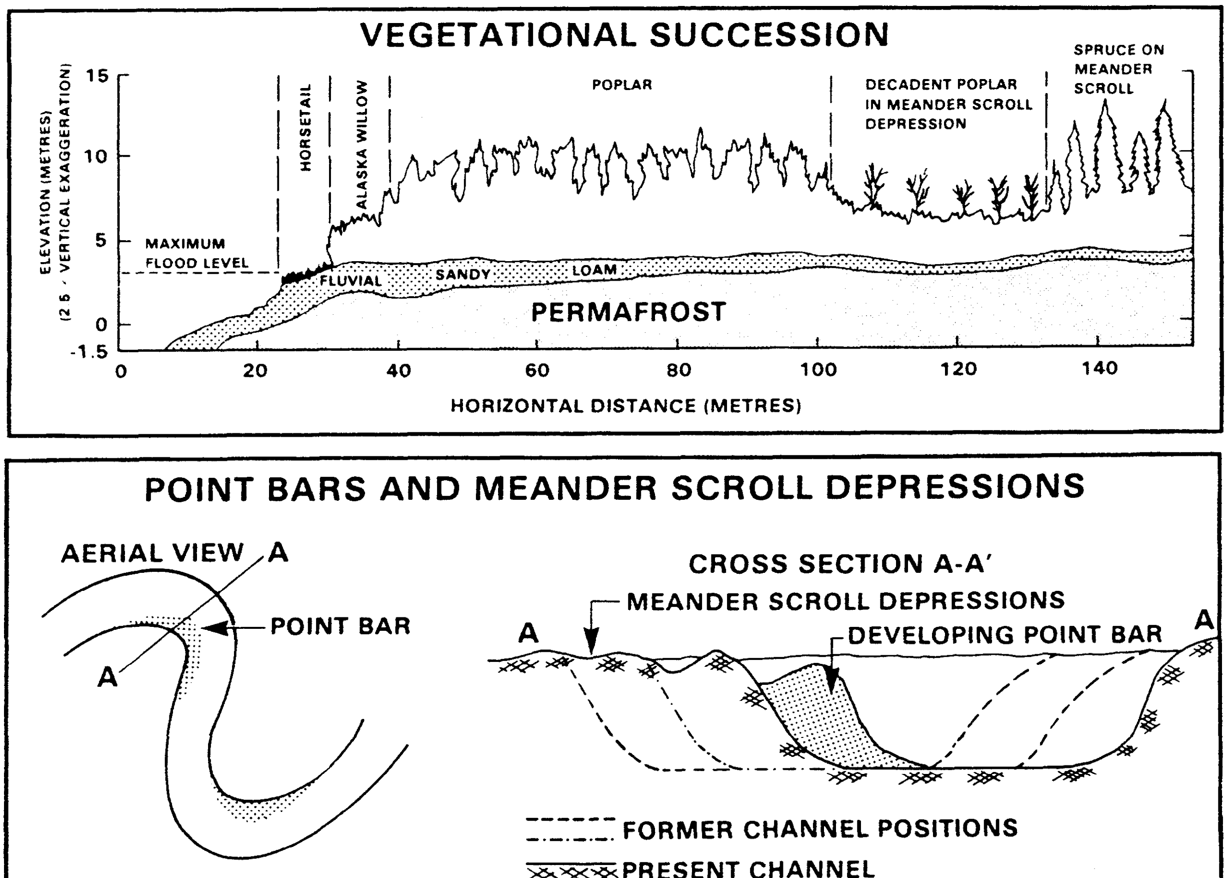


FIGURE 2.3-2 *Schematic illustration of a point bar, how they are formed and the relationship between soil depth, proximity to river channels and vegetational succession. (Source: Mackenzie River Basin Committee, 1981).*

primarily in flat, low-lying, poorly drained areas. Soils associated with these polygonal features are classified as dominantly Static Cryosols in polygon centres, and Turbic Cryosols at the polygon edges (Esso Resources, 1982).

2.3.1.3 Alluvial Deposits

The most extensive area of active alluvial deposition occurs in the lower Mackenzie River Delta which widens into many lakes and channels. Extensive alluvial fan deposits also occur at the mouths of many Arctic rivers and streams flowing across the Yukon Coastal Plain into the Beaufort Sea. Silt and sand are the main materials deposited by low energy streams and channels in the Mackenzie Delta. During years with high flood levels, such as in 1961, 1971 and 1972, up to 98% of the Delta has been covered with water (Mackay, 1963). As a result, most soils have not had sufficient time to develop, and are predominantly Cumulic Regosols which have numerous alternating layers of sand, silt and organic materials.

Studies by Hardy Associates (1981) show that point bar soils are mainly composed of thick layers of sand which alternate with thinner layers of silty sand and some organics. The youngest soils (those nearest the channels) under willow vegetation have the deepest active layers, over 1 m deep, and are classified as Cumulic Regosols (Figure 2.3-2). There are surface organic layers in these soils and their estimated sedimentation rates are high (greater than 7.0 cm/yr). However, with increasing distance from the channels, sedimentation rates decrease to approximately 0.05 cm/yr in the oldest and highest sites which seldom flood. As elevations increase, surface organic layers increase in thickness and active layer depths decrease to between 26 and 36 cm. These older soils are classified as Cumulic Regosolic Static Cryosols (Esso Resources, 1982) and they generally support poplar and spruce vegetation (Section 4.5).

A variety of soils occur in alluvial fan deposits along streams east and west of the Delta. Flooded terraces near streams are usually well drained, and have active layers containing cobbles and buried organic layers. These soils are classified as Cumulic Regosols and Regosolic Static Cryosols.

Older, former flood plains are generally imperfectly drained because of the presence of permafrost within the active layer. Soils here may be influenced by cryoturbation and are classified as Regosolic, Brunisolic and Gleysolic Static and Turbic Cryosols. Active layers range from 30 to 80 cm in thickness, and surface organic layer thicknesses vary from 10 to 40 cm.

2.3.1.4 Glaciolacustrine and Lacustrine Deposits

Medium textured glaciolacustrine deposits are not widespread, occurring primarily near Tuktoyaktuk in association with polygons and pingos. The soils are poorly drained and are classified as Gleysolic Static and Turbic Cryosols.

Poorly drained medium to fine textured lacustrine sediments are common in the many thermokarst depressions and basins. Soils on mineral parent materials in these depressions are classified as Gleysolic Static and Turbic Cryosols (Esso Resources, 1982).

2.3.1.5 Colluvial and Bedrock Deposits

Stable, relatively well developed soils on mountain ridges and unstable, colluvial, cryoturbated soils on mountain and foothill slopes are common along the northern flanks of the British and Richardson mountains. Bedrock soils on stable mountain ridges are generally well drained and often display distinct horizons within silt-loam textured residual materials over angular rocks. These bedrock soils are classified as Regosolic, Orthic and Brunisolic Static Cryosols.

On mountain and foothill slopes, soils are classified as Regosolic and Gleysolic Turbic Cryosols. This results from the combination of cryoturbation and gravity which influences the downslope movement of the surface soil and rocks producing stone stripes, steps and solifluction lobes. These soils have dark colored organic-rich shallow active layers 30 to 50 cm thick, with indistinct horizons because of the continual mixing of materials.

On the moderately to gently sloping terrain of the Yukon Coastal Plain, soils are generally less well drained and finer textured than on steep rocky slopes and mountain ridges. In addition, cryoturbation is more prevalent than downslope movement due to gravity, although a combination of the two processes often results in solifluction. Soils on these gentle slopes are also classified as Regosolic and Gleysolic Turbic Cryosols (Esso Resources, 1982) and generally have shallow active layers with more distinct horizons than soils found on steep slopes.

2.3.1.6 Eolian Deposits

Sandy, well drained soils, deposited and reworked by wind and water, are widely distributed along the Beaufort Sea coast. They are classified as Regosols and Cumulic Regosols. They often have active layers greater than 100 cm deep near the coast, and contain portions of buried organic layers from former surface vegetation. In contrast, less recently deposited soils are generally found further from the coast and are imperfectly to poorly drained. These are classified as Regosolic Static and Turbic Cryosols (Esso Resources, 1982).

2.3.2 SOILS ON ORGANIC PARENT MATERIALS

Zoltai and Pettapiece (1973) have estimated that less than 3% of the coastal Beaufort region is covered with organic soils more than 40 cm deep. Organic deposits are not as prevalent in this region as in more southern areas, including parts of the Mackenzie Valley (Volume 3C), due to the slow growth of peat-forming vegetation.

Organic soils which occur in association with high centre polygons (or peat polygons) have been described by Zoltai and Pettapiece (1973). These polygons are peat plateaus with a polygonal trench pattern caused by the growth of ice wedges within the peat. The organic material of these soils is initially derived from sedges, which grow in the water-filled early development stage of low centre polygons. During later stages of development, Sphagnum becomes the dominant vegetation, and the peat build-up continues, raising the centre of the polygon in relation to the ice wedge trenches. These raised centres gradually become ice-cored.

The surface fibric Sphagnum materials in these soils have accumulated under present or very recent climatic conditions. However, subsurface layers of mesic sedge peat may be indicative of earlier times when permafrost was absent. The lower portions of most organic soils are more humified, possibly indicating that a warmer climatic period occurred approximately 2,500 to 3,000 years ago. These soils are classified as Mesic and Fibric Organic Cryosols, (Esso Resources, 1982).

2.4 HYDROLOGY AND WATER QUALITY

2.4.1 SURFACE WATER

The surface water hydrology of the Beaufort Sea coastal area is described according to three physiographic areas: the Yukon Coastal Plain, the Macken-

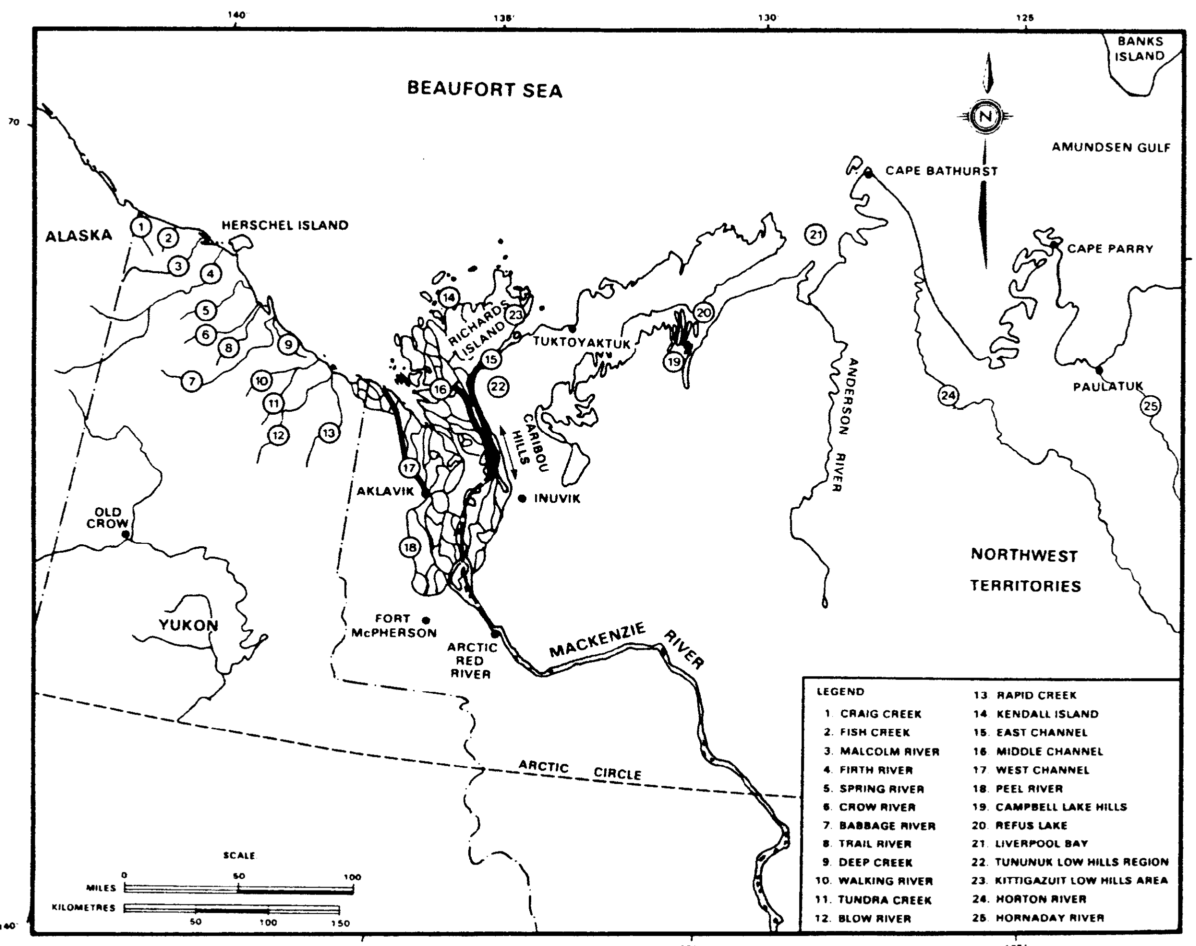


FIGURE 2.4-1 *Map showing rivers along the Yukon coast*

zie Delta and the Anderson Plain (Figure 2.2-1). Extensive hydrological studies have been carried out in the Yukon Coastal Plain (McCart et al., 1974; McDonald & Lewis, 1973; Northern Engineering Services Co. Ltd. (NESCL), 1976d and 1977) and in the Mackenzie Delta (NESCL, 1976 a,b,c; Anderson and MacKay, 1973a, b; Davies, 1975). Few such studies have been published for the Anderson Plain. This section summarizes the present knowledge of the hydrological regime in these areas and cites relevant studies. Further information on the hydrology of the Mackenzie River is provided in Volume 3C.

2.4.1.1 Streamflows and General Characteristics

Along the Yukon Coastal Plain streamflows are influenced by long cold winters and short cool summers. Annual precipitation throughout the area is generally less than 400 mm (Burns, 1974). Evapotranspiration losses are correspondingly low so that annual runoff is comparable to that of the Mackenzie Valley at about 200 mm. Table 2.4-1 lists the larger rivers and creeks of the Coastal Plain together with their drainage areas. Their locations are shown in Figure 2.4-1.

TABLE 2.4-1

MAJOR RIVERS BETWEEN YUKON-ALASKA BORDER AND MACKENZIE DELTA

NAME	DRAINAGE AREA (km^2)
Craig Creek	120
Fish Creek	240
Malcolm River	1100
Firth River	6200
Spring River	560
Crow River	970
Trail River	770
Babbage River	5000
Deep Creek	700
Walking (Running) River	420
Tundra Creek	110
Blow River	3700
Rapid Creek	1100

Flow-gauging stations have been constructed by the Water Survey of Canada (WSC) on the Babbage and Firth rivers. The mean annual flow of the Firth River between 1976 and 1979 was approximately 41 m^3/sec. Peak flows during this time period ranged from 80 to 250 m^3/sec during the typical snowmelt season (May to early June). At times ice jams can cause abnormally high water levels. In addition, rapid rises and flooding may result from intense rainstorms (Lyons, 1976) (Plate 2.4-1).

Point Separation marks the head of the Mackenzie Delta. To the east and west the boundaries of the Delta are sharply defined by the Caribou Hills and the Richardson Mountains, respectively (Plate 2.4-2). The channels of the Delta have been classified by Mackay (1963) into the following groups:

- distributary channels which diminish in volume as they distribute their flow to other channels;
- river channels which receive water from distributary channels;
- network channels which link main distributary and tributary systems;
- lake channels which interconnect lakes with other lakes or with other types of channels;
- reversing channels which reverse frequently and sufficiently to affect channel characteristics; and
- tidal channels which are located at the Mackenzie Delta — Beaufort Sea boundary and have reversing flows.

The following hydrology discussion focuses on the major river channels, the second of those groups classified above.

The major channels of the Mackenzie Delta are the Middle, East and West channels (Figure 2.4-1). The distribution of water discharge through these channels varies considerably from year to year. However, the Middle Channel always carries the major portion of the flow through the Delta (Anderson and MacKay, 1973a), an example being a mean annual flow of 10,400 m^3/sec or 93% of the total. Seasonal variations in the percentage of flow carried by the Middle Channel (example 85% of total in summer versus 95% of total in winter) result from the fact that several Delta channels, particularly those on the west side, are completely frozen during the winter. Table 2.4-2 presents flow data for channels of the Mackenzie Delta in 1977, listing maximum daily, minimum daily and mean annual flows.

TABLE 2.4.2

FLOW DATA FOR CHANNELS IN THE MACKENZIE DELTA (WSC. 1978) IN m^3/SEC. FOR 1977

	Max Daily	Min Daily	Annual Mean
Aklavik Channel above Schooner Channel Station No. 10MC005 1974-1976	1416	64	351
East Channel at Inuvik Station No. 10LC002 1973-1976	923	7	160
Kalinek Channel above Oniak Channel Station No. 10LC006 1974-1975	1756	32	249
Middle Channel above Napoiak Channel Station No. 10MC006 1974-1976	31435	1926	8411
Peel Channel above Aklavik Station No. 10MC003 1974-1975	3455	69	515
West Channel below Aklavik Channel Station No. 10MC004 1974-1975	6684	204	983

PLATE 2.4-1 *Braided channels of the lower Malcolm River on the Yukon coast. The very wide flood plain is caused in part by high spring flows and ice jams causing flooding. (Courtesy, Woodward-Clyde Cons.)*

PLATE 2.4-2 *The broad Mackenzie Delta is characterized by many types of channels and much of it floods in the springtime. It is bordered on the west by the Richardson Mountains shown in the background. (Courtesy, Woodward-Clyde Cons.)*

Generally, flooding of the middle and outer Delta occurs each June as a result of snowmelt and spring runoff. Periodically, summer rainstorms, particularly those occurring in the headwaters of the Peel or Rat rivers, may cause flooding of channels in the western area of the Delta. In addition, the flow rates and water levels of the outer Delta channels may be influenced considerably by storm surges in the Beaufort Sea (Berry et al., 1975; Hurst, 1971; and Slaney, 1974). For example, Hurst (1971) recorded conditions during a September, 1970 storm along the Beaufort Sea coast from Herschel Island to Darnley Bay. The highest wind speeds (103 km/hr, gusting to 135 km/hr) were in the area west of Tuktoyaktuk and generated wave heights of 9.1 m offshore and 1.5 m onshore, and storm surges of 2.4 m. East of this area, the maximum recorded wind speed was 80 km/hr, which produced a 1 m storm surge.

Slaney (1974) showed that water levels in outer Delta channels varied considerably during the summer, with a trend to decreasing levels toward autumn. Rapid temporary rises were caused by storm surges.

The banks of the Mackenzie Delta channels erode rapidly as a result of high flow velocities and thermal niching. In a detailed study of bank erosion of the upper Mackenzie Delta, Outhet (1974) discussed the relationship between bank erosion and permafrost. It was found that the warm river water thawed ice-rich silty banks, causing up to 30 m of channel migration in a single year. This erosion also contributes substantially to the large volumes of suspended sediments deposited by the Mackenzie River into the nearshore Beaufort Sea. During the maximum flow period from June to September average discharges of sediment regularly exceed one million tonnes per day.

The Anderson Plain is low and flat along the coast, rising to a 180 to 300 m high escarpment further inland. Surface elevations continue to increase southward to between 240 and 300 m, while stream valleys and channels incise the escarpment to depths ranging from 150 to 210 m (Douglas, 1972). The largest drainage system in the area is the Anderson River. At a point just below the confluence of the Carnwath River, the Anderson River had a mean annual flow rate (1969-1979) of 113 m^3/sec (WSC, 1978).

The hydrology of the Anderson River is typical of many northern rivers. Peak flows occur during a two to three week period in late May through early June when the ice breaks up. Relatively high flows are maintained during July and August until freeze-up in late September or early October. Discharges diminish through the winter, reaching lowest flows (1/10th of spring discharge) prior to thaw. This cycle results in most of the total annual flow being discharged over a short period of time, and this in turn may cause rapid erosion of river banks. The deep valley of the Hornaday Canyon and the rapid formation of the Horton delta were considered to result from rapid bank erosion (Zoltai et al., 1979).

Lakes are numerous because of the geological history and low relief of much of the onshore Beaufort area. Mackay (1963) classified and generally described the several thousands of lakes in the modern Mackenzie Delta west of the Caribou Hills. Most of these are less than 3 m deep and were categorized on the basis of their origin as follows:

- Abandoned Channel Lakes form when channel inflection points silt in or channel loops are cut off and tend to become elongate lakes or chains of lakes;

- Arcuate (Point Bar) Lakes form in the swales of migrating point bars and tend to be very shallow and short-lived;

- Flood Plain Lakes occupy depressions formed by channel levees; many have low or no closure from the adjacent channels and are flooded annually by the spring freshet as are most lakes in the outer Delta;

- Thermokarst Lakes are formed in depressions resulting from the thaw of ice-rich permafrost; and

- Dammed Lakes form by the damming of stream mouths along the boundaries of the modern Delta.

Many of these lakes are a fundamental part of the Delta ecosystem and are replenished with nutrients annually by the spring flood.

Between Kendall Island and Cape Dalhousie on the Pleistocene Coastal Plain, 15% of the surface is covered with lakes (Mackay, 1963). In the Tununuk Low Hills region, lakes are relatively deep and the shorelines are smooth compared with those of the Kittigazuit Low Hills area. The undifferentiated coastlands zone features a highly indented coastline with spits in many areas and has medium to large lakes. On the McKinley Bay coastal plain, particularly along the eastern coast, spits and bars are numerous. In the Liverpool Bay area, lakes have smooth shores and are irregularly shaped. East of Refus Lake there are rolling hills with large partially-drained lakes. Southwest of Refus Lake the terrain is similar although the lakes are even more irregularly shaped than those of the Liverpool Bay region. The Eskimo Lakes, with an approximate area of 880 km^2, have numerous bowed peninsulas projecting inward.

effectively forming channels connecting the lakes. Flows through these channels may reverse because of tidal action, causing water to back up. During storms the current through these channels may be strong. South of the Eskimo Lakes, the Caribou Hills region has few bodies of water, while the Campbell Lake Hills zone has numerous elongated lakes. On the east side of the Anderson River uplands there are some lakes, but few are drained. West of the river's mouth, however, numerous lakes do drain.

2.4.1.2 Ice Conditions

During the winter, most streams of the Yukon Coastal Plain have extremely low flows or no flow at all. Extensive "aufeis" occur in the floodplains of the Malcolm, Firth and many of the other Coastal Plain rivers. Aufeis are composed of ice developed on the ground surface followed by the progressive build-up of ice upon itself. Such icings may be fed by groundwater seepage, springs, streams or a combination of these.

Several ice studies have been conducted in the Mackenzie Delta, including those by Anderson and MacKay (1973b, 1974), Blench and Associates Ltd. (1975), Davies (1975), and Slaney (1974, 1975). The following description of ice conditions of the Delta was compiled from these sources.

Freeze-up usually begins in early October when air temperatures stay below freezing. Freezing starts in the north, moving progressively upstream. Therefore, in general, ice thickness in the channels is greater near the mouth of the Mackenzie River than it is further south, reaching an average maximum thickness of 1.35 m in April. Maximum thickness is a function of temperature, snow cover, channel depth, and water mixing.

During break-up, ice jams may form at sharp bends or at channel restrictions within the Delta, causing diversions, reversals of flow, and/or overtopping of levees. Usually by May temperatures have risen above freezing, and extensive snowmelt occurs on the ice-covered channels. As the streamflow increases beneath the ice, due to melting snow and ice upstream, leads open along the shoreline of the main river channels. Break-up in coastal lakes generally occurs within one or two weeks of the opening of the main river channels.

2.4.1.3 Water Quality

The water quality of some of the lakes and streams in the Yukon Coastal Plain has been studied by McCart et al. (1974) and Aquatic Environments Limited (1977). It was noted that water was generally of high quality, being slightly alkaline (ph ranging from 7.4 to 8.5). Turbidity and suspended sediment concentrations were variable, while specific conductivities varied from 15 to 540 micro-mhos/cm. Some lakes had a slightly brown colour, thought to be the result of the decay of organic materials.

Descriptions of the water quality of the Mackenzie Delta may be obtained from the following references: Davies (1975), Lewis and Forbes (1975), Lyons (1976), Reeder (1973), Reid et al. (1974), and Slaney (1974, 1975). In addition, Water Survey of Canada maintains several water quality stations on the Delta. The data generated from these stations are stored in the Water Quality NAQUADAT system of Environment Canada (Water Quality Branch, 1981).

In general, the river water of the Mackenzie Delta is drinkable, although it is highly turbid, particularly during summer. Similarly, potable water can be obtained from the region's lakes (Slaney, 1974). Table 2.4-3 provides the ranges of some water quality parameters for surface water in the West and Main channels of the Mackenzie Delta, and for the Peel River at Fort McPherson.

2.4.2 GROUNDWATER

Although permafrost has previously been regarded as an impermeable barrier to groundwater flow, this is not strictly correct. According to estimates by Harlan (1974), the rate of water movement through frozen ground is of the same order as that through partially saturated unfrozen soils, being driven by a thermal gradient analogous to an hydraulic gradient.

In the Beaufort Sea coastal area, significant quantities of groundwater are found only at depth, beneath the permafrost, and in unfrozen zones beneath larger lakes and rivers which do not freeze to the bottom across their full width (Tolsteikhin and Tollstikin, 1974; Williams and Van Everdingen, 1973). Thus, while water movement through frozen ground may be possible, the areal extent and thickness of permafrost severely restricts this movement. Supra-permafrost groundwater (that which flows through the active layer within a few metres of the ground surface) generally only occurs during the thaw season.

Substantial quantities of groundwater do flow within the unfrozen alluvial deposits of larger streams and in some cases these provide continuous winter streamflow, springs, open water, and aufeis conditions in the stream bed. Warm springs, indicative of deep sub-permafrost groundwater sources, have been identified in several of the stream valleys in the British Mountains and foothills (NESCL, 1977). These springs have substantial flows and are principally responsible for the significant fish overwintering and spawning areas present in the upper reaches of

TABLE 2.4-3

SOME WATER QUALITY PARAMETERS FROM SELECTED MACKENZIE RIVER & PEEL RIVER WSC STATIONS (ENV. CAN., 1981)

		West Channel Station No.: 00NW10MC004			Main Channel Station No.: 00NWMC0005			Peel River Station No.: 00NW10MC0002		
		Low	High	Ave	Low	High	Ave	Low	High	Ave
Specific conductivity	(USIEkm)	250.0	420.0	338.0	100.0	300.0	207.0	186.0	412.0	314.0
Hardness	(mg/L)	105.4	153.3	122.1	74.8	145.8	125.4	63.9	215.0	157.5
Turbidity	(m)	0.04	0.07	0.06	0.02	0.06	0.04	0.5	460.0	60.5
pH	(pH units)	7.7	8.0	—	7.4	8.1	—	7.2	8.3	—
Nitrogen	(mg/L)	0.53	0.55	0.54	0.29	0.64	0.45	—	—	—
Total Phosphorus	(mg/L)	0.012	0.025	0.019	0.011	0.121	0.031	<0.003	0.009	0.006
Oxygen	(mg/L)	9.8	11.0	10.2	5.4	14.0	10.3	11.1	11.2	11.2
Silicon	(mg/L)	1.08	1.39	1.19	1.39	1.91	1.75	—	—	—
Potassium	(mg/L)	0.7	0.9	0.8	0.9	1.6	1.2	0.4	2.6	0.7
Sodium	(mg/L)	3.3	4.4	3.7	4.5	10.9	8.8	1.0	5.7	3.9
Calcium	(mg/L)	28.7	39.8	32.7	11.5	40.1	33.24	21.5	62.0	45.2
Magnesium	(mg/L)	8.2	13.1	9.8	7.3	11.2	10.3	2.5	17.3	11.1
Bicarbonate	(mg/L)	122.0	144.0	129.0	106.0	155.0	135.0	54.0	187.0	130.0
Chloride	(mg/L)	1.0	2.7	1.6	2.1	35.0	14.2	1.1	6.6	2.7
Sulphate	(mg/L)	26.6	35.2	29.7	23.2	67.8	44.8	21.0	73.0	43.0
Manganese	(mg/L)	<0.001	<0.001	—	<0.001	0.02	0.008	<0.01	<0.01	—
Iron	(mg/L)	< 0.05	0.13	0.10	< 0.05	0.18	0.076	0.02	0.02	—
Copper	(mg/L)	0.012	0.021	0.017	0.003	0.030	0.011	—	—	—
Zinc	(mg/L)	0.001	0.005	0.002	<0.001	0.008	0.002	—	—	—
Arsenic	(mg/L)	—	—	—	—	—	—	<0.0005	0.010	0.0043
Cadmium	(mg/L)	<0.001	<0.001	—	<0.001	0.001	0.001	0.001	0.001	—
Lead	(mg/L)	<0.001	0.002	0.001	<0.001	0.002	0.002	—	—	—

Source: Water Quality Branch

streams such as the Firth River (McCart et al., 1974). They may have discharge rates ranging from 0.03 m^3/s to 0.78 m^3/s and temperatures ranging from 2° to 5°C, and result in very extensive "aufeis" fields, some of which may persist through the short summer season. Evidently there are also significant flows within the alluvium of these streams which result in extensive "aufeis" in the lower reaches or deltas of the Firth and Malcolm rivers, Craig Creek and others (NESCL, 1977). The extent and depth of these unfrozen zones and volumes of flow are not well documented.

Within the Mackenzie Delta great depths of unfrozen alluvium exist in some areas beneath the major stream channels; these presumably also carry substantial flows of fresh groundwater. MacKay (1974) demonstrated that groundwater under excess hydrostatic pressure is a major factor in the growth of pingos which are particularly common on the Tuktoyaktuk Peninsula.

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CHAPTER 3

MARINE PLANTS AND ANIMALS

The following sections summarize existing information on the marine plants and animals of the Beaufort and northeast Chukchi seas (Figure 3.0-1). Primary emphasis has been placed on the coastal and offshore marine resources of the Canadian Beaufort which are most likely to be within the zone of influence of hydrocarbon exploration, production and transportation activities in the region. This chapter provides an overview of the available information regarding the species composition, distribution and abundance of marine flora and fauna. This description forms part of the background for the assessment of the potential environmental effects of normal hydrocarbon production and transportation activities (Volume 4), as well as for assessing the impacts of possible accidental spills within the region (Volume 6). Further details and site-specific data can be found in the various supporting documents to this EIS, as well as in the original literature sources (Section 3.8).

Subsequent sections cover marine mammals, birds, resource use, and special habitats and have been adapted from an earlier summary of the biological resources of the Beaufort Sea and northeast Chukchi Sea (LGL and ESL, 1982) and from the results of more recent studies. Descriptions of lower trophic levels, Arctic food webs, and fish populations are also based on LGL and ESL (1982), as well as on a variety of other investigations. To assist the reader, Table 3-1 is provided; it defines many of the more important biological terms used in Chapters 3 and 4.

3.1 ARCTIC MARINE FOOD WEBS

This section summarizes available information on trophic relationships within marine communities of the Beaufort and northeast Chukchi region and identifies important ecological links between dominant species. However, this overview of the major energy pathways between the various producer and consumer levels, necessarily has many details omitted. The actual food webs for this region are likely more elab-

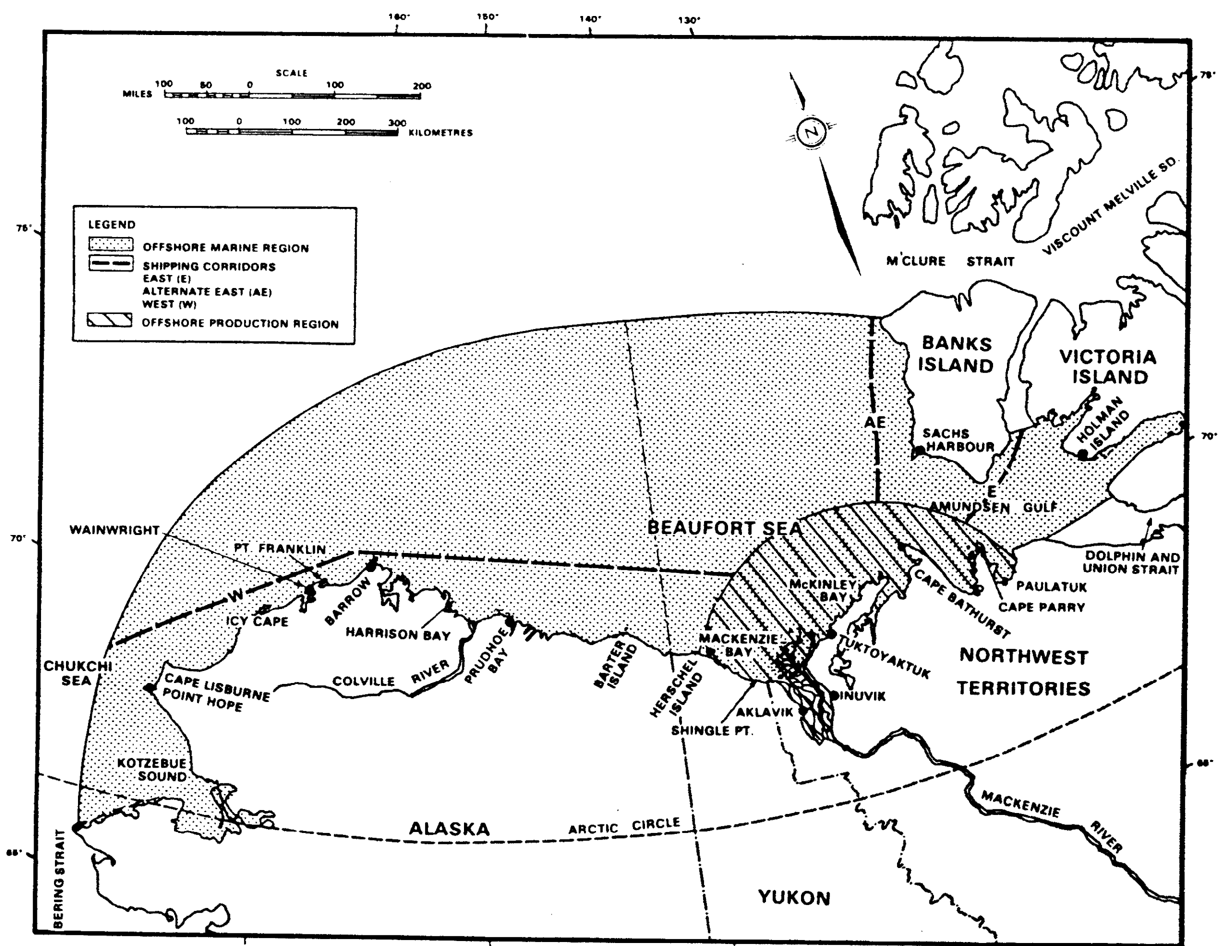


FIGURE 3-1 *Approximate boundary of the offshore marine region. Particular attention has been paid to the animals and plants inhabiting the proposed offshore production area.*

TABLE 3.1
GLOSSARY OF BIOLOGICAL TERMS

Algae	A group of aquatic one-celled, colonial or many-celled plants which contain chlorophyll, e.g. seaweed, pond scum.
Anadromous	Fish that return from the ocean to freshwater to reproduce (spawn), e.g. salmon.
Autotrophic	The capability of an organism to make its own food, e.g. photosynthesis by plants.
Benthos	Plants or animals that live on or in the bottom of the sea (or lake).
Bloom	The production of large numbers of plankton or epontic organisms in a relatively short time period.
Cellulose	The fundamental constituent of the cell wall of all green plants.
Copepodite	A stage in the life of some young invertebrates.
Demersal	Fish that live on and/or near the bottom of the sea (or lake).
Detritus	Accumulation of fine material worn away or broken off rocks. Also material suspended in the water column including fragments of small plants and animals, and waste products of small animals living in the water.
Detritivores	Organisms that utilize detritus for food.
Epifauna	Animals that live on the surface of the bottom sediments in the sea. Some epifauna may be mobile and may occasionally burrow into the bottom substrate, but usually they occupy the surface.
Epontic	The under surface of the ice.
Estuarine	A coastal area where freshwater (usually originating from a river) is mixed and diluted by seawater.
Euphotic Zone	A zone near the surface of the sea into which sufficient light penetrates for photosynthesis to occur.
Euryhaline	The ability to tolerate a wide variation in the salt content of the water.
Fauna	Animals in general, or animal life as distinguished from plant life.
Fecal pellets	The solid or semi-solid wastes from zooplankton and some other invertebrates.
Flagellates	Organisms which have a fine long thread-like projection which they use for movement (Dinoflagellate = flagella).
Food Web	A diagramatic presentation of a natural community, which indicates what each member eats. The bottom of the web are plants and bacteria and large carnivores are the top of the web.
Flora	Plants in general or plant life as distinguished from fauna (animal life).
Fry	Young fish, usually less than one year old.
Herbivore	An animal that feeds on plants.
Heterotrophic	An organism whose food is organic material produced by other organisms.
Infauna	Animals that live buried in the bottom sediments of the sea (or lake).
Invertebrate	An animal without a backbone, e.g. worms.
Larvae	The pre-adult form in which some animals hatch from the egg.
Macrophytes	Large aquatic plants (algae) which usually grow only where a solid substrate for attachment is available.
Meiofauna	Very small animals that live on and/or in the bottom of the sea.
Microbial	Microscopic organisms.
Nauplii	A stage in the life of some young invertebrates.
Nonspawners	Adult fish that are sexually mature, but will not reproduce during that year.
Oleoclastic	Organisms which can utilize oil for food.
Pelagic	Inhabiting the open water of the sea (or lake), in contrast to the seabottom.
Photic Zone	A zone near the surface of the sea into which sufficient light penetrates for photosynthesis to take place (= euphotic).
Photosynthesis	The formation of organic compounds by plants from water and carbon dioxide using the energy absorbed from sunlight by chlorophyll.
Phytoplankton	Aquatic plants (algae) that live in the water column.
Plankton	Small plants and animals that live in the water column.
Predation	Preying on other animals, as opposed to eating (grazing on) plants.
Primary Product (ion) (ivity)	The energy produced by plants through photosynthesis.
Psychrotrophs	Organisms that can tolerate cold temperatures.
Psychrophiles	Organisms that grow best at cold temperatures.
Respiration	The taking of oxygen from the environment and giving off of carbon dioxide. For example, pumping air in and out of lungs, or water over gills.
Secondary Product (ion) (ivity)	The energy produced by animals which eat plants.
Spawn	The eggs (roe) and sperm (milt) from fish, or the act of depositing these products during periods of fish reproduction.
Taxonomic	The scientific classification of living things.
Trophic (Levels)	Related to feeding, refers to the position of an animal in the food web.
Vertebrate	An animal with a backbone.
Zoobenthos	Animals that live on or in the seabottom.
Zooplankton	Small animals that live in the water column.

orate and variable than depicted in the figures contained in this section. This is partly a result of the limited quantitative data available for some species or taxonomic groups. For example, one of the major food web unknowns is the extent of coastal feeding by fish and invertebrates and the availability of different primary food sources in winter. Graphical depiction of a food web is complicated by changing diets as species move from the larval or infant stage through juvenile to the adult form. This is also true of the groups which prey on a certain life history stage of a particular species. For example, adult Arctic char may prey upon juvenile fourhorn sculpins but not the large adult sculpins.

The trophic data available for the Beaufort and northeast Chukchi region vary with species and season. Wherever possible, links between groups have been based on dominant food organisms found in stomach content analyses (at least 20% of contents), although some links are inferred by the literature. For example, since 'gulls feed on small fish,' they probably prey to a greater or lesser extent on Arctic cod, boreal smelt and herring.

Four major sources of primary production provide initial energy to Arctic marine food webs: terrestrial vegetation, macrophytic algae, benthic microalgae (including epontic algae) and phytoplankton. These autotrophic groups include a large number of species which, through photosynthesis, convert various inorganic carbon sources into the organic carbon of living plant tissue. Terrestrial vegetation and macrophytic algae are usually broken down physically and microbially to detritus before entering the Arctic marine food web, while the unicellular algal species are usually consumed directly by herbivores. The nutrition derived from ingestion of detritus or peat from terrestrial sources is mainly from the bacteria coating the decaying plant fibers (Newell, 1965; Kistritz, 1978), although some invertebrates apparently have enzymes which break down cellulose and derive nutrition from the peat itself (Schneider and Koch, 1979).

The extreme seasonal variability in the physical and chemical environment of nearshore Arctic waters influences the availability of these primary food sources. Some terrestrial peat enters the nearshore marine environment as a result of coastal erosion during storms in the open water season. A large amount of peat also becomes suspended in the numerous fresh water streams and rivers after being washed off the land during spring snowmelt. The Mackenzie River is probably a major contributor to the detrital input to the Beaufort Sea. Formation of microbial detritus likely begins in freshwater as the peat particles move downstream. These particles, along with inorganic riverine sediments, settle out of suspension over a large area of the coastal zone. Although the balance between detrital input and its consumption by invertebrates has not been determined, the common occurrence of peat in many benthic grab samples taken from coastal areas suggest that this potential food source is abundant, and is likely available throughout the year. However, Schneider and Koch (1979) indicated that both particle size and longevity of terrestrial peat in a marine environment are important factors determining its nutritional value.

Macrophytic algae (seaweeds) are probably a minor contributor to the nearshore detrital biomass in the Beaufort and northeast Chukchi region since they are only sparsely distributed along this coast. Macrophytic algae could be locally important as detrital producers in certain areas when storms and ice scour break off fronds and release organic substances into the water column, but they are not a dominant source of detritus in the region. Other contributors to the detrital biomass are dead microalgae, phytoplankton and invertebrate fecal pellets which are subsequently decomposed by aquatic micro-organisms.

Unicellular algae are a dominant source of nutrition for herbivorous invertebrates in benthic, epontic and planktonic habitats. Although many Arctic diatom species are adapted to relatively low light intensities, there is little or no reproduction (cell division) between November and February, and relatively few living cells are available to invertebrate grazers. In early spring the epontic algal populations of pennate diatoms begin to grow and divide with increasing daylight. Epontic algae are probably relatively common in most coastal and offshore areas away from the freshwater input of large winter-flowing rivers such as the Colville and Mackenzie. These areas probably support a large number of grazing invertebrates during the spring. However, as leads form in the offshore ice pack, the phytoplankton populations begin to proliferate in the water column. This community in turn feeds zooplankton and other pelagic invertebrates. Centric diatoms are generally dominant in late spring phytoplankton communities, with pennate diatoms becoming more prevalent in nearshore waters later during the growing season. Flagellates tend to be more abundant in offshore areas after the initial bloom of diatoms (Section 3.5.4). After the nearshore ice has receded, small "seed" colonies of benthic diatoms (particularly *Amphipleura rutilans*) begin growing in areas where light penetrates to the bottom. Microalgae slowly cover the bottom and maximum primary productivity is reached by early August (Matheke and Horner, 1974).

Recent observations of the feeding behaviour and life cycles of certain epontic fauna indicate that the undersurface of sea ice and its flora may be more important to the ecology and bioenergetics of these invertebrates than abundance or biomass estimates alone would indicate. Divers have observed that amphipods and other metazoans graze on the epontic flora under fast ice during the spring bloom (Horner, 1972, 1976, 1977; Welch and Kalff, 1975; Buchanan et al., 1977). The presence of partially digested diatoms in the digestive tracts and fecal pellets of polychaetes, copepods and amphipods substantiates the presence of this trophic pathway within epontic communities (Horner, 1972, 1977; Horner and Alexander, 1972a, 1972b; Buchanan et al., 1977).

The dominant trophic pathways from primary producers to the major invertebrate groups are illustrated in Figure 3.1-1. The shallow water epifaunas are the most important components of coastal Arctic food chains. With the exception of some omnivorous crustaceans which prey on small zoobenthos, detritus and benthic microalgae, all pathways are between primary producers (or detritus from primary producers) and herbivorous invertebrates. Numerous studies have shown that mysids, amphipods, cumaceans and isopods comprise major portions of the diets of Arctic fish, birds and marine mammals in this region (Bendock, 1977; Divoky, 1978; Fraker et al., 1978; Griffiths and Craig, 1978; Griffiths and Dillinger, 1980; Griffiths et al., 1975, 1977; Johnson, 1978, 1979; Kendel et al., 1975; Lowry et al., 1980; Stirling et al., 1976).

Few trophic specialists, which rely on a single food source, have been identified in the Beaufort and northeast Chukchi region. Most zoobenthic species feed opportunistically on a heterogeneous assortment of the primary energy sources. A large portion of the indigenous nearshore species are deposit feeders rather than filter feeders, and capture or trap particles that settle to the bottom. Schneider and Koch (1979) reported a broad dietary overlap between 17 invertebrate species (representing mysids, amphipods, isopods and polychaetes) in Elson Lagoon, Alaska, following a study of fecal pellet composition. The most common food items of this fauna were pennate diatoms, peat fibres, diatom chains and dinoflagellates, with several of the crustacean species also containing fragments of other crustaceans and polychaete setae.

One of the common amphipod species *(Gammarus setosus)* is well adapted to foraging for a variety of food items found in the region. This animal will ingest almost any mineral or organic particle which is at least 62 microns in diameter, although not all materials ingested provide nutritional benefits. *G. setosus* can assimilate organic matter from coarse peat particles which have been in the sea for some time, as well as from drifting fragments of the macrophytic alga *Laminaria*. However, the species does not derive nutrition from silt particles, fine particles of marine peat, or from coarse peat which has been recently eroded into the sea (Schneider and Koch, 1979). The common shallow water oppossum shrimp, *Mysis littoralis*, also ingests small peat particles without deriving any apparent nutritional value. The size of peat particles probably influences the rate at which its dissolved organics are leached, and may also affect its suitability as a substrate for growth of microbial decomposers. Few other species examined in the study of Schneider and Koch (1979) ingested significant quantities of peat during the summer, but the importance of detrital peat may be in its availability during the winter months when algal food sources are scarce. The ability to use alternate energy sources

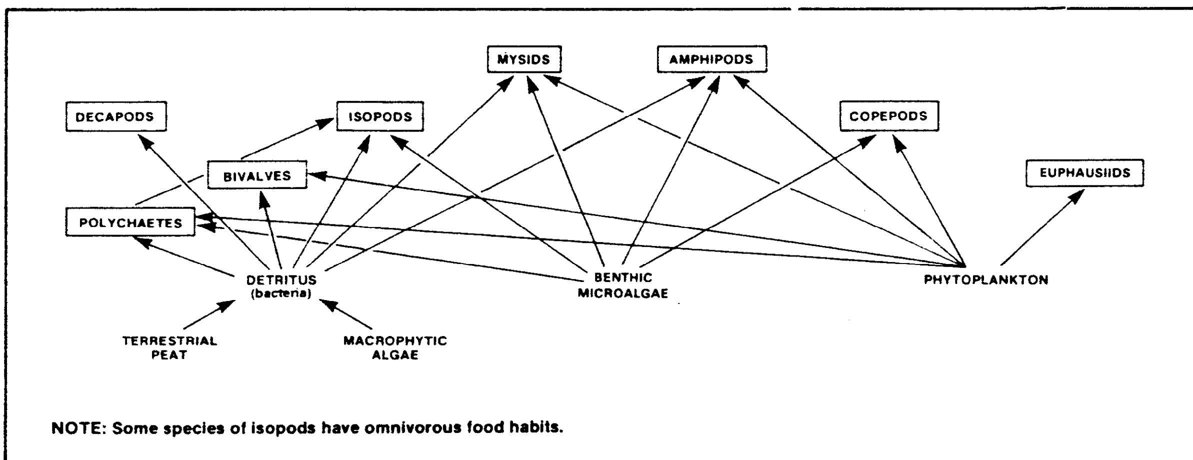


FIGURE 3.1-1 *Major trophic relationships between primary producers and primary consumers (Herbivores) in the Beaufort and Northeast Chukchi seas. Most zoobenthic species (primary consumers) feed opportunistically on a heterogeneous assortment of the primary energy sources.*

according to their seasonal availability is probably widespread among many Arctic marine invertebrates.

Mysids and amphipods grow the most during the summer months when primary producers are relatively abundant, but continue to grow at a slower rate throughout the winter (Griffiths and Dillinger, 1980). For example, an estimated 60 to 70% of the carbon incorporated by nearshore epifauna in Simpson Lagoon, Alaska, was thought to originate from marine primary production pathways (Schell, 1979). This proportion may be much less where the highly turbid plume of the Mackenzie River can reduce light penetration to only a few centimetres (Grainger, 1975).

Studies in Simpson Lagoon by Griffiths and Dillinger (1980) showed that the standing stock of epibenthic crustaceans was large relative to the numbers consumed daily by members of higher trophic levels. A net shoreward movement of epifauna was also observed, at least during the summer, and this recruitment more than compensated for losses due to predation.

Although not indicated as dominant trophic pathways in Figure 3.1-1, some species with predatory or omnivorous feeding habits occur within this level of Arctic marine food webs. For example, the large isopod *Saduria entomon* not only feeds on diatoms and detritus, but also occasionally preys on polychaetes, bivalves, cumaceans, and other smaller crustaceans. This highly mobile species is attracted to areas with substrate disturbance such as those associated with dredging activities, possibly due to enhanced feeding opportunities (Robilliard and Busdosh, 1979). Certain decapods, mysids and amphipods also prey on smaller invertebrates, while the amphipod *Boeckosimus affinis* has been observed in the thousands feeding on fish captured overnight in gill nets (Busdosh et al., 1979).

Fish species in this region feed almost exclusively on invertebrates or other fish (Figure 3.1-2). None are considered herbivorous as adults, although larval or juvenile stages may occasionally feed on diatoms or other algae. Demersal marine fish, such as flounders and sculpins, and anadromous whitefish consume marine infauna, including bivalve molluscs and polychaetes, or slow-moving epifaunal species (Percy, 1975; Kendal et al., 1975). Mysids and amphipods are common in the diets of almost every fish species indigenous to the Beaufort and northeast Chukchi seas. These two groups represent the major trophic links between the primary producers and members of upper trophic levels. Copepods are also part of a dominant trophic pathway since many fish species have young which feed extensively on these smaller crustaceans.

The Arctic cod *Boreogadus saida* has been identified as a major link in the more intensively studied marine food webs of the eastern Arctic (Davis et al., 1980). This small pelagic schooling fish is also common in parts of the western Arctic away from the Mackenzie Delta. Arctic cod are probably a large consumer of the mysid, amphipod and copepod biomass since schools containing millions of fish have been observed feeding in nearshore zones such as Simpson Lagoon in Alaska (Craig and Haldorson, 1980). Arctic cod, in turn, provide an important food source for other fish, birds and marine mammals.

Coastal waters of the region support an estimated 2 million migratory birds between spring and autumn (Section 3.3). Figure 3.1-3 illustrates the principal feeding relationships of the various bird groups with members of lower trophic levels. Large numbers of geese and swans feed primarily on freshwater sedges and grasses in coastal lagoons and tundra ponds. Loons, dabbling ducks, scaup, scoters, eiders and oldsquaws occur in freshwater and nearshore marine habitats where they prey mainly on invertebrates during the nesting and late summer moulting/staging period. In addition to utilizing nearshore habitats, eiders, oldsquaws, alcids, loons, phalaropes, terns, gulls, and jaegers range farther offshore and many include or rely on small fish and pelagic invertebrates in their diets. Early in the spring, large numbers of offshore migrants stage in the active leads and polynyas where the phytoplankton blooms supplement the ice edge epontic communities, which in turn attract euphausiids and Arctic cod. Oldsquaws occasionally feed on the bivalve mollusc *Cyrtodaria kurriana* in Simpson Lagoon (Johnson, 1979), and on polychaetes, echiuroids, and bivalve species elsewhere in the region (Divoky, 1978). King eiders, common eiders and loons also feed on infaunal invertebrates.

Generally, the diet of marine mammals in the Beaufort and northeast Chukchi seas is comprised of Arctic cod and large crustaceans such as isopods, mysids, amphipods and euphausiids (Figure 3.1-4). Lowry et al. (1978) reported that bowhead whales landed off Point Barrow had been feeding on copepods, mysids and euphausiids. Beluga whales probably do not feed in the Mackenzie estuary during July, but consume squid and Arctic cod in offshore areas.

Ringed seals are the most abundant marine mammal in the region (Section 3.2.2). This species preys on pelagic euphausiids *(Thysanoessa spp.)*, hyperiid amphipods, mysids and shrimp in spring and summer,

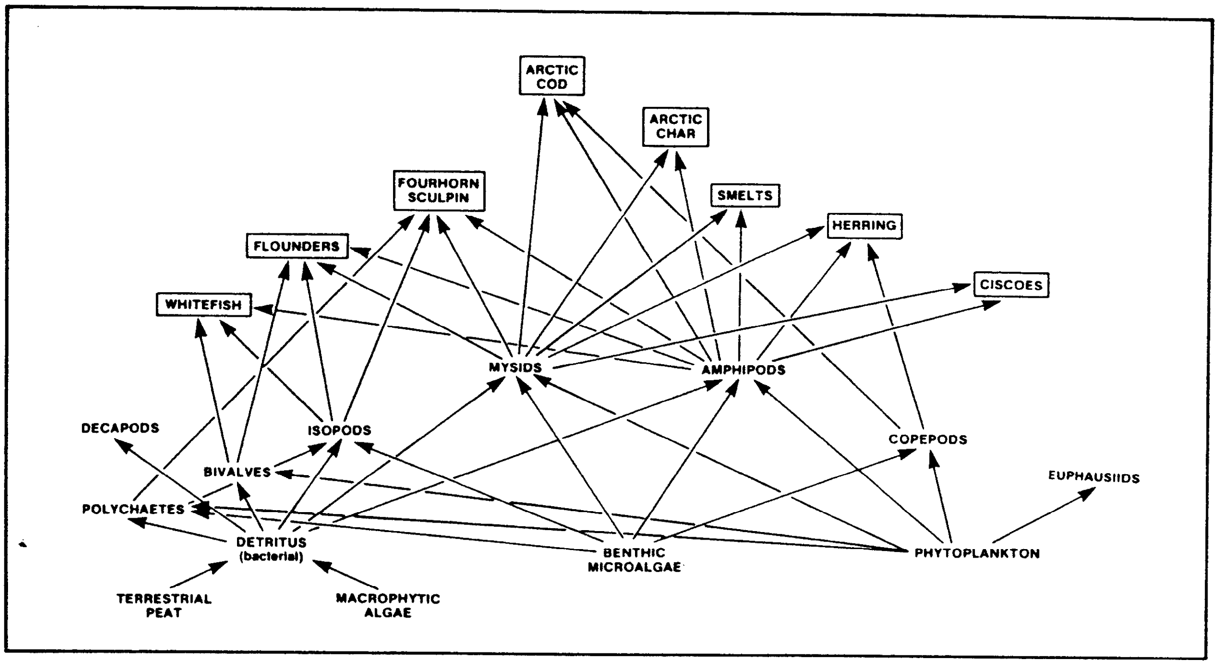


FIGURE 3.1-2 *Major trophic pathways leading to fish species in the Beaufort and Northeast Chukchi seas. Mysids and amphipods are common in the diets of almost every fish species indigenous to this region.*

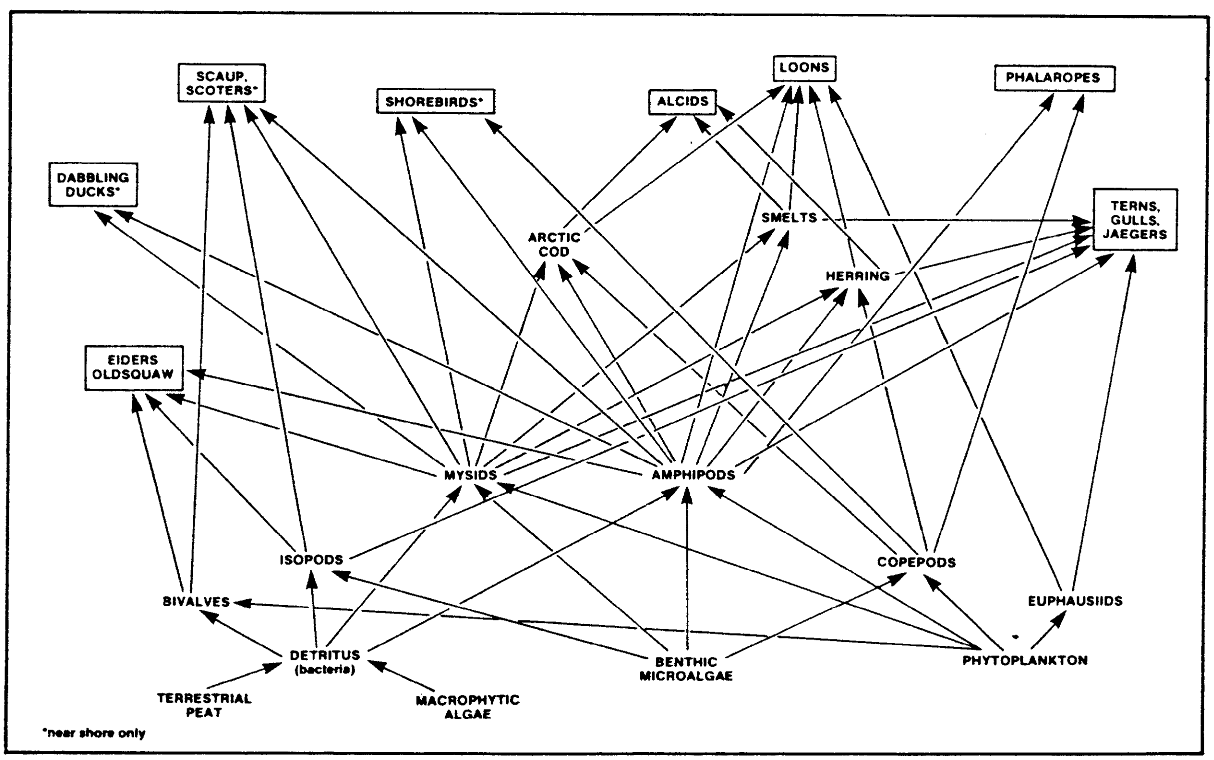


FIGURE 3.1-3 *Major pathways leading to birds in the Beaufort and Northeast Chukchi seas. The coastal waters of the region support an estimated 2 million migratory birds between spring and autumn.*

and mainly on Arctic cod in fall and winter (Lowry et al., 1980). Bearded seals and walrus are much less common than ringed seals in the Beaufort Sea, both being more abundant in the Chukchi Sea. These species prey mainly on epibenthic and infaunal organisms such as bivalves and large crustacea.

The polar bear and Arctic fox are considered here with the true marine mammals since they are an important and integral part of marine food webs. Polar bears prey extensively on seals, in particular subadult and pup ringed seals, although they will consider almost anything on the ice as potential prey. Smith (1975) demonstrated that predation by polar bears can have potentially important effects on levels of ringed seal populations. At the same time natural factors, such as changing annual ice conditions, can affect the ringed seal population which, in turn, can affect the abundance and distribution of polar bears (Stirling et al., 1975; Stirling and Smith, 1977; Stirling, 1978).

During the winter and spring Arctic foxes in coastal areas move onto the sea ice and prey extensively on seal pups and seal carrion left by bears, while in the summer and fall they go ashore and prey primarily on rodents such as lemmings and Arctic ground

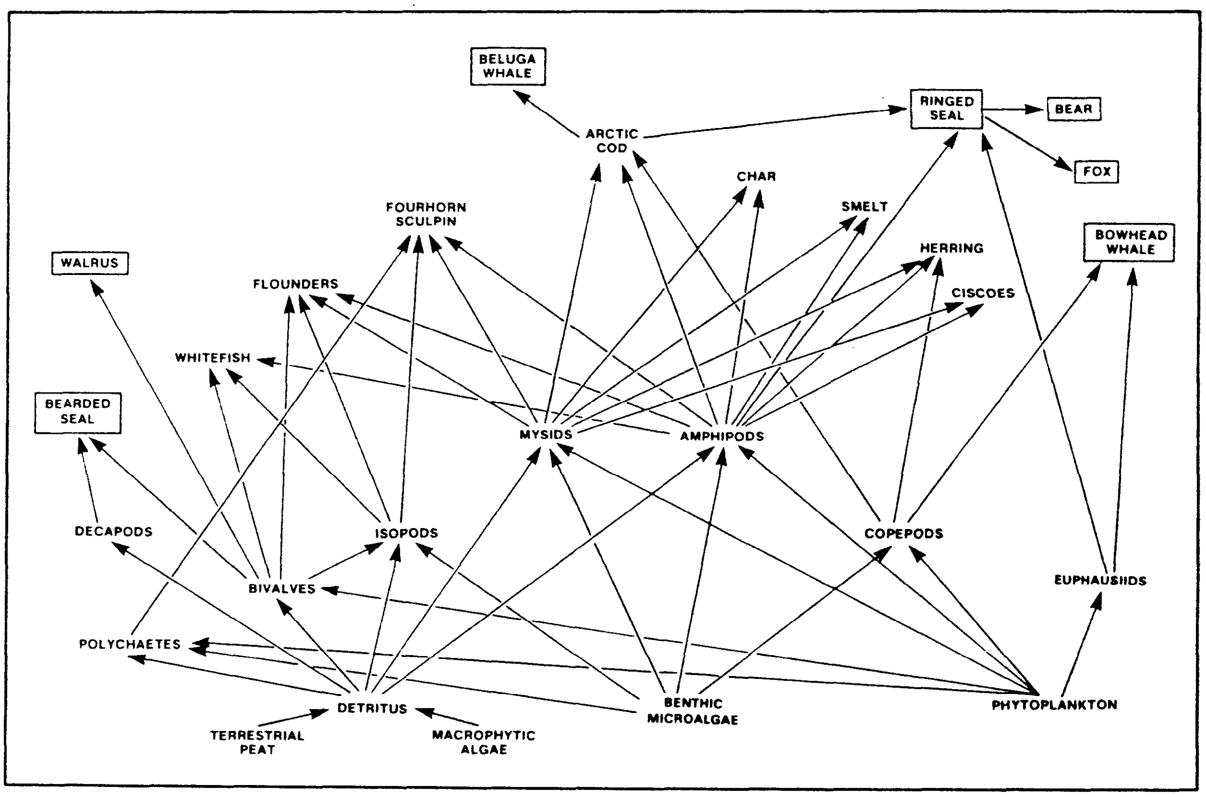


FIGURE 3.1-4 *Major trophic pathways leading to marine and marine-associated mammals in the Beaufort and Northeast Chukchi seas. Ringed seals are the most abundant marine mammal in the region.*

squirrels. Arctic fox populations in the central Arctic are subject to large natural fluctuations as a result of oscillations in the lemming populations (Macpherson, 1969), although these fluctuations have not been documented for the Beaufort Sea region. In the latter population, the abundance and distribution of bears and seals may also have an effect on the coastal population of Arctic foxes which inhabit the sea ice (Stirling and Smith, 1977).

The emphasis in research into Arctic marine food webs is gradually changing from a qualitative or observational approach to one based on ecological energetics. This bioenergetic approach has been most evident in the eastern Arctic and Alaskan Beaufort, where trophic inter-relationships have been better defined than in the Canadian Beaufort. Nevertheless, existing information for the entire Beaufort and northeast Chukchi region is sufficient to identify important trends which have implications to the susceptibility of this ecosystem to disturbance.

The major path of energy flow for the region is based on microalgal production and utilization of detritus in benthic habitats. It is also apparent that crustacea such as isopods, mysids and amphipods are the dominant primary consumers in nearshore habitats of the Beaufort and northeast Chukchi seas, and that these herbivores assume an extremely important role in the support of secondary and tertiary vertebrate consumers. On the basis of available abundance data, it would appear that the major secondary consumers in the region are fish, oldsquaws and eiders, while ringed seals are probably the dominant tertiary consumer in terms of total energy flow from lower trophic levels.

There is considerable variability and overlap in the diets of primary, secondary and tertiary consumers. The majority of consumers in the region appear to have the ability to alter their diet in response to spatial and temporal differences in the availability and abundance of food sources. Few organisms rely solely on a single food source, and this adaptability would appear to be a necessary survival strategy in a physical environment characterized by a high degree of variability and extreme conditions. This adaptability in terms of utilization of alternate food sources, together with the large degree of overlap in the diets of many consumers, particularly benthic epifauna, would contribute to the stability of the entire ecosystem by making it less susceptible to natural or induced perturbations which affect a single biological component. Consequently, past generalizations regarding the short and simple Arctic food webs and their apparent susceptibility to disturbance appear somewhat dated. The fact that Arctic ecosystems are well adapted to a rigorous and variable physical environment would tend to decrease, and not increase, their susceptibility to short term sources of disturbance.

3.2 MARINE MAMMALS

The Beaufort and northeast Chukchi seas support resident and migratory populations of several species of marine mammals, as well as terrestrial mammals which are associated with the sea ice during all or part of their annual cycle. The following section discusses the abundance, spatial and temporal distribution, activities, and known important habitats of the six major species that occur within the region. The resident species include the ringed seal, bearded seal, polar bear and Arctic fox, while migratory species include the bowhead whale and white whale. Other species of marine mammals that are known to range to the Beaufort and northeast Chukchi seas are also briefly discussed.

3.2.1 WHALES

3.2.1.1 Bowhead Whale

The Bowhead whale *(Balaena mysticetus)* is an Arctic baleen whale that may reach a maximum length of 18 m and weight of 50,000 kg (Plate 3.2-1). This species is most closely related to the northern and southern right whales *(Eubalaena glacialis* and *E. australis)*, and is designated as an endangered species under United States legislation. In addition, the bowhead whale is considered an endangered species by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and by the International Union for Conservation of Nature and Natural Resources (IUCN). The International Whaling Commission (IWC) considers all bowhead populations to be protected stocks.

Historically bowhead whales were distributed throughout Arctic and subarctic waters in five presumably discrete stocks. These populations occurred in the Sea of Okhotsk; in the Bering, Chukchi and Beaufort seas; in Hudson Bay; in Davis Strait and Baffin Bay; and finally, near Spitsbergen west to eastern Greenland (IWC, 1978). However, from 1600 to 1900 the bowhead whale was the subject of an intense commercial harvest throughout its range, and all stocks are now considerably reduced. The last population to be exploited was the western Arctic population that winters in the Bering Sea and ranges to the Beaufort and Chukchi seas during spring, summer and fall. This stock was estimated to number between 11,700 and 18,000 prior to intense commercial exploitation (Mitchell, 1977, as cited in Tillman, 1980). Commercial whalers harvested this stock between 1848 and 1915, and were estimated to have killed more than

PLATE 3.2-1 *An adult bowhead whale in the southeastern Beaufort Sea — summer 1981. This Arctic baleen whale may reach a length of 18 m and a weight of 50,000 kg. (Courtesy, LGL Ltd.)*

19,000 bowheads during that period (Bockstoce, 1980).

The current 'best' estimate of the present size of the western Arctic population of bowhead whales is 2,264, and within the range from 1,783 to 2,865 (Braham et al., 1979a). Krogman et al. (1981), based on 1980 and 1981 observations further suggest that the actual western Arctic population size may fall within the upper limits of Braham et al.'s (1979a) estimate (i.e., between 2,264 and 2,865). This population comprises about 75% of the world's bowhead whales based on the current population estimates. The present western Arctic population is estimated to be about 10% of its original abundance (Breiwick et al., 1981). Eberhardt and Breiwick (1980) suggest that the lower size limit of the western Arctic bowhead population was probably not less than 600 whales in 1912, a year which may have been the low point in the abundance of this population. Breiwick et al. (1981) calculated that, at a kill level of 25 per annum, a minimum of 40 years will be required for this population to recover to 9,000 (50% of its original abundance of 18,000) if the present stock currently numbers 2,700.

After the collapse of the whaling industry in 1915 in response to a drastic decline in both the value of baleen and availability of the bowhead, the Alaska Inuit resumed a small subsistence hunt which has been regulated on an annual quota basis by the IWC since 1978 (Marquette and Bockstoce, 1980) (Section 3.6.2). It is illegal for Canadian Inuit to harvest bowheads.

It is believed that bowheads of the western Arctic population mate during or just prior to the spring migration (Everitt and Krogman, 1979). Gestation probably lasts at least 11 months (Nishiwaki, 1972), and calving probably occurs just prior to or during migration, since young-of-the-year have been recorded during spring movements (Braham et al., 1980a). The low percentage of calves (2-4%) recorded in both western and eastern Arctic bowhead populations (Braham et al., 1979a, 1980b; Davis and Koski, 1980; Renaud and Davis, 1981; Fraker et al., 1981) suggest that the reproductive potential of this species is low compared to other baleen whale populations (4 to 8.5%) (Ohsumi, 1979). The slow and incomplete recovery of this and other bowhead populations after the cessation of whaling activity also provides evidence for a low reproductive potential.

During years of average ice conditions, the western Arctic population of bowheads winter amongst the pack ice in the Bering Sea from St. Lawrence Island south to Matthew Island (Braham et al., 1979b). They leave the Bering Sea during March and April, passing Point Barrow, Alaska from mid April to early June (Braham et al., 1980a). The migration of bowheads along the northwest coast of Alaska is characterized by little or no feeding activity (Ljungblad et al., 1980), with concentration of most (if not all) migrants within the lead adjacent to the landfast ice between Cape Lisburne and Point Barrow (Braham et al., 1980a). Migrants pass in at least two "waves" or "pulses" throughout the spring and early summer (Marquette, 1978; Braham et al., 1980a). Although the significance of this bimodal or trimodal distribution is unknown, it may be associated with age and/or sexual segregation, since the large males and cows with calves are usually more prevalent in late May and June, while most of the whales seen from mid April through early May are smaller (Carroll and Smithhisler, 1980; Braham et al., 1980a).

East of Point Barrow, bowheads travel northeast along an offshore route through leads in the pack ice to the eastern Beaufort Sea, and then intercept and follow the major lead west of Banks Island to Amundsen Gulf (Braham et al., 1980a). Depending on ice conditions, later migrants may follow the nearshore lead on a more direct route through the eastern Beaufort Sea to Amundsen Gulf (Figure 3.2-1). Although a few recent observations and reports

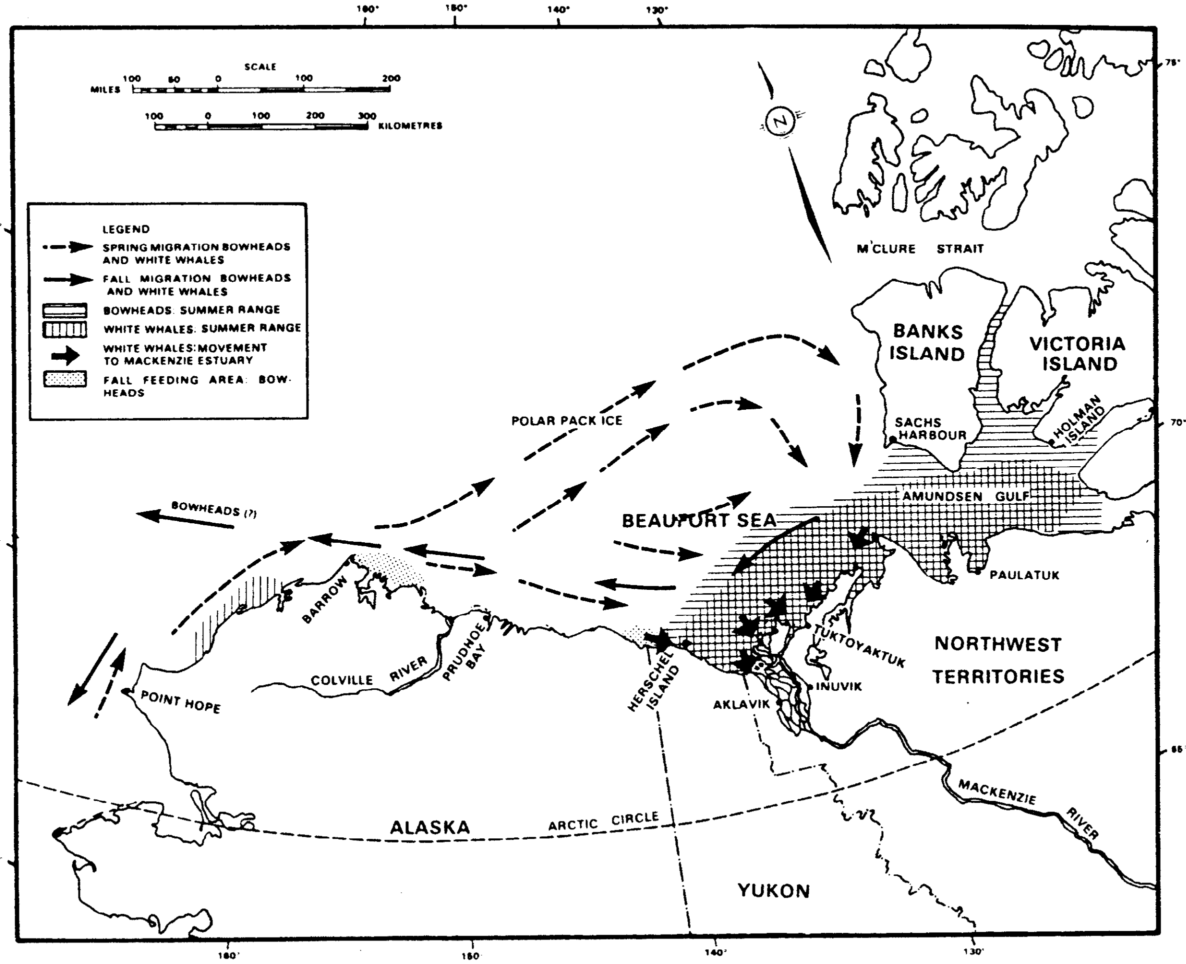


FIGURE 3.2-1 *Migration routes and summer range of bowhead and white whales in the Beaufort and Chukchi seas. Bowheads and white whales first arrive at the summer range during early to mid May and leave during late August and September.*

from Eskimo whalers near Point Barrow indicate that some bowheads do not migrate as far east as the Canadian Beaufort, the distribution and abundance of whales remaining in Alaskan waters has not been documented (Braham et al., 1980a).

The first bowheads usually arrive at their summer range in the eastern Beaufort Sea and Amundsen Gulf during early to mid May, although they are not present in substantial numbers until about mid June (Fraker et al., 1978; Fraker, 1979; Fraker and Bockstoce, 1980). The summer range functions as a major feeding area (Wursig et al., 1981; Griffiths, 1981). Although their distribution on the summer range depends on ice conditions, bowheads initially occupy areas off the Bathurst Peninsula and Amundsen Gulf (Fraker and Bockstoce, 1980). However, recent observations and historical whaling records indicate that there is a gradual westward extension of the range to include areas off the Mackenzie Delta and Tuktoyaktuk Peninsula, usually by late July or early August (Fraker and Bockstoce, 1980).

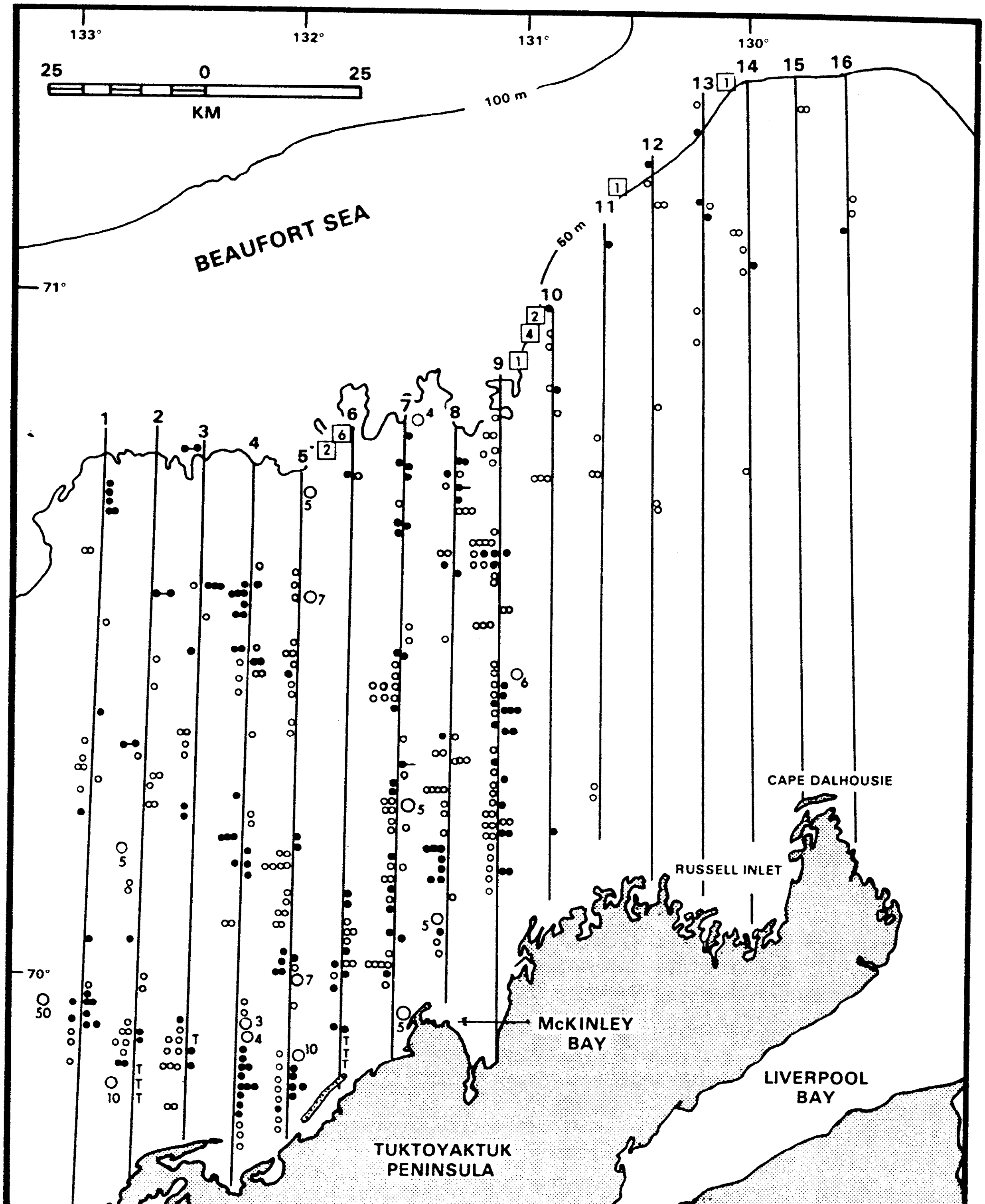
Recent observations of bowheads in the eastern Beaufort during the period from July to September indicate that there are differences in the distribution of bowhead whales off the Mackenzie Delta and Tuktoyaktuk Peninsula from year to year (Fraker et al., 1981; Fraker and Fraker, 1981; Renaud and Davis, 1981; LGL, in prep.). In 1980, industry-sponsored bowhead surveys were conducted near artificial island (Issungnak 0-61) construction activities 32 km north of Pullen Island (Fraker and Fraker, 1981) and throughout the area off the Tuktoyaktuk Peninsula to the 50 m isobath (Renaud and Davis, 1981) to provide information on the distribution of bowheads on their summer range. Construction of Issungnak began in 1978 and various industrial activities have been underway there since then. Bowheads were observed during aerial surveys and by industry personnel near offshore operations between 1976-1978, but only a few were reported near Issungnak in 1979 (Fraker and Fraker, 1979). However, in August 1980, relatively large numbers of bowheads were observed near Issungnak by both aerial survey and industry personnel. During five aerial surveys conducted near Issungnak during the period from August 5-12, 1980, the densities of bowheads observed 'on-transect' ranged from 0.028 to 0.055 whales/km^2 (Fraker and Fraker, 1981). A subsequent survey near Issungnak on August 22, 1980 indicated a lower density of bowheads (0.026/km^2), and Fraker et al. (1981) suggested that the whales had then moved east to areas off the Tuktoyaktuk Peninsula. Industry personnel at Issungnak also reported 17 sightings of bowheads (ranging from 1 to 40-50 animals per sighting) between August 2-18, 1980, but reported only one more whale during the remainder of the summer (September 11). Although the non-systematic and various degrees of sighting effort in different years prevents a precise interpretation, the results of these and past surveys indicate that the summer distribution of the bowhead whale varies from year to year. The results of systematic surveys in 1980 and 1981 more clearly demonstrate the year-to-year differences.

The systematic bowhead surveys in the eastern Beaufort in 1980 were conducted during August 6-7 and 21-24, and September 3-4 over waters north of the Tuktoyaktuk Peninsula to the 50 m isobath (Renaud and Davis, 1981). Although only six bowheads were observed on the first survey, a major influx of bowheads had occurred by August 21-24. The 755 bowheads estimated to have been at the surface in the survey area on those days (or 26-42% of the western Arctic population, based on estimates of Braham et al., 1979a) were present in waters to the 50 m isobath from Toker Point to McKinley Bay (Figure 3.2-2). No allowance was made for whales beneath the surface, consequently, actual numbers in the surveyed area were probably much larger than the 755 estimated. Bowheads were also observed to the east, west and north of the area surveyed on August 21-24. Although Fraker and Fraker (1981) suggest that the whales observed in this survey had moved in from the west (e.g. Issungnak), it was not known if this was an isolated event related to the delayed spring migration in 1980 or typical of the annual distributional pattern. During the final survey in early September, 1980, an estimated 222 bowheads were present at the surface in the study area and were moving primarily to the southwest and west through offshore waters (Renaud and Davis, 1981).

In 1981, surveys similar to the 1980 systematic surveys were conducted over waters north of the Tuktoyaktuk Peninsula and Mackenzie Delta during July 18-25, August 5-17, August 19-29 and September 7-14 (LGL, in prep.). Whereas the 1980 surveys extended offshore only to the 50 m isobath, the 1981 surveys extended offshore to the 100 m isobath. At the time of this writing, data analyses and report preparation were still in progress and only the following general trends are reported. Only two bowheads were seen during the first survey. By the second survey, bowheads had started to move into the survey area but were north of 70°30'N latitude. During the third survey, bowheads were widely distributed in the survey area but many were still north of 70°30'N latitude. Fewer animals were present in the survey area during this third survey in the 1981 than during the comparable one in 1980. During the last survey fewer animals were seen and they were closer inshore.

The summer range of the bowhead whale appears to function primarily as a feeding area. Recent studies of the behavior of bowheads on their summer range indicate that feeding was the predominant activity. The types of feeding behavior and the results of stomach content analyses of whales landed in Alaska (Johnson et al., 1966; Lowry et al., 1980) suggest that bowheads feed primarily on zooplankton, although infaunal and epibenthic organisms also comprise an unknown portion of their diets. Since it is illegal to kill bowheads in Canada, samples of stomach contents from whales feeding on their range in the southeastern Beaufort are unavailable. However, the preliminary results from a study of the biological and physical characteristics of bowhead feeding areas in the eastern Beaufort Sea show that hydrozoans and copepods dominate the zooplankton community, while mysids and isopods were the most abundant epibenthos, and polychaete worms and bivalve molluscs were the major infaunal invertebrates (Griffiths, 1981). In addition, preliminary results of this study showed that bowheads tend to concentrate in areas of significantly higher copepod biomass than surrounding areas (Griffiths, 1981). Stomach contents of bowheads landed near Barter Island, Alaska in September-October, 1979, contained predominantly copepods and euphausiids (Lowry and Burns, 1980), while two bowheads landed near Point Barrow had been feeding primarily on euphausiids and mysids (Lowry et al., 1978). Although other items in the stomach contents of the whales from Barter Island (e.g. gammariid amphipods, isopods, small fish, pebbles) were not considered major food items, the presence of pebbles and benthic invertebrates indicated that some bowheads must feed on or near the bottom, at least in nearshore areas. During aerial surveys in 1980, several bowheads were observed to be apparently feeding on the bottom in areas 25 km west of Issungnak (Wursig et al., 1981) and off the Tuktoyaktuk Peninsula (Renaud and Davis, 1981).

During September and October, bowheads migrate west from the Canadian Beaufort Sea into the Alaskan Beaufort Sea and then into the Chukchi and Bering seas (Ljungblad et al., 1980). Most whales probably follow a route within 40 km of the mainland coast (Figure 3.2-1). There have been a relatively large number of recent observations of bowheads along the Yukon coast between Shingle Point and Kay Point during August and September. These reports include sightings of 1 to 7 whales, with most



•	I INDIVIDUAL ON-TRANSECT	2	INCIDENTAL OBSERVATION OF 2 INDIVIDUALS
•—•	COW-CALF PAIR ON-TRANSECT	O5	5 INDIVIDUALS OFF-TRANSECT (ASSOCIATION NOT RECORDED)
•—	SOLITARY CALF ON-TRANSECT	T	MUD TRAIL CAUSED BY A FEEDING (?) BOWHEAD WHALE
o	I INDIVIDUAL OFF-TRANSECT	—	SURVEYED TRANSECT LINES
ooo	GROUP OF 3 INDIVIDUALS OFF-TRANSECT		

FIGURE 3.2-2 *Distribution of bowhead sightings, August 21-24, 1980. During this survey 755 bowheads were estimated to have been seen at the surface, representing 26-42% of the total population. (Source: Renaud and Davis, 1981).*

sightings occurring within 3.2 km of the shore (Fraker and Bockstoce, 1980). In some years, feeding apparently continues within 25 km of the shore during the fall migration off northern Alaska, at least in areas just east of Point Barrow (Braham et al., 1977; Lowry et al., 1978) and west of the Alaska-Yukon border (Ljungblad et al., 1980; Ljungblad, 1981; and Lowry and Burns, 1980). During aerial surveys of the bowhead fall migration through Alaskan waters in 1979, Ljungblad et al. (1980) reported 134 individual or group sightings (total number of whales seen was 249) between Demarcation Bay and Point Barrow. The sightings occurred primarily along the 20 m isobath. Bowheads were observed moving in an unhurried manner, (e.g. 2.8 to 5.6 km/hr) and were possibly feeding during the migration (Ljungblad et al., 1980; Ljungblad, 1981). East of Point Barrow, some bowheads may move toward areas of the Chukcki Sea near Wrangel Island, USSR before migrating back to the Bering Sea (Braham et al., 1977).

3.2.1.2 White Whale (Beluga)

The white whale *(Delphinapterus leucas)* is a small, toothed whale that occurs in the subarctic and Arctic waters of North America and Eurasia. White whales which occur in the Canadian Arctic are believed to belong to five distinct populations that total 28,500 to 32,700 whales (Sergeant, 1973; Sergeant and Brodie, 1975; Fraker and Fraker, 1979; Davis and Finley, 1979; Brodie et al., 1980). The stock that ranges to the Beaufort and Chukchi seas during spring, summer and fall has been estimated to number at least 7,000 (Fraker and Fraker, 1979).

The average lengths of female and male adults harvested from the Beaufort Sea population were 3.6 m and 4.3 m, respectively (Fraker, 1980). The reproductive potential of this species is not well understood because there is uncertainty about the validity of the aging method. Original methods advocated that two dentinal layers were laid down each year (Brodie, 1971; Sergeant, 1973), while a more recent opinion (Sergeant, 1979) suggests only one layer is added per year. Depending on which aging method is correct, females mature at 5 or 10 years of age. They have a single calf every third year (Brodie, 1971), and the average life span is 25 or 50 years. Mating occurs during the spring, and calves are born about 14.5 months later (Brodie, 1971). The major food items of white whales feeding in offshore waters of the Beaufort Sea and Amundsen Gulf probably include squid and Arctic cod, although other fish and invertebrates may contribute significantly to the diet depending on prey size and availability (Fraker, 1977; Fraker et al., 1978).

White whales migrate from wintering areas in the Bering Sea during March and April, usually passing Point Barrow, Alaska between late April and June (Braham et al., 1977). East of Point Barrow, white whales migrate through leads far offshore in the Beaufort Sea and eventually follow the major lead which usually exists west of Banks Island to Amundsen Gulf (Figure 3.2-1) (Fraker, 1977). Depending on ice conditions, the first white whales generally arrive in the eastern Beaufort Sea during mid May (Fraker, 1977, 1979). Later migrants may be able to follow a more southerly route and move along nearshore leads to the gulf or directly to the Mackenzie estuary (Plate 3.2-2). Some individuals may spend from 4 to 6 weeks in Amundsen Gulf before moving to the estuary (Fraker, 1979).

During late June and early July, there is a westward migration of white whales from Amundsen Gulf to the Mackenzie estuary. The migration is concentrated along the landfast ice edge off the Tuktoyaktuk Peninsula, across northern Kugmallit Bay, and along the northeast and north coasts of Richards Island (Fraker, 1977). White whales do not typically follow narrowly defined routes elsewhere in the southeastern Beaufort Sea (Fraker, 1977). The majority of white whales from this population are believed to concentrate in the Mackenzie estuary from late June or early July through to mid July. By late July and early August, only small numbers occur in the estuary. Within the Mackenzie estuary, white whales usually occur within three concentration areas: in 'Niakunak Bay' (Shallow Bay), in Kugmallit Bay near Hendrickson Island, and in East Mackenzie Bay near Kendall, Garry and Pelly islands (Figure 3.2-3) (Fraker, 1977, 1978; Fraker and Fraker, 1979, 1981). However, recent studies have cast doubt on the validity of including East Mackenzie Bay in the same category as the former areas since it is usually used later in July or in early August, and by consistently fewer whales than Niakunak and Kugmallit bays.

These 'concentration areas', which are located near major outflow channels of the Mackenzie River, are characterized by warm (e.g. 10 to 18°C), turbid, freshwater. These areas are shallower (less than 2 m) than most adjacent areas in the Mackenzie estuary (Fraker et al., 1979). Recent studies of the distribution of white whales within the estuary during July have indicated that the break-up of the landfast ice has a marked effect on the number of whales which reach each concentration area (Fraker and Fraker, 1981). For example in 1972, 1978, 1979 and 1980, the late break-up of ice in Kugmallit Bay was probably responsible for the use of that area by only small numbers of whales (Slaney, 1974; Fraker, 1978; Fraker and Fraker, 1979, 1981), while the earlier break-up in West Mackenzie Bay permitted large numbers of whales to reach Niakunak Bay and West

PLATE 3.2-2 *A group of beluga whales (white whales) in an offshore lead. Up to 7,000 have been counted in the shallow waters of the Mackenzie estuary during the summer season.*

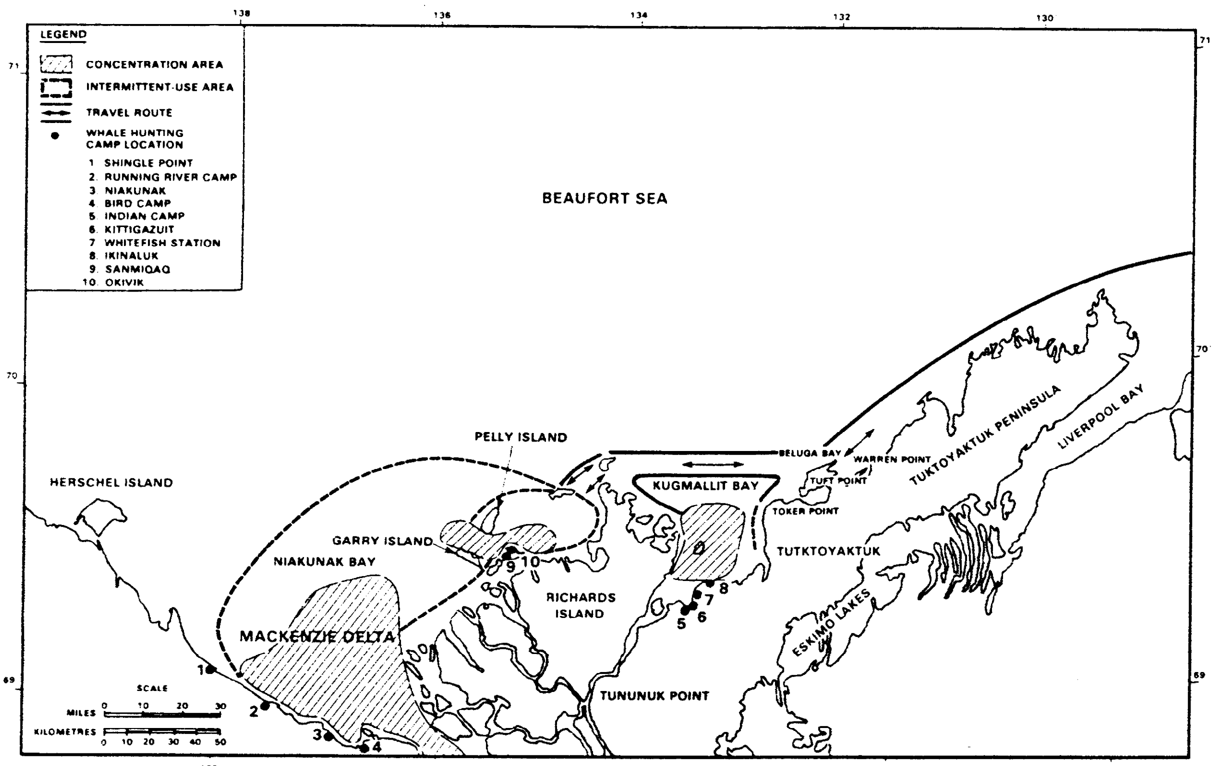


FIGURE 3.2-3 *White whale concentration and intermittent use areas in the Mackenzie River estuary. (Source: Fraker and Fraker, 1982).*

Mackenzie Bay. In 1980, the maximum estimate of white whales in Niakunak Bay was 4,234 (July 10), while the maximum recorded in Kugmallit Bay was 120 on July 24 (Fraker and Fraker, 1981). On the other hand, large numbers of whales were present in both Niakunak and Kugmallit Bay since 1976, 1977 and 1981 when the landfast ice in Kugmallit Bay fractured earlier than usual in relation to the timing of the white whale migration. Maximum population estimates during 1976, 1977 and 1981 were 3,500, 3,800 and 2,460 in Niakunak Bay and 2,000, 1,750 and 1,040 in Kugmallit Bay, respectively (Fraker, 1977; Fraker and Fraker, 1982). West Mackenzie Bay is used mainly by whales migrating to and from Niakunak Bay, although in late July and early August whales often congregate in the shallow near-shore areas. Similarly, East Mackenzie Bay many be used by whales migrating to Niakunak Bay during years when the ice fractures there first, but it is used by few (less than 1,000) whales during the July concentration period.

The total number of whales calculated to have been present during the peak period in 1980 was 4,500 on July 10 (Fraker and Fraker, 1981). In 1979, the total estimate during the peak period was 7,000 on June 30 (Fraker and Fraker, 1979). Year-to-year variation in the estimates of the maximum number of whales within the Mackenzie estuary may be the result of actual differences in the number of whales, the proportionate time whales occur and are observed near the surface, and/or weather interference during surveys. The 1979 estimate is considered the current 'best' estimate of maximum numbers of whales in the Mackenzie estuary, since it was made under excellent weather conditions and at a time when whales were spending more time than usual at the surface. Calves are not included in the estimates because they are too dark to be reliably counted in the turbid water.

Sergeant (1973) and Sergeant and Brodie (1975) hypothesized that white whales congregate in estuaries to calve. Nevertheless, harvest data and recent observations indicate that both sexes and all age classes occur within the Mackenzie estuary. There has been no direct evidence that calving occurs within the estuary, but there is considerable evidence that some white whales calve offshore (Fraker, 1977). Fraker et al. (1978) suggest that whales may congregate in the Mackenzie estuary because the water is shallow and relatively warm, and probably beneficial to newborn calves during the rearing period.

Although white whales generally occur in the aforementioned concentration areas during the first half of July, relatively large numbers are also occasionally observed for short periods (2 to 3 days) over wide 'intermittent-use' areas seaward of the concentration areas (Figure 3.2-3) (Fraker, 1977). These areas may be used as feeding grounds. However, the almost complete lack of food in stomachs of white whales landed in the concentration areas and the lack of observations of whales feeding in these areas indicates that adults feed little, if at all, when they are in the concentration areas of the estuary (Fraker, 1977).

The number of whales observed in the concentration areas is usually highest during the first half of July. Many may move offshore to feed at the edge of the pack ice, while some may remain in, or return to, the estuary since white whales have been observed in the estuary until September (Fraker and Fraker, 1981). From mid July to mid August, white whales are frequently observed along the edge of the Tuktoyaktuk Peninsula. Fraker and Fraker (1981) recorded 123 whales off the Peninsula on August 12, 1980, and suggested that they were probably returning to the estuary. During surveys in the vicinity of Issungnak 0-61 in late July and early August, 1980, relatively few white whales were recorded by observers and industry personnel. Most sightings involved whales moving in all directions, and no repetitive patterns were evident. In addition, there is some evidence that some white whales move farther east into Amundsen Gulf, Liverpool Bay and the Eskimo Lakes during the latter part of the open water period (Fraker et al., 1978). Systematic aerial surveys conducted in nearshore and offshore areas of the eastern Beaufort Sea and Amundsen Gulf by industry during 1981 will provide additional information on the distribution of white whales during the summer.

During their residence in the Mackenzie estuary, white whales are harvested by Inuit from Tuktoyaktuk, Inuvik and Aklavik. Alaskan Inuit also hunt white whales along the ice edge during the spring migration (Section 3.6.2.2). Archaeological records indicate that white whales have been harvested at the East Channel of the Mackenzie Delta for at least 500 years (McGhee, 1974; cited in Fraker, 1980), and there are indications that the harvest of earlier years may have exceeded the current harvest (Fraker et al., 1978). The annual harvest of white whales in the western Arctic by Canadian and Alaskan Inuit averages about 167 (Fraker, 1980). However, based on loss rates of 33% in the Mackenzie estuary and 67% in Alaska, Fraker (1980) estimated that the total annual kill is probably just under 300. This is equivalent to 4.3% of the adult population based on 1979 estimates by Fraker and Fraker (1979).

Between 1972 and 1981, an average of 133 white whales were landed annually in the estuary (Section 3.6.2.2). Hunting effort is generally greater in Kugmallit Bay, with landings from this area typically accounting for 60 to 80% of the entire harvest. In 1980, poor weather conditions and a marked decrease in the number of whales present in Kugmallit Bay were responsible for a total catch of only 90 whales of which 42% were landed in Kugmallit Bay (Fraker and Fraker, 1981). However, the 1981 catch of 149 whales was the most successful harvest since 1976 and was well above the average (Fraker and Fraker, 1982).

The fall migration of white whales from the eastern Beaufort Sea begins during late August and September. Fraker and Fraker (1981) concluded that the majority of fall migrants probably travel offshore near the edge of the pack ice, since only a few have been sighted in coastal areas during numerous surveys and they have been observed migrating through offshore waters in Alaska (Fraker et al., 1978; Johnson, 1979).

3.2.1.3 Other Whales

The gray whale *(Eschrichtius robustus)* is a medium sized baleen whale which feeds primarily on benthic invertebrates (Rice and Wolman, 1971). This species is designated as a rare and endangered species under U.S. legislation, although the California stock of gray whales has been recently reclassified from a 'protection stock' to a 'sustained management stock' by the International Whaling Commission. Although the Californian population of gray whales summer mainly in the north Pacific Ocean, and the Bering and Chukchi seas, gray whales regularly enter the western Beaufort near Point Barrow during the summer. During the summer of 1980 three gray whales were sighted in the eastern Beaufort Sea (Rugh and Fraker, 1981; Renaud and Davis, 1981). One was sighted there in the summer of 1981 (LGL, in prep.).

The narwhal *(Monodon monoceros)* is a small, toothed whale closely related to the white whale. Narwhals occur primarily in eastern Canadian and Greenland Arctic waters, but may occur as stragglers in the Beaufort and Chukchi seas (Geist et al., 1960; Smith, 1977; Reeves, 1978).

A small number of killer whales *(Orcinus orca)* may migrate to the Chukchi Sea during summer, but they rarely range east of Point Barrow, Alaska (Leatherwood and Dahlheim, 1979).

3.2.2 SEALS

3.2.2.1 Ringed Seal

The ringed seal *(Phoca hispida)* is the smallest pinniped, attaining an average adult weight of about 50 kg (Plate 3.2-3). This species is the most abundant and widespread marine mammal in the Canadian Arctic, and is harvested by virtually all coastal Arctic

PLATE 3.2-3 *Yearling ringed seal. The ringed seal is the smallest pinniped, attaining an adult weight of about 50 kg. (Courtesy, Canadian Wildlife Service).*

communities (Section 3.6.1.1). During the period from late spring to late autumn, ringed seals in the central Beaufort Sea prey primarily on pelagic invertebrates (e.g. the amphipod *Parathemisto libellula)*, while the Arctic cod *(Boreogadus saida)* is the principal food item during the period from November to April (Lowry et al., 1980). Polar bears prey extensively on subadult ringed seals, although they are also known to take some adults as well. Arctic foxes prey heavily on pups in subnivean birth lairs during the spring (Smith, 1976). Predation by bears and foxes is the major source of natural mortality of ringed seals (Smith, 1976; Stirling and McEwan, 1975).

Stirling et al. (1981a) summarized the results of seal surveys conducted from 1974 to 1979 in the south eastern Beaufort Sea. The study areas encompassed a coastal region 160 km off the mainland shore and off the west coast of Banks Island in the Canadian Beaufort Sea, and western Amundsen Gulf to 123°45'W. Aerial surveys were conducted during the peak of the diurnal cycle of the haul-out period. Estimates of the number of hauled-out seals are considered indices of abundance rather than counts of the total population because no correction was made for seals that remained under the ice during the surveys. Densities and total estimated counts of ringed seals in the study area are indicated in Figure 3.2-4. The estimated population in the Beaufort Sea region between 1974 and 1979 has ranged from a low of approximately 23,000 in 1977 to a high of approximately 62,000 animals in 1978. Between 1974 and 1975, there was an apparent 50% decline in the number of ringed (and bearded) seals in the Canadian Beaufort region. Stirling et al. (1977) and Stirling et al. (1981a) speculate the decline was probably related to the severe ice conditions during the winter of 1974-75. Similar decreases in the ringed seal population of the Alaskan Beaufort and northeast Chukchi seas were also recorded between 1974 and 1975 (Eley and Lowry, 1978). The decline was believed to have resulted from a combination of factors which included a decrease in production of pups, a probable increase in mortality, and large scale movements of a significant proportion of the population out of the eastern Beaufort Sea (Stirling et al., 1977, 1979; Smith and Stirling, 1978). The ringed seal population remained low through 1975 to 1977, but between June 1977 and June 1978, numbers increased 2.5-fold. The 1979 estimates were similar to those recorded in 1974 prior to the major decline. Stirling et al. (1980) suggest the seal population in the eastern Beaufort Sea has recovered from the 1974-1975 decline, but that total numbers will continue to fluctuate among years.

During winter, breeding adults occupy the landfast ice where they maintain breathing holes (Smith, 1973). They are known to occupy large bays of Amundsen Gulf, and to a lesser extent, the inshore landfast ice areas off Tuktoyaktuk Peninsula and the west coast of Banks Island (Stirling et al., 1977) (Figure 3.2-5). Subadults and non-breeding adults typically concentrate in leads and areas of thin ice in the transition zone during winter and spring (Stirling et al., 1977). Very low densities of ringed seals occur in pack ice areas (Burns and Eley, 1977).

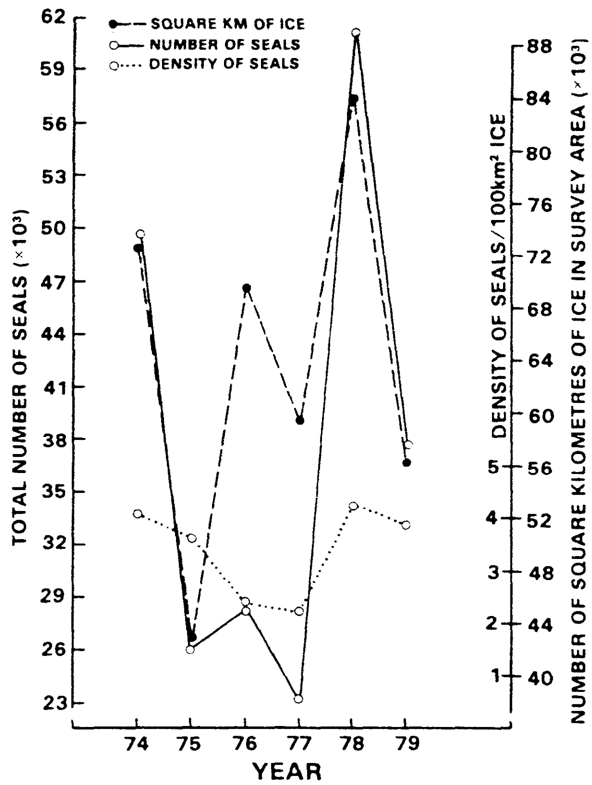


FIGURE 3.2-4 *Total numbers of ringed seals on the ice and densities of seals per 100 km² in the southeastern Beaufort Sea. (Source: Stirling et al., 1981a).*

Females are sexually mature at 6 years of age (males 7 years) and gestation lasts about 9 months after a delayed implantation (Smith, 1973). Pupping occurs during late March and early April in subnivean lairs on the landfast ice (Smith and Stirling, 1975). The lactation period lasts about 1.5 to 2.0 months (McLaren, 1958; Smith, 1973). Newborn pups average 65 cm in length and 4.5 kg in weight.

In the eastern and western Arctic, large numbers of ringed seals haul-out to moult in June (Smith, 1973). In the Canadian Beaufort Sea and western Amundsen Gulf, Stirling et al. (1981a) reported highest densities of hauled-out seals in fast ice along the Yukon coast, around Cape Parry and along the southwest coast of Banks Island (Figure 3.2-6). They preferred areas with a high proportion of ice cover and moderate water depths (50 to 75 m) (Stirling et al., 1981a).

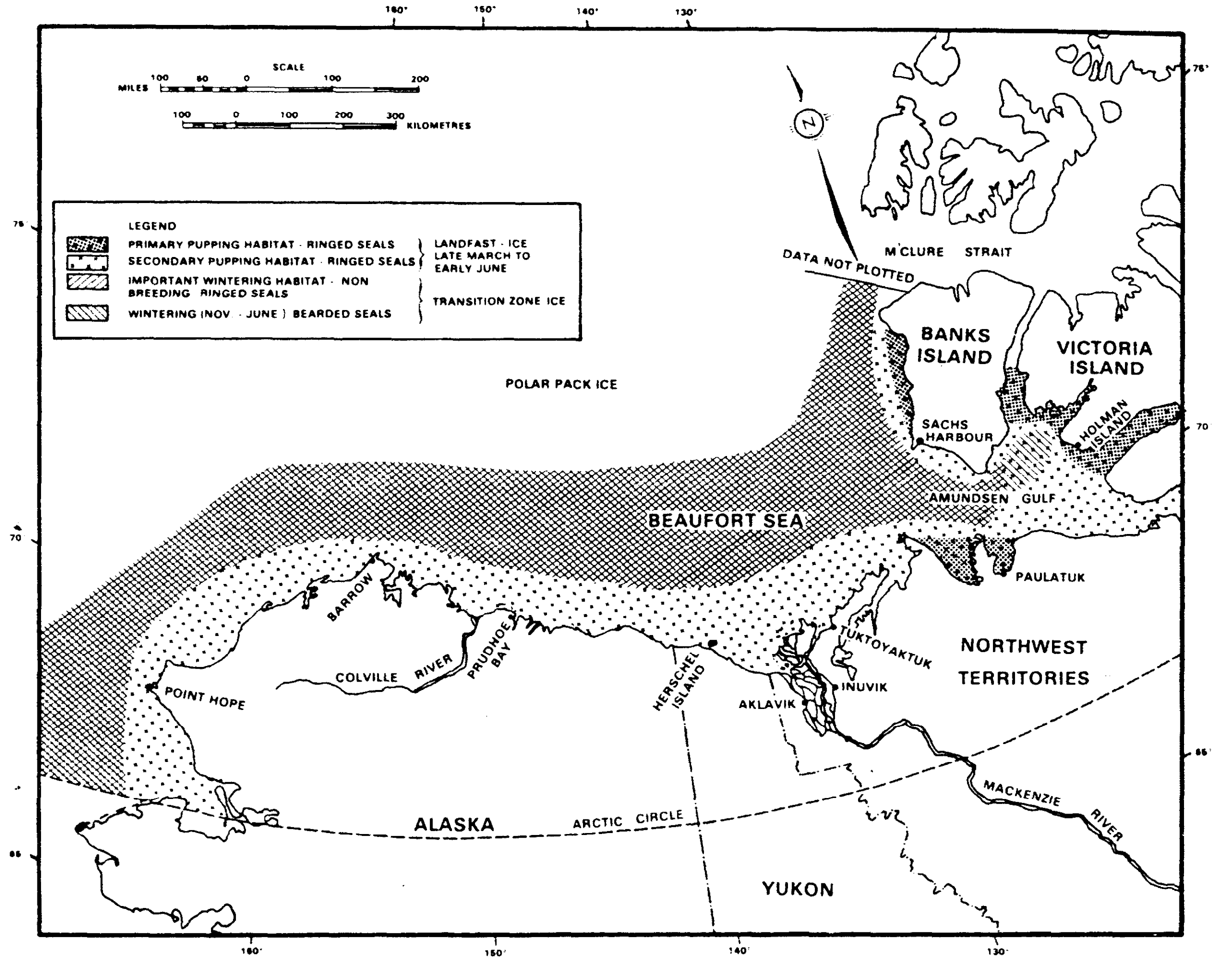


FIGURE 3.2-5 *Distribution of important seal wintering and pupping habitats in the Northeast Chukchi Sea, Beaufort Sea and Amundsen Gulf. During winter breeding, ringed seals occupy the landfast ice, where they maintain breathing holes.*

The distribution of ringed seals during the open water season has not been well documented, although concentrations are known to occur at the edge of the pack ice north of Alaska and the Yukon, as well as near ice remnants along the coast (Eley and Lowry, 1978). Other seals remain in ice-free nearshore waters. Recent industry sponsored aerial surveys conducted off the Tuktoyaktuk Peninsula to the 50 m isobath indicated high densities (mean 0.416/km^2, range 0.025 to 1.434/km^2) of ringed seals during August 21-24, 1980 (Renaud and Davis, 1981). This density estimate is considered a minimum figure because of the low detectability of ringed seals in the outer portions of the 800 m wide transect strip and because no allowance was made for animals beneath the surface. Since few seals were observed during surveys conducted on August 6-7 and September 3-4, 1980, the authors concluded that a major influx of ringed seals may have occurred by the late August survey (Renaud and Davis, 1981). At least some of the seals appeared to be feeding in the area.

3.2.2.2 Bearded Seal

The bearded seal *(Erignathus barbatus)* is a large, solitary seal that ranges throughout Arctic waters. Adults attain an average weight of 340 kg and a length of 2 m (Plate 3.2-4).

The Bering and Chukchi sea populations of bearded seals total approximately 300,000 to 450,000 (Burns and Frost, 1979). Uncorrected estimates of the size of the bearded seal population in the Canadian Beaufort to 160 km offshore from the mainland and Banks Island, and western Amundsen Gulf to 123°45'W (during haul-out) ranged from 3,072 (1974), 1,389 (1975), 1,687 (1976), 1,309 (1977), 3,109 (1978), to 2,056 (1979) (Stirling et al., 1981a). As indicated by these estimates, the bearded seal population declined (like the ringed seal population) by at least 50% between 1974 and 1975. Stirling et al. (1977) speculated the decline was in response to heavy ice conditions in 1974-75, and was caused by decreased reproduction, a probable increase in mortality, and emigration. However, recent estimates (1978, 1979) suggest that the bearded seal population has recovered from the decline observed in 1975, and that numbers will probably continue to fluctuate (Stirling et al., 1980).

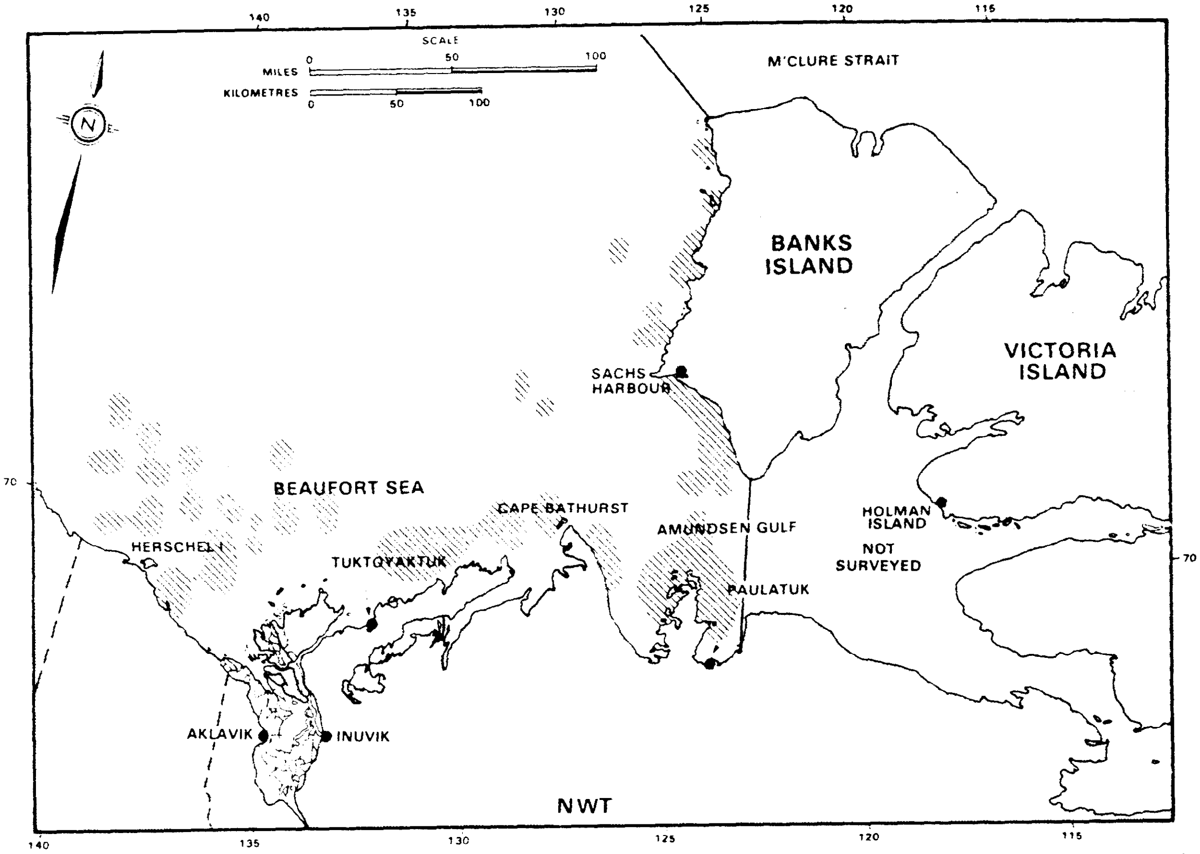


FIGURE 3.2-6 *General distribution of hauled-out ringed seal concentrations, 1974-1979. (Adapted from Stirling et al., 1981a). Highest densities have been recorded in fast ice along the Yukon coast, around Cape Parry, and along the southwest coast of Banks Island.*

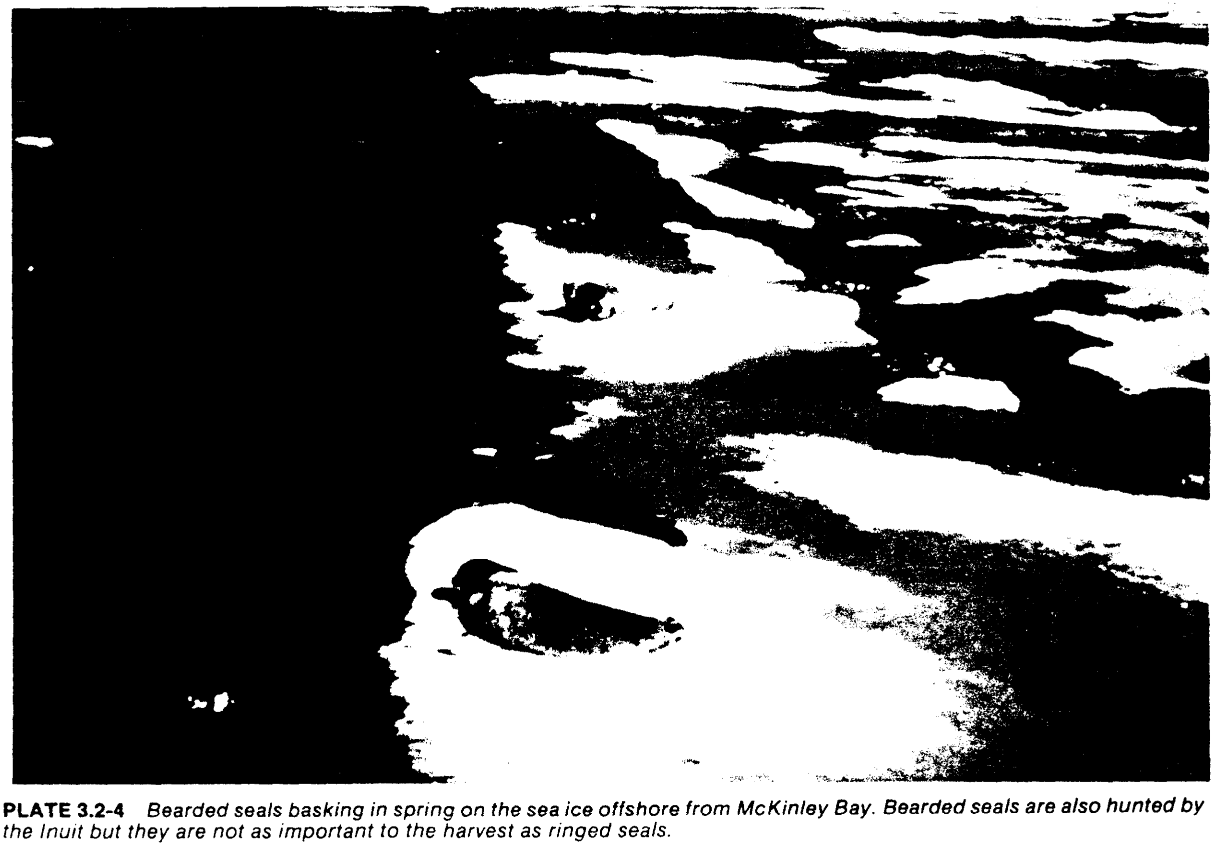


PLATE 3.2-4 *Bearded seals basking in spring on the sea ice offshore from McKinley Bay. Bearded seals are also hunted by the Inuit but they are not as important to the harvest as ringed seals.*

Bearded seals are hunted by the Inuit, but are not as abundant or important to the harvest as ringed seals (Section 3.6.1.1). Bearded seals feed primarily on benthic and epibenthic organisms, and are typically restricted to the shallower waters of the continental shelf. This species prefers broken ice areas with shallow depths (less than 50 m) (Stirling et al., 1981a), and may be limited to an effective feeding depth of 90 to 100 m (Ivashin et al., 1972, cited in Stirling et al., 1977).

Females are sexually mature at six years of age, while males are sexually mature at seven years. Females mate every year, and gestation lasts approximately 11.5 months. The pups are usually born on the moving pack ice during late April and early May, and lactation lasts for 12 to 18 days before the pups are abandoned (Burns and Frost, 1979). The average weight of a newborn pup is about 45 kg.

During the winter, most bearded seals occur in shallow water areas in the transition zone or in nearshore pack ice areas (Figure 3.2-5) (Eley and Lowry, 1978). Although bearded seals do not typically maintain breathing holes in the fast ice, this has been observed during prolonged icebound periods in Amundsen Gulf (Stirling and Smith, 1977).

During the summer open water period, the population of bearded seals in the western Beaufort is believed to be augmented with seals from the Chukchi Sea (Burns and Frost, 1979). Unsuitable feeding areas for bearded seals predominate in the eastern Beaufort because the pack ice is typically located north of the continental shelf and they prefer shallow water areas with associated pack ice. However, bearded seals are relatively common in certain nearshore areas near southern Banks Island, Cape Parry and Herschel Island during summer (I. Stirling, T.G. Smith, pers. comms., cited in LGL and ESL, 1981).

3.2.2.3 Pacific Walrus, Other Seals and Sea Lions

The Pacific race of walrus *(Odebenus rosmarus divergens)* occurs in the Bering and Chukchi seas, and was historically present in the Beaufort Sea (Fay, 1957). Walruses feed primarily on infaunal invertebrates such as bivalve molluscs, and are usually restricted to shallower waters within the 100 m isobath (Vibe, 1950).

The Pacific walrus population has now recovered or exceeded pre-exploitation levels of 200,000, and there is evidence which suggests that the carrying capacity of the available range has been reached (Fay et al., 1977; Lowry et al., 1979). The majority of the Pacific population winters on the pack ice in the Bering Sea, although small herds may remain in the Chukchi Sea. During spring and summer, most walruses move northward with the retreating edge of the pack ice. Although a few walruses may reach the western Beaufort Sea, they rarely range to the eastern Beaufort (Eley and Lowry, 1978).

The spotted seal *(Phoca largha)* is a small phocid which occurs primarily in the Bering Sea, although some individuals may occur as far east as the Colville River in the Beaufort Sea during summer (Eley and Lowry, 1978). The ranges of both the hooded seal *(Cystophora cristata)* and the harp seal *(Pagophilus groenlandicus)* are primarily Arctic-Atlantic, and only infrequent and isolated records of these seals exist for the Beaufort Sea (see LGL and ESL, 1981). The northern fur seal *(Callorhinus ursinus cynocephalus)* and northern sea lion *(Eumetopias jubatus)* occur occasionally in the Alaskan Beaufort (Eley and Lowry, 1978), and the northern fur seal has been recorded on four occasions in the eastern Beaufort Sea (Harington, 1966).

3.2.3 POLAR BEAR

The polar bear *(Ursus maritimus)* has a circumpolar distribution and ranges in Canada from the High Arctic Islands to James Bay (Plate 3.2-5). In November 1973, Canada, Denmark, Norway, U.S.A. and the Soviet Union signed an international agreement for the conservation of polar bears which stated that "Each contracting party shall take appropriate action to protect the ecosystems of which polar bears are a part..." (see Stirling et al., 1975). The polar bear population in areas from Cape Lisburne, Alaska to the Alaska-Yukon border has been estimated at 2,500 (Eley and Lowry, 1978), while an additional 1,700 to 1,800 bears were estimated to occur in the Canadian Beaufort Sea and Amundsen Gulf during the period from 1972-1974 (Stirling, 1978). Polar bears within the Beaufort region show a high degree of fidelity to specific locations during spring. In the Canadian Beaufort-Amundsen Gulf region, the polar bear population has two components; one is associated with the west coast of Banks Island and the other with the mainland coast. The latter component constitutes part of a population shared with Alaska (Stirling et al., 1981b). The polar bear population associated with the Alaskan Beaufort Sea coast is presently being studied by the U.S. Fish and Wildlife Service (S. Amstrup, pers. comm.). Preliminary results support the findings of Stirling et al. (1981b) that the mainland coastal population is shared between Alaska and Canada.

Polar bears are hunted by the Inuit throughout the Canadian Arctic under a community quota system regulated by the Northwest Territories government (Section 3.6.3). The six settlements in the Canadian Beaufort Sea harvest a total of about 50 to 60 bears each year, although the quotas are reviewed annually.

PLATE 3.2-5 *Mother polar bear and cubs travelling across sea ice in late spring. The west and south coasts of Banks Island are primary polar bear denning areas in the Beaufort region.*

Alaskan Inuit along the north coast also hunt polar bears, and killed an annual average of 26 bears between 1973-1979 (Alaska Department Fish and Game, pers. comm).

Adult male bears range from 450 to 550 kg in weight, while adult females weigh from 180 to 270 kg (Stirling et al., 1975). Polar bears prey primarily on ringed seals in the transition zone, although bearded seals are also locally important. During spring in 'normal' years, up to 80% of the ringed seals taken by polar bears were two years old or less (Stirling and Smith, 1977). Few of the seals killed are entirely consumed by bears, and seal carrion is an important food item of Arctic foxes (Stirling, 1974; Stirling and McEwan, 1975).

Natural changes in the distribution and abundance of the Beaufort Sea ringed seal population has been demonstrated to cause changes in the abundance and distribution of polar bears in the western Arctic (Stirling, 1978). For example, population estimates in 1975 indicated that the total number of bears in the Canadian Beaufort Sea-Amundsen Gulf could have been as low as 1,000, while an estimated 1,521 were present in 1974 (Stirling et al., 1975). The reduction in seal populations (Sections 3.2.2.1 and 3.2.2.2) during the winter of 1974-75 were believed to be responsible, at least in part, for reduced cub survival and changes in the distribution and abundance of bears (Stirling et al., 1975, 1976).

Polar bears are typically restricted to areas with sea ice throughout most of the year (Figure 3.2-7). Data collected on the distribution and habitat preferences of polar bears in the western Arctic from 1971 to 1979 are presented in Stirling et al. (1981b). During the winter and spring, most adult males, non-breeding females, females with yearlings and two year olds, and subadults in the Canadian Beaufort showed a strong preference for the floe edge and areas of moving ice with ⅞th or more ice cover, probably due to the accessibility of seals in these areas (Stirling et al., 1975; Stirling et al., 1981b). Adult females with cubs-of-the-year in this region showed a marked preference for stable landfast ice with deep snow drifts along the pressure ridges (Stirling et al., 1981b). During late spring and summer, most polar bears usually remained with the retreating pack ice and continued to prey on seals (Stirling et al., 1975).

Breeding occurs during April, May or June and the average age of first breeding in females is 5.4 years. Delayed implantation occurs, and gestation lasts 8 to 9 months (Lentfer, 1980). Although polar bears of both sexes and all ages may occupy temporary dens or shelters during adverse weather, winter denning is particularly crucial for pregnant females. The maternal

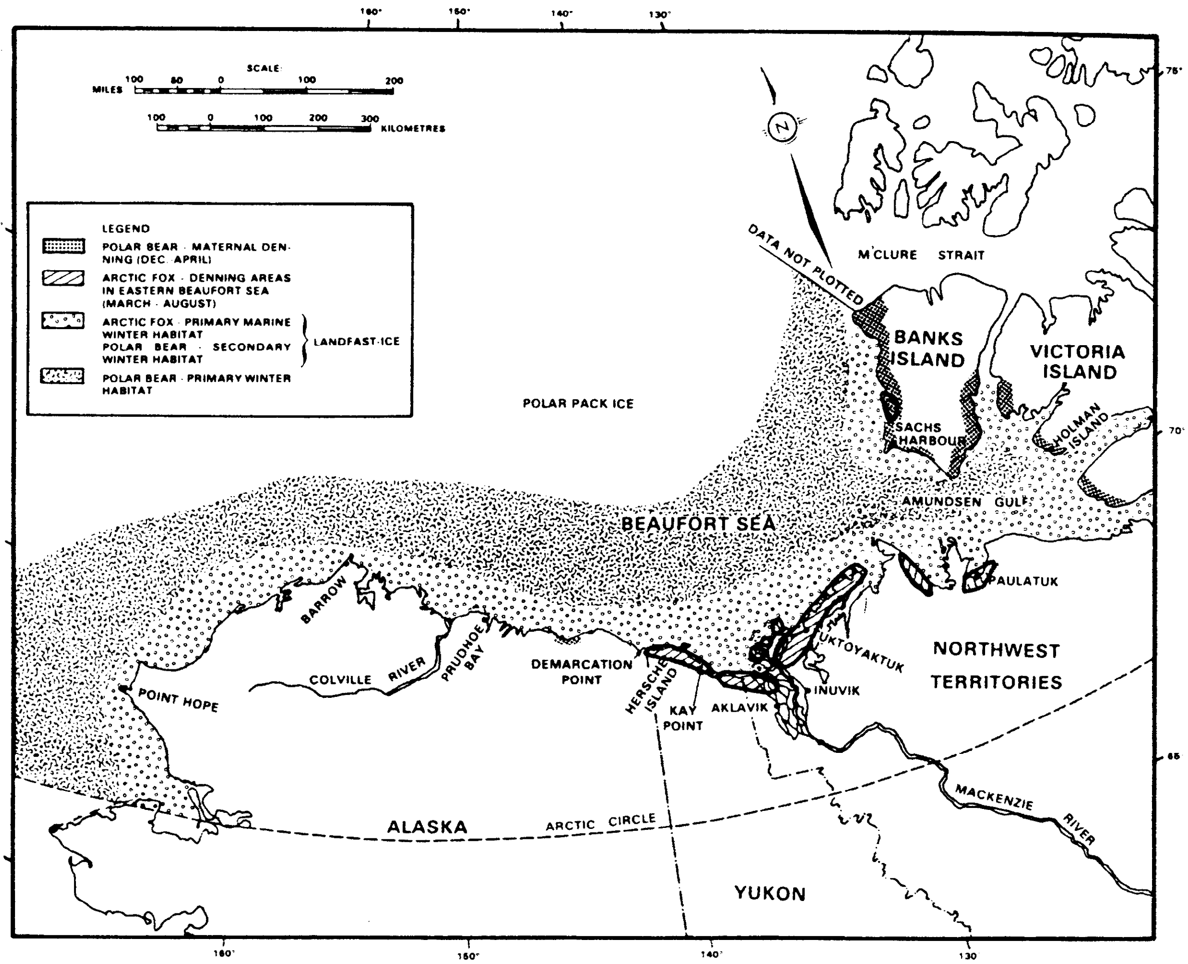


FIGURE 3.2-7 *Distribution of polar bear and Arctic fox habitats in the Northeast Chukchi Sea, Beaufort Sea and Amundsen Gulf. Arctic foxes are known to scavage on the sea ice on the remains of seals killed by polar bears.*

dens are usually excavated in snow banks on leeward slopes of coastal hills or valley sides near the sea, and are characterized by entranceways leading to one or more 'rooms' (Harington, 1968). However, in the Alaskan Beaufort, maternity dens are also known to occur on drifting ice, although the number of females denning in these areas has not been documented (Lentfer, 1975). Pregnant females usually occupy the maternal dens during early November, and the cubs are born in December and January (Lentfer, 1975; Schweinsburg et al., 1977). At birth, the cubs weigh 600 to 800 gm. Female polar bears are believed to produce an average litter of 1.63 every third year (Lentfer, 1980). During late March or early April, females and young-of-the-year emerge from the dens and move onto the landfast ice to prey on ringed seals. Young bears usually remain with their mother for 1 to 2 years after they leave the dens (Stirling et al., 1975).

Primary denning areas in the Canadian Beaufort Sea include the west and south coasts of Banks Island, and to a lesser extent, the west coast of Victoria Island (Figure 3.2-7 and 3.2-8) (Stirling et al., 1975, 1981b). Maternity denning occurs infrequently along the mainland coast. Stirling et al. (1981b) reported a single den in this area during 1971-1979 and states that Inuit hunters found only three during the past decade. Connors (1978) identified a denning area for polar bears near Camden Bay in Alaska.

3.2.4 ARCTIC FOX

The Arctic fox *(Alopex lagopus)* is a small terrestrial mammal that ranges throughout the Arctic tundra of North America and Eurasia (Plate 3.2-6). Arctic foxes are terrestrial throughout most of their range, although foxes from Arctic coastal populations may move onto the nearshore landfast ice during winter. Consequently, this species is considered in the following section because they are known to occur in the marine environment during certain periods of their life cycle; however, details of the distribution, abundance and biology of this species are discussed further in Section 4.1.4.1.

Arctic foxes are trapped on the sea ice by residents of the Beaufort and northeast Chukchi region, and

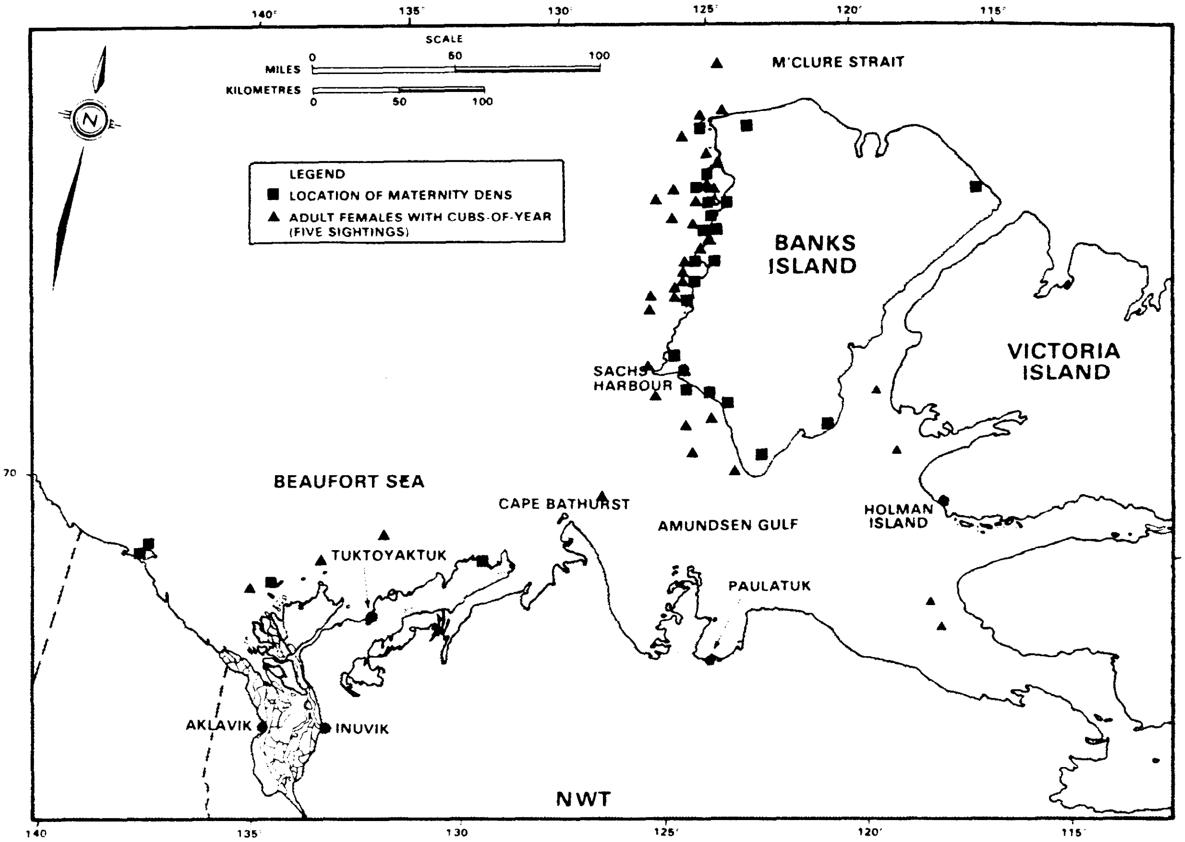


FIGURE 3.2-8 *Summary of captures, recaptures and resightings of adult female polar bears with cubs from mid-March to the end of May, 1971-1979. (Source: Stirling et al., 1981b).*

PLATE 3.2-6 *The Arctic fox is a small terrestrial mammal which ranges throughout the Arctic tundra and the landfast ice area of the Beaufort Sea in winter. (Courtesy, Territorial Wildlife Service, N.W.T.).*

provide a major source of cash income for many small communities in Canada and Alaska (Sections 3.6.4 and 4.6.1). This species is the most economically important terrestrial mammal in the southeastern Beaufort Sea region and is widely distributed throughout most mainland areas adjacent to the Beaufort and northeast Chukchi seas and on Banks and Victoria islands. The abundance and distribution of Arctic foxes on the sea ice in the Beaufort region has not been documented. Primary marine winter habitat for this species is indicated on Figure 3.2-7.

Arctic foxes are known to scavenge on the sea ice on the remains of seals killed by polar bears (Degerbøl and Freuchen, 1935; Macpherson, 1969; Stirling and Smith, 1977), and are also major predators of ringed seal pups during spring (Smith, 1976). For example, following a three year study in Prince Albert Sound and eastern Amundsen Gulf, Smith (1976) estimated that a minimum of 4.4% to 21.9% (in different years) of the ringed seal pups were taken by Arctic foxes. During spring and summer, Arctic foxes go ashore to den. They prey primarily on lemmings, and Arctic fox populations are reported to fluctuate dramatically in response to the cyclic abundance of this species (Macpherson, 1969; Banfield, 1974).

The most important known denning areas for Arctic foxes in coastal areas of the Mackenzie Delta-Tuktoyaktuk Peninsula region occur between Demarcation Point and Kay Point (Figure 3.2-7) (Nolan et al., 1973). Other important denning areas are located from Kay Point to Shingle Point, in the outer Mackenzie Delta (Richards Island), and the north side of the Tuktoyaktuk Peninsula, (Nolan et al., 1973; Slaney, 1975).

3.3 BIRDS

The following section briefly summarizes the major activities and important habitats of the primary species of marine-associated birds that frequent the Beaufort and northeast Chukchi seas. A more detailed description of the biology, distribution, abundance, phenology and important habitats of all major species of birds known to occur in marine and terrestrial areas of the Beaufort Sea region is provided in Section 4.2.

The available information on the spring routes of the major species which migrate to or through the Beaufort region are summarized in Figure 3.3-1. In general, offshore routes are probably the most heavily used but also the least well documented. Major coastal and offshore migrants include loons, brant, oldsquaws, eiders, phalaropes, jaegers and murres. Snow geese, white-fronted geese, Canada geese, some brant, swans, diving ducks other than eiders and oldsquaw, dabbling ducks, most shorebirds, and terrestrial species migrate overland to reach the western Arctic nesting grounds. During late April and early May most offshore migrants travel along a broad front through the Beaufort Sea after passing Point Barrow, with specific routes probably related to the locations of ice leads. As spring progresses, later migrants probably follow a route closer to the mainland coast when moving through the Beaufort Sea.

From May through mid June, the most important areas in the Beaufort region for marine-associated birds are the patches of open water (less than 25 m deep) which provide feeding and resting areas for hundreds of thousands of spring migrants (Barry et al., 1981). On June 5 and 9, 1980, Barry et al. (1981) conducted aerial surveys along the edge of the fast ice areas between Herschel Island and Baillie Islands, along the Amundsen Gulf polynya and along the west coast of Banks Island north to Bernard Island. Oldsquaws, eiders, loons and glaucous gulls were the predominant species in areas of open water, and, with the exception of loons, most birds were observed within 1 to 2 km of the landfast ice edge (Barry et al., 1981). The densities of birds recorded along the ice edge in the spring of 1980 are presented in Figure 3.3-2. The largest numbers of birds, predominantly eiders, were seen in leads off southwestern Banks Island, between Cape Kellett and Big River. Other important areas in spring include the ice edge between Cape Dalhousie and Baillie Island, and off Cape Parry and Booth Islands (Barry, 1976). A similar trend was also recorded in 1981 during a survey on June 9 (Barry and Barry, 1982).

In the entire Beaufort and northeast Chukchi region, the largest concentration of nesting birds occurs in the Cape Lisburne-Cape Thompson area of Alaska. Large colonies of black-legged kittiwakes (Springer and Roseneau, 1978), murres and several other species of seabirds nest in the area (Sowls et al., 1978; Springer and Roseneau, 1978) (see Section 4.2). In the Canadian Beaufort Sea region the largest concentration of nesting birds is the snow goose colony located 16 km inland along the Egg River on southern Banks Island (Bellrose, 1976; Barry, 1976). This colony contained an estimated 198,000 nesting snow geese in 1981 (see Section 4.2). Other colonies within the Canadian Beaufort region include a colony of about 800 murres at Cape Parry (Plate 3.3-1) (Barry, 1976; Ward, 1979), brant and snow goose colonies on the Anderson River delta and Mackenzie Delta, and small colonies of gulls, terns and common eiders at various locations along the mainland coast and the western coasts of Banks and Victoria islands (see Section 4.2). In addition, numerous other species are widely dispersed during the nesting period at river deltas and in tundra areas adjacent to the coasts. From early June through July, the most important littoral zone nesting areas include the mainland

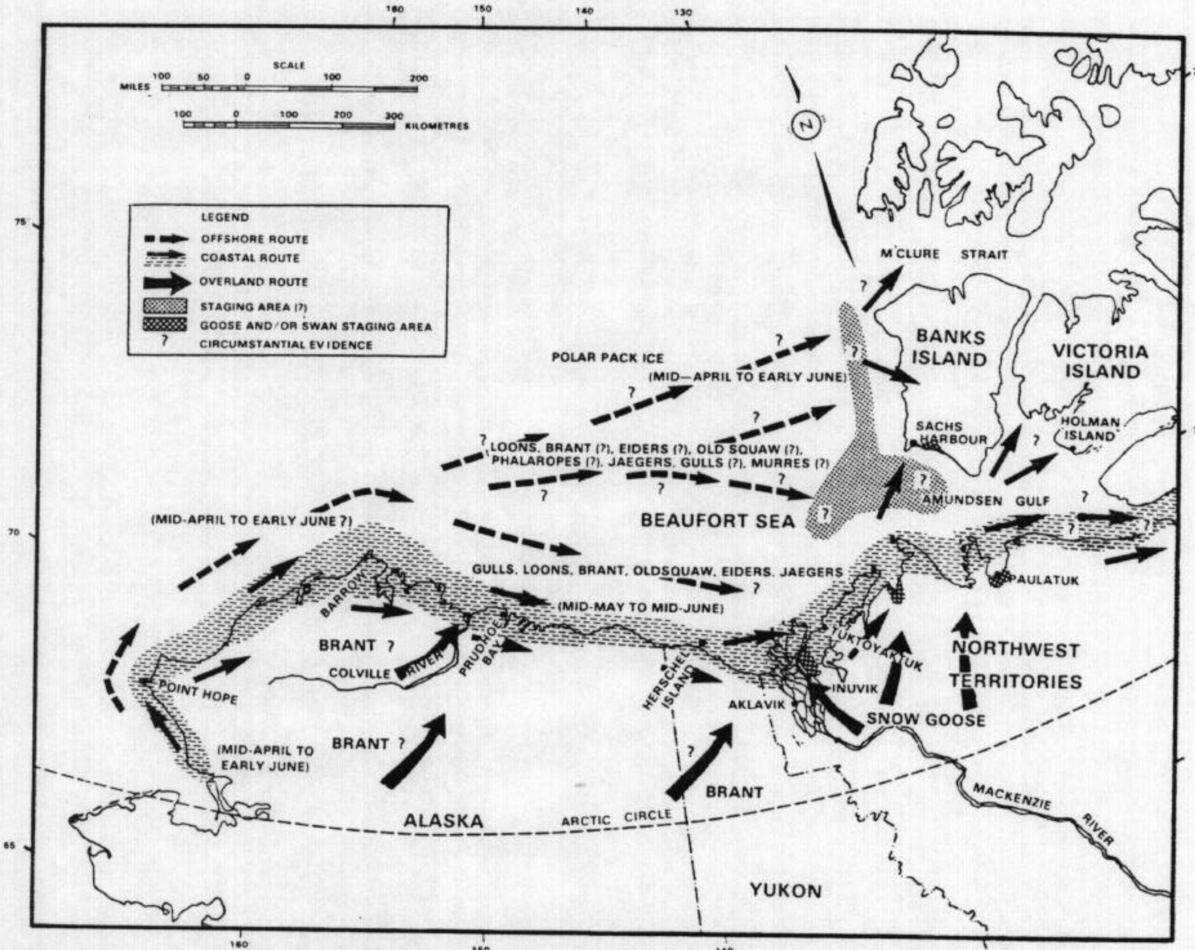


FIGURE 3.3-1 *Summary of the spring migration routes of birds through the Northeast Chukchi-Beaufort region (from LGL & ESL, 1982)*

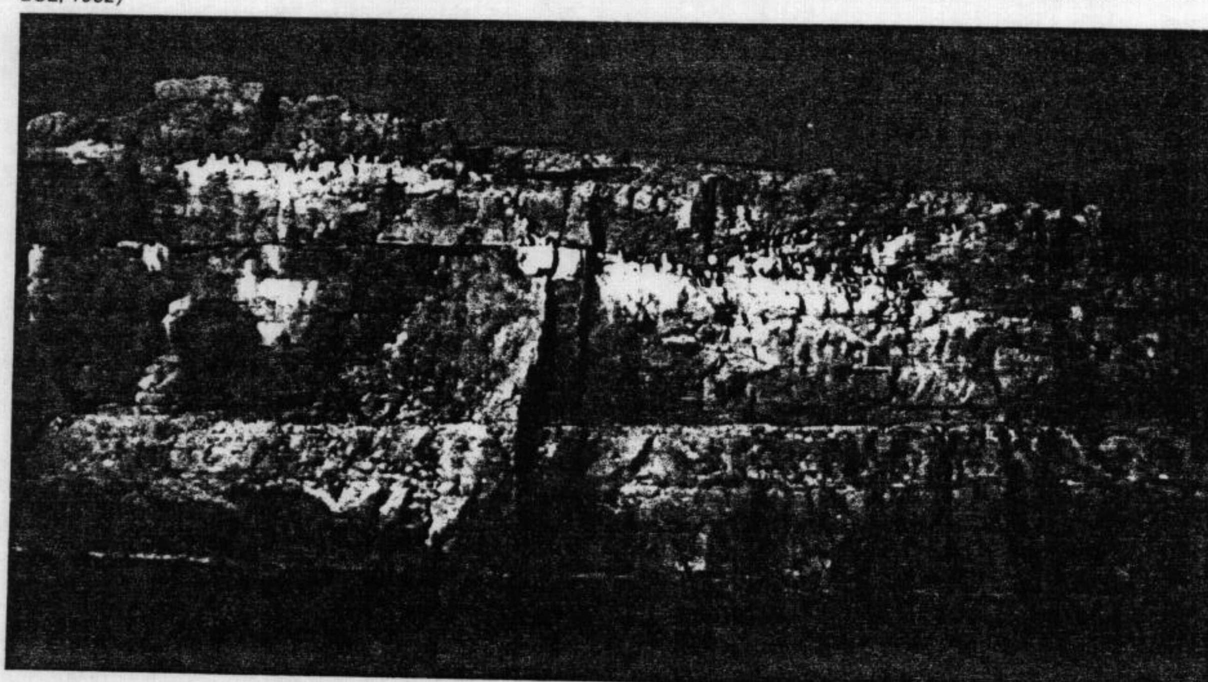


PLATE 3.3-1 *A colony of murres, estimated at 800, live on the cliffs at Cape Parry.*

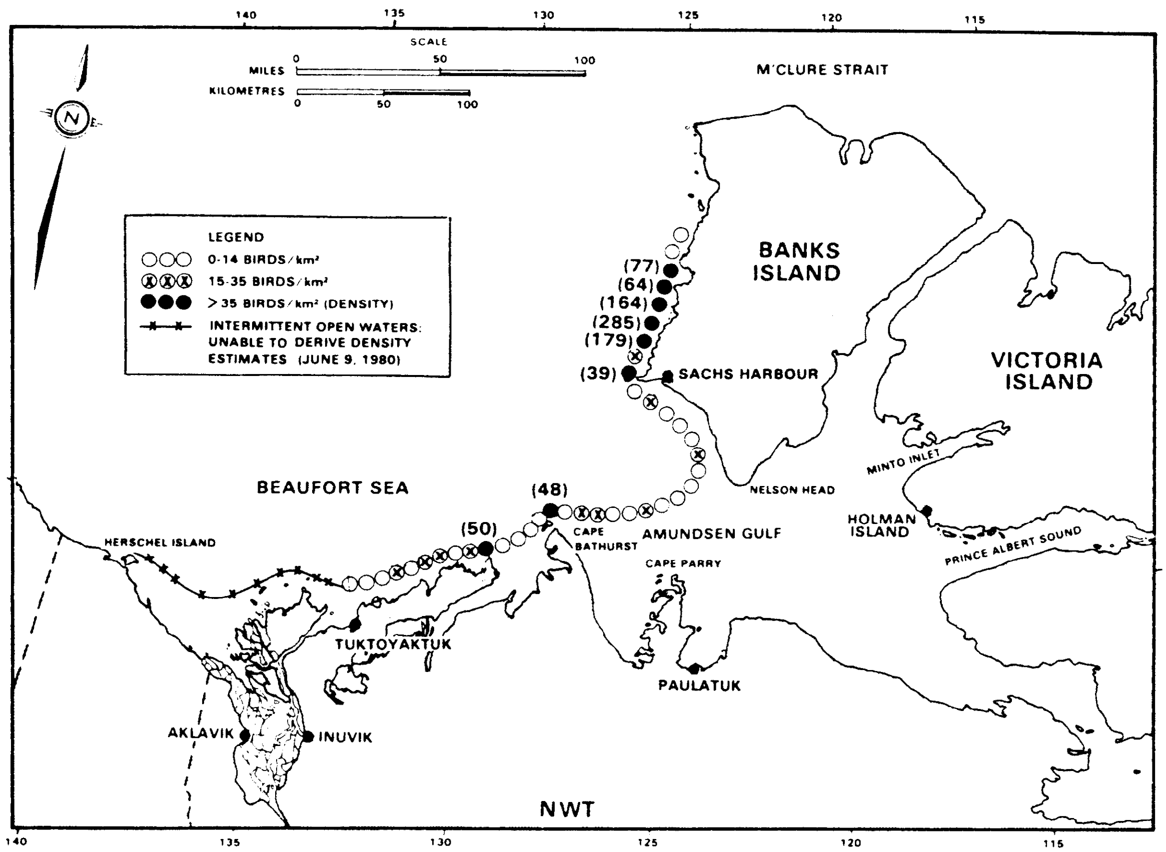


FIGURE 3.3-2 *Densities of marine birds along the ice edge, June 5, 1980. The largest numbers of birds, mainly eiders, were seen in leads off southwestern Banks Island. (Source: Barry et al., 1981).*

between Blow River and Tent Island in Shoalwater Bay, Pelly Island, the seaward edge of the Kendall Island Bird Sanctuary, Swan Channel, the Anderson River delta and Cape Parry (Barry et al., 1981).

There are several species of ducks, geese, swans and alcids which moult and are flightless for at least 2 to 3 weeks during their residence in the Beaufort and northeast Chukchi region (Tuck, 1960; Bellrose, 1976). The major species of birds that moult in these coastal marine areas include oldsquaws, female eiders, white-winged and surf scoters, greater scaup, brant, snow geese, thick-billed murres and black guillemots. Some species of waterfowl usually moult and rear their broods in sheltered bays and coastal lagoons along much of the mainland coast during the period from mid July to mid August (Barry et al., 1981). Marine coastal areas of the Canadian Beaufort Sea and Amundsen Gulf that are used the most by moulting and/or brood-rearing waterfowl are indicated in Figure 3.3-3, and include Nunaluk Spit, lagoons between Toker Point and Warren Point, McKinley Bay to Nuvorak Point, Wood Bay, Harrowby Bay, Ikpisugyak Bay and Langton Bay (Barry et al., 1981). In addition, the Investigator Islands and areas from Ramsay Island to Deans Dundas Bay on southwestern Victoria Island are also important moulting areas for female eiders (Barry et al., 1981).

The major routes of fall migrants departing from the Beaufort-Chukchi area are shown in Figure 3.3-4. In the eastern Beaufort, migration is both coastal and offshore, with many species believed to fly directly from the Arctic Islands toward Point Barrow. Migration may begin as early as late June, with a reverse (westward) migration of non-breeding jaegers (Johnson et al., 1975) and a westward moult migration of male oldsquaws (Searing et al., 1975). In July and early August, post-breeding male eiders migrate westward to moulting areas in the Bering Sea (Manning et al., 1956; Thompson and Person, 1963; Johnson, 1971). Female phalaropes migrate westward in mid July, and male phalaropes and some juveniles follow during August (Parmelee et al., 1967; Connors et al., 1979). Female eiders and their young migrate westward during late August through September (Johnson, 1971; Timson, 1976). Brant begin to move westward in mid August (Searing et al., 1975), while oldsquaws and loons migrate through coastal waters during September and October (Searing et al., 1975; Johnson, 1979). Staging areas used by brant and oldsquaw occur in littoral areas along the entire coastline of the Beaufort-Chukchi region, although concentration areas are only known to occur in barrier island lagoons, bays, and sheltered areas in Alaska (Johnson, 1979). Brant are particularly abundant at Cape Halkett, Alaska (King, 1970). Important coas-

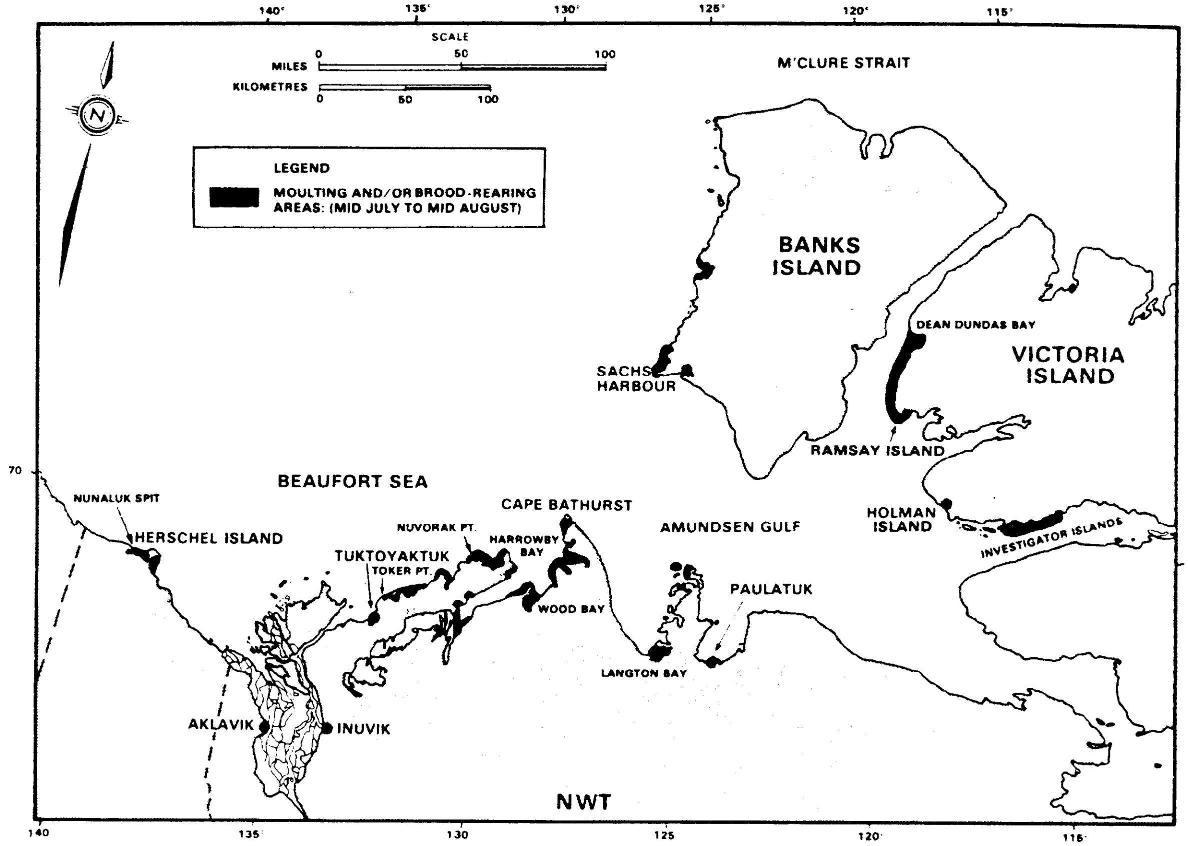


FIGURE 3.3-3 *Marine coastal areas most used by moulting and/or brood-rearing waterfowl in the southeastern Beaufort Region. (Based on Barry et al., 1981).*

tal staging areas for overland migrants such as snow geese and white-fronted geese occur primarily along the Yukon and Alaskan North Slope and in the Mackenzie Delta (Koski, 1975, 1977a, 1977b) (Figure 3.3-4).

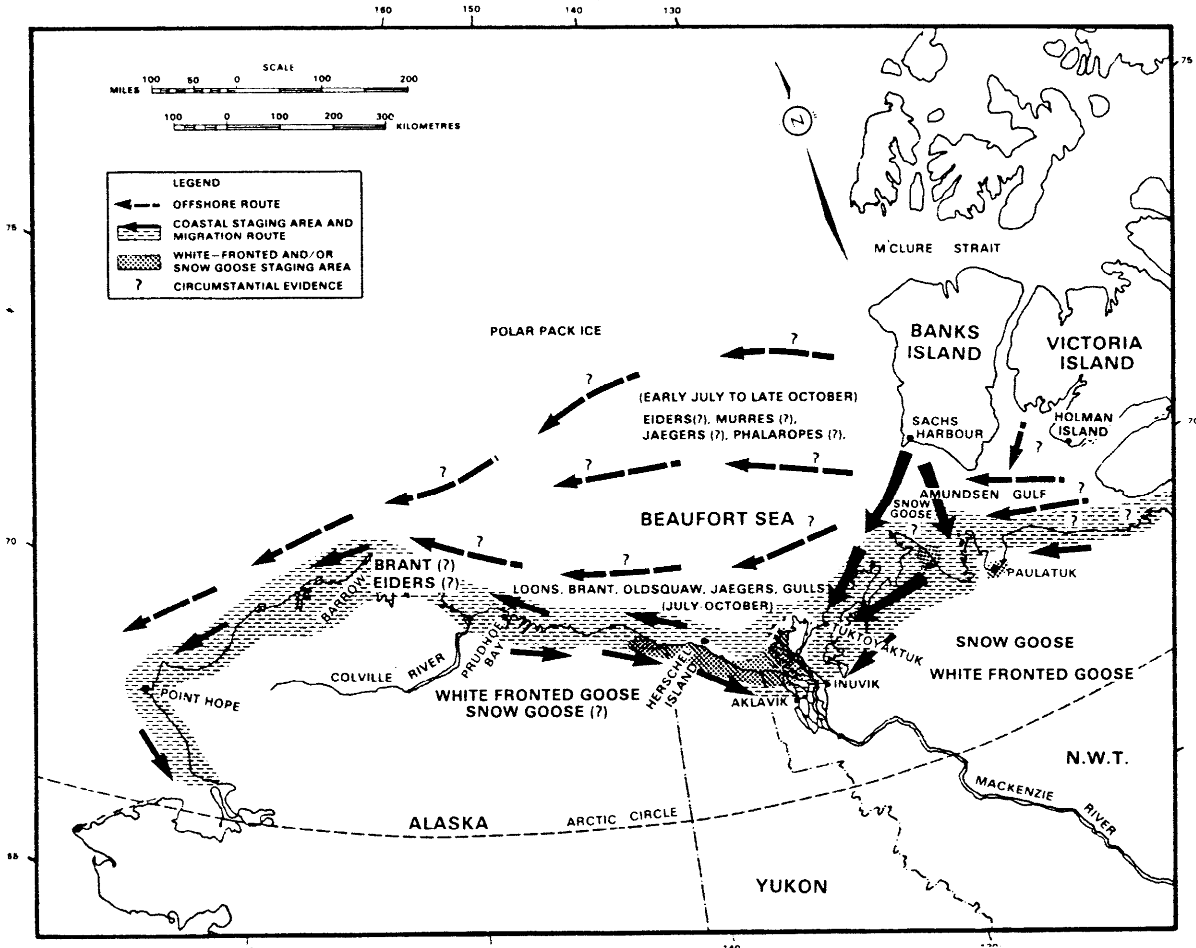


FIGURE 3.3-4 *Summary of the fall migration routes of birds through the Northeast Chukchi-Beaufort region. Most marine birds have left the Beaufort Region by the end of October in any given year. (Source: LGL and ESL, 1982).*

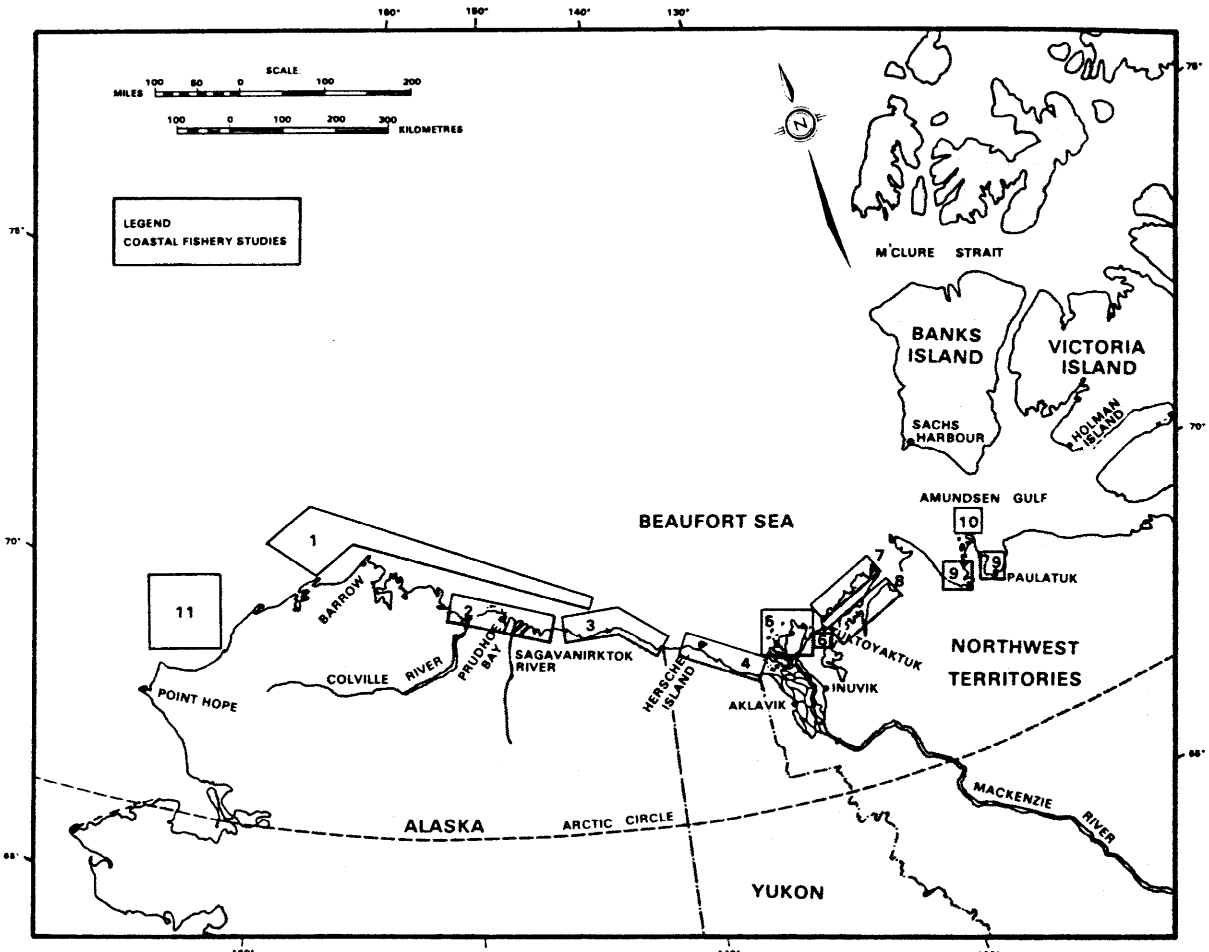


FIGURE 3.4-1 *General areas where coastal fisheries studies have been carried out. The investigators are listed in Table 3.4-1.*

3.4 FISH

Knowledge of the fish of the Beaufort and northeast Chukchi seas has increased substantially in the last decade, with the most recent information having been collected from areas where industrial developments have been proposed, such as the Alaskan North Slope (Prudhoe Bay) and Mackenzie Delta areas (Figure 3.4-1; Table 3.4-1). Consequently, the inshore fish species of the Beaufort Sea (especially of southern coastal zones) and many of their life history characteristics and habitats are becoming reasonably well known. However, less is known about the offshore fish resources of the eastern Beaufort Sea and off the coasts east of the Tuktoyaktuk Peninsula, west of the Colville River, and along Banks Island. Sampling programs for fish in Arctic waters, complicated by logistics, weather and ice conditions, have been largely restricted to the open water months and have generally used limiting types of sampling gear. As a result of these sampling biases, some species and sizes of fish may have been present but not captured in surveys conducted to date in the Beaufort and northeast Chukchi region. On the other hand, the most recent studies, done in relation to hydrocarbon exploration and development in Alaska, used various types of sampling gear throughout the summer and, in some cases, winter (e.g. Craig and Haldorson, 1980; Tarbox and Thorne, 1979; Moulton et al., 1980). Overall, these studies in Alaska have been more comprehensive than any completed to date in the Canadian portion of the Beaufort Sea.

3.4.1 THE PHYSICAL ENVIRONMENT AND FISH DISTRIBUTION

Fish in the Beaufort Sea include species from both the Pacific and Atlantic oceans, as well as those endemic to Arctic waters. Certain features of the physical environment of the Beaufort and northeast Chukchi seas, described in Chapter 1.0, affect the species composition, distribution and abundance of fish. These are mainly the freshwater drainages entering the sea which reduce coastal salinities, local wind patterns which create longshore currents, and ice formation during winter.

The Mackenzie and Colville rivers, as well as smaller watercourses along the mainland North Slope, discharge plumes of relatively warm nutrient-rich fresh

TABLE 3.4-1

LIST OF FIELD STUDIES RELATED TO BEAUFORT/N.E. CHUKCHI MARINE ENVIRONMENTS
(Areas shown in Figure 3.4-1)

Area 1

Frost et al., 1978

Area 2

Bendock, 1977
Craig, 1977
Craig and Haldorson, 1980
Craig and McCart, 1974
Craig and McCart, 1975
Craig and Mann, 1974
Furniss, 1975
Kogl and Schell, 1974
Moulton et al., 1980
Roguski and Komarek, 1972
Tarbox and Moulton, 1980
Tarbox and Spight, 1979
Tarbox and Thorne, 1979
Yoshihara, 1973

Area 3

Griffiths et al., 1977
Roguski and Komarek, 1972

Area 4

Craig and McCart, 1974
Craig and Mann, 1974
Griffiths et al., 1975
Kendel et al., 1975
McAllister, 1962

Area 5

Brunskill et al., 1973
de Graaf and Machniak, 1977
Envirocon Ltd., 1977
Galbraith and Hunter, 1979

Area 5 (cont'd)

Mann, 1975
Olmsted, 1977
Percy, 1975
Poulin, 1975, 1976
Poulin and Martin, 1976
Slaney, 1973a, 1974, 1975

Area 6

Bray, 1975
Byers and Kashino, 1980
Dept. of Fisheries and Oceans, 1980
Hunter, 1979
Slaney, 1973b

Area 7

Bray, 1975
Dept. of Fisheries and Oceans, 1980
Hunter, 1979
Jones and DenBeste, 1977

Area 8

Bray, 1975
Hunter, 1979
Poulin and Martin, 1976

Area 9

Hunter, 1979

Area 10

Galbraith and Hunter, 1979

Area 11

Quast, 1974

AREA 12

Galbraith and Hunter, 1979

water during the summer. These create a fluctuating coastal environment with higher temperatures and lower salinities compared to offshore waters. Ocean circulation patterns and winds tend to confine these freshwater inflows to inshore waters and sweep them along the coastline. Consequently, brackish warm water is common along the Beaufort coastline in summer, particularly in the lagoons and embayments behind the many barrier islands along the mainland coast. Since the Mackenzie River is much larger than the Colville River, the influence of its plume usually extends much further away from its mouth than does the influence of the Colville River plume.

While the offshore environment of the Beaufort Sea is a cold marine water mass which remains relatively stable year-round, the inshore waters of many regions have large seasonal fluctuations in turbidity, temperature and salinity. Consequently, the coastal species must be physiologically tolerant of these conditions. During the spring and summer nearshore surface salinities can range from 1 to 25 ^{o}/oo, with waters becoming more saline as the summer progresses. Temperatures increase from a range of 0 to 5°C in the spring to as high as 16°C by mid August in the surface layer of some protected waters.

Along the coasts, the mixing between the freshwater runoff and the marine-offshore waters varies throughout the region, and appears to affect the fish species present in coastal areas. In some areas there is considerable mixing, which results in a relatively homogeneous brackish nearshore environment (Craig and Haldorson, 1980). However, in other areas, such as off Prudhoe Bay, the Yukon coast, the Mackenzie River Delta, and Tuktoyaktuk Peninsula, a wedge of cold saline water often exists beneath the upper fresh or brackish warm water layer (Moulton et al., 1980; Kendel et al., 1975; Byers and Kashino, 1980). Nevertheless, both well-mixed brackish and stratified waters remain relatively close (within 10 km) to the coastline.

During the open water season, the species composition of fish in the Beaufort and northeast Chukchi seas reflect the spatial and seasonal differences in salinity, temperature and ice conditions. Marine species prefer cold saline or brackish waters, while anadromous species inhabit the warmer brackish coastal waters. Freshwater species are occasionally found along the coasts, usually near river mouths and outer river deltas (Craig and Haldorson, 1980; Percy, 1975).

During winter most of the nearshore waters, less than 2 m deep, are frozen to the bottom. Some nearshore areas possess pockets of seawater which may become hypersaline during the winter months with salinities up to 60 $^{o}/oo$ (Griffiths et al., 1977; Craig and Haldorson, 1980). The fresh water in coastal habitats diminishes during the winter months and becomes largely restricted to coasts off the Colville and Mackenzie deltas. Therefore, overwintering habitat for anadromous fish is mainly confined to inland freshwaters or deep river channels in the deltas of the Colville and Mackenzie rivers (Craig and McCart, 1975; Craig and Haldorson, 1980), while indigenous marine species remain in coastal and offshore waters (Tarbox and Thorne, 1979).

3.4.2 SPECIES COMPOSITION

A list of all fish species documented for the Beaufort and northeast Chukchi seas is provided in Table 3.4-2. There are at least 43 Beaufort Sea fish species and 47 species present in the northeast Chukchi Sea. More occur in the Chukchi Sea due to some fish species entering from the north Pacific Ocean. By comparison, over 300 species have been documented off the east and west coasts of southern Canada (Leim and Scott, 1966; Hart, 1973). The lower variety in the Arctic seas has been attributed to low temperatures, low productivity, and extensive ice action which precludes the use of shoreline habitats typical of southern areas (McAllister, 1977).

The relative abundance and species composition of fish collected during summer surveys conducted from the Colville River to the Tuktoyaktuk Peninsula area are shown in Table 3.4-3. The species composition is considered to be representative for the region although differences in relative abundance suggested by these data may be a reflection of differences in the month of sampling, weather conditions, depth and sampling gear (Plate 3.4-1).

Anadromous species found during the open water season in nearshore areas of the Beaufort Sea (generally less than 5 m deep) include Arctic cisco, least cisco, Arctic char, boreal smelt, humpback whitefish, broad whitefish, and inconnu. These anadromous species spend much of their time in marine coastal waters during some phase of their life history, and are important to either the domestic or commercial fisheries along the southern Beaufort Sea coastline. Arctic char and whitefish species are the most important anadromous fish harvested (Section 3.6.6).

Common marine species caught in the nearshore Beaufort region include Arctic cod, Pacific herring, fourhorn sculpin, Arctic flounder, and starry flounder. Saffron cod, snailfish, sandlances and eelpouts have also been consistently reported in the region. Marine species are of lesser importance to the domestic fishery than anadromous species. Some marine fish such as cod are considered to be particularly important as food for marine mammals and birds (Section 3.1).

Overall the most common species found in coastal waters of the Beaufort Sea are Arctic cisco, least cisco, fourhorn sculpin, Arctic char and Arctic cod. These five species accounted for over 90% of all fish collected in Simpson Lagoon (Craig and Haldorson, 1980), Kaktovik Lagoon (Griffiths et al., 1977), Nunaluk Lagoon (Griffiths et al., 1975), near Prudhoe Bay (Bendock, 1977), along the Yukon coastline (Kendel et al., 1975), and along the Tuktoyaktuk Peninsula (Jones and Den Beste, 1977; Byers and Kashino, 1980; Dept. of Fisheries and Oceans, 1980). More diverse fish communities exist in coastal areas adjacent to the large delta habitats of the Mackenzie and Colville rivers.

Freshwater fish species are found in some Beaufort Sea coastal waters, particularly near the Colville and Mackenzie rivers. Burbot, northern pike, Arctic grayling, round whitefish and lake trout have been collected in these areas. However, these fish are found almost exclusively in association with river 1974).

TABLE 3.4-2

ANADROMOUS AND MARINE FISH SPECIES DOCUMENTED IN THE BEAUFORT AND NE CHUKCHI SEAS

Group and Species	Common Name	Abbreviation*	N.E. Chukchi Sea	Beaufort Sea
ANADROMOUS				
Lampreys:				
Lampetra japonica	Arctic lamprey	ARLM		+
Salmonids:				
Coregonus autumnalis	Arctic cisco	ARCS	+	•
Coregonus clupeaformis	humpback whitefish	HBWF		+
Coregonus nasus	broad whitefish	BDWF		+
Coregonus sardinella	least cisco	LSCS	+	+
Coregonus laurettae	Bering cisco	BCS	+	+
Oncorhynchus gorbuscha	pink salmon	—	+	+
Oncorhynchus keta	chum salmon	—	+	+
Oncorhynchus tshawytscha	chinook salmon	—	+	+
Oncorhynchus nerka	sockeye salmon	—	+	+
Prosopium cylindricaem	round whitefish	RWF		+
Salvelinus alpinus	Arctic char	CHAR	+	+
Stenodus leucichthys	inconnu	INCO		+
Smelts:				
Osmerus eperlanus	boreal smelt (Arctic rainbow smelt)	BORS	+	+
MARINE				
Herring:				
Clupea harengus pallasii	Pacific herring	PHER	+	+
Smelts:				
Mallotus villosus	capelin	CP	+	+
Sticklebacks:				
Gasterosteus aculeatus	threespine stickleback	—	+	
Pungitius pungitius	ninespine stickleback	—	+	+
Cods:				
Arctogadus glacialis	polar cod	PCD		+
Boreogadus saida	Arctic cod	ARCD	+	+
Eleginus navaga	saffron cod	SACD	+	+
Greenlings:				
Hexagrammos stelleri	Whitespotted greenling	—	+	
Sculpins:				
Artediellus scaber	rough hookear sculpin	—	+	+
Enophrys lucasi	—	—	+	
Gymnocanthus tricuspis	Arctic staghorn sculpin	—	+	+
Hemilepidotus sp.	—	—	+	
Icelus bicornis	twohorn sculpin	—		+
Icelus spatula	spatulate sculpin	—	+	+
Megalocottus platycephalus	flathead sculpin	—	+	
Microcottus sellaris	saddle sculpin	—	+	
Myoxocephalus axillaris	axillary sculpin	—	+	
Myoxocephalus jaok	jaok	—	+	
Myoxocephalus quadricornis	fourhorn sculpin	FHSC	+	+
Myoxocephalus scorpioides	Arctic sculpin	—		+
Myoxocephalus scorpius	shorthorn sculpin	—	+	
Myoxocephalus stelleri	steller's sculpin	—	+	

TABLE 3.4-2 (Cont'd)

ANADROMOUS AND MARINE FISH SPECIES DOCUMENTED IN THE BEAUFORT AND NE CHUKCHI SEAS

Group and Species	Common Name	Abbreviation*	N.E. Chukchi Sea	Beaufort Sea
Nautichthys priblovius	korablik sculpin	—	+	
Triglops pingeli	ribbed sculpin	—	+	+
Poachers and Alligator fishes:				
Asidophoroides olriki	Arctic alligatorfish	—	+	+
Podothecus acipenserinus	sturgeon poacher	—	+	
Lumpfishes and Snailfishes:				
Eumicrotremus derjugini	leatherfin lumpsucker	—		+
Liparis herschelinus	bartail seasnail	SSN	+	+
Liparis koefoedi	gelatinous seasnail	—		+
Sandlances:				
Ammodytes hexapterus	Pacific sand lance	—	+	+
Pricklebacks:				
Eumesogrammus praeciscus	fourline snakeblenny	—	+	+
Lumpenus fabricii	slender eelblenny	—		+
Lumpenus macultus	shanny	—		+
Lumpenus medius	stout eelbenny	—	+	+
Stichaeus punctatus	Arctic shanny	—	+	
Eelpouts:				
Gymnelis viridis	fish doctor	—	+	+
Lycodes mucosus	saddled eelpout	—		+
Lycodes palearis Arctica	wattled eelpout	—	+	
Lycodes pallidus	pale eelpout	—	+	
Lycodes polaris	polar eelpout	—		+
Lycodes rossi	Ross's eelpout	—	+	+
Anglerfishes:				
Ceratias holbilli	deepsea angler	—		+
Flatfishes:				
Atherestes stomias	arrowtooth flounder	—	+	
Hippoqlossoides robustus	Bering flounder	—	+	
Limanda aspera	yellowfin sole	—	+	
Liopsetta glacialis	Arctic flounder	ARFL	+	+
Platichthys stellatus	starry flounder	STFL	+	+
Pleuronectes quadrituberculatus	Alaska plaice	—	+	

*See Table 3.4-3

Sources: Alverson and Wilimovsky (1966); Craig and Haldorson (1980); Frost et. al. (1978); Hildebrand (1948); Percy (1975); Quast and Hall (1972, 1974); Tarbox and Spight (1979).

TABLE 3.4-3

PERCENTAGE OCCURRENCE OF VARIOUS FISH SPECIES DURING SUMMER SURVEYS ALONG THE SOUTHERN BEAUFORT SEA COAST (DOES NOT REPRESENT A COMPLETE SPECIES LIST FOR EACH STUDY)

Gear	Location	Number	FISH SPECIES* ANADROMOUS							MARINE							
			ARCS	LSCS	BDWF	BORS	CHAR	HBWF	INCO	ARCD	SACD	ARFL	STFL	FHSC	PHER	SSN	CP
Poulin (1977)**																	
Gillnets Seines	Greater Mackenzie Delta - (Herschel Island - McKinley Bay)	12,179	17.3	46.4	1.0	14.2	1.8	2.0	5.4	0.5	0.4	1.2	P	6.4	1.8	—	—
Byers and Kashino (1980)																	
Gillnets	Kugmallit Bay (Tuktoyaktuk Peninsula)	346	12.7	13.9	—	44.2	—	1.4	0.6	1.2	0.9	1.4	2.9	12.4	6.4	—	—
Gillnets	Tuktoyaktuk Harbour	284	48.2	20.1	1.4	18.0	—	—	0.4	—	0.4	1.1	1.1	2.5	6.3	—	—
Seines	Kugmallit Bay and Adjacent Tuktoyaktuk	200	29.0	36.5	7.0	1.5	—	4.5	2.0	—	—	3.0	1.5	11.0	—	P	—
Trawls	Peninsula	295	7.1	1.7	—	25.1	—	—	—	18.0	0.7	0.3	4.7	38.3	2.4	—	—
Galbraith and Hunter (1979)																	
Gillnets Seines Trawls	Tuktoyaktuk Vicinity	8,458	12.7	30.3	3.9	16.3	—	3.9	3.0	20.6	—	P	P	6.7	14.6	—	—
Trawls 1973	Amundsen Gulf 130-540m deep	335	—	—	—	—	—	—	—	89.9	—	—	—	—	—	1.0	—
Trawls 1974	Offshore Mackenzie Delta Tuk Peninsula 10-120m deep	237	68.8***	16.5	—	3	—	P	—	—	—	—	—	—	—	—	—
Griffiths et al. (1975)																	
Gillnets	Nunaluk Lagoon (Mouth of Malcolm River)	1,440	52.2	2.3	—	—	18.6	—	0.1	—	—	1.5	—	25.4	—	—	—
Griffiths et al. (1977)																	
Gillnets Seines	Kaktovik Lagoon (Barter Island)	2,507	15.0	2.0	0.1	0.2	4.0	—	—	8.0	—	1.0	—	70.0	—	0.1	P
Craig and Haldorson (1980)																	
Gillnets	Simpson Lagoon (East of Colville River)	781	56.3	11.6	3.8	—	14.2	2.2	—	0.1	—	0.4	—	9.2	—	—	1.0
Seines		450	16.7	48.2	1.1	0.7	3.6	—	—	7.6	—	0.7	—	20.9	—	0.2	—
Fyke Nets		189,513	1.5	1.3	0.2	0.6	1.1	P	—	74.2	0.3	0.4	—	20.6	P	P	P
Faber (Tow) Net		366	—	—	—	—	—	—	—	83.1	—	—	—	—	—	16.9	—
Offshore Trawls		154	—	—	—	—	—	—	—	30.5	—	—	—	27.9	—	40.9	—
Moulton et al. (1980)																	
Gillnets Fyke Nets Faber Nets Trawls	Prudhoe Bay	4,935	0.1	0.1	0.1	—	0.5	—	—	88.2	0.1	—	—	2.0	—	1.8	6.3
Bendock (1977)																	
Gillnets Seines Trawls	Alaska North Slope (Harrison Bay - Flaxman Island)	28,369	4.0	30.0	2.0	P	14.0	1.0	—	20.0	P	P	—	28.0	—	P	—
Doxey (1977)																	
Gillnets Fyke Nets	Prudhoe Bay	26,661	3.9	30.5	2.5	0.2	13.0	0.6	—	19.6	P	0.1	—	29.0	—	0.2	0.2
Tarbox and Spight (1979)																	
Trawls	Prudhoe Bay	638	0.3	—	—	—	—	—	—	92.8	—	—	2.2	—	1.6	1.6	—
Frost et al. (1978)																	
Trawls	Offshore 40-400m deep Beaufort/N.E. Chukchi Sea	496	—	—	—	—	—	—	—	39.1	—	—	—	—	—	5.4	—

(P) Less than 0.1 percent
(-) Not reported
* Abbreviations of species identified in Table 3.4-2
** Summary of the following studies: Kendel et al. (1975); Machniak and De Graff (1975); Slaney (1973, 1974, 1975), Percy (1975); Galbraith and Fraser (1974).
*** Reported also in Galbraith and Fraser (1974) (see Section 3.4.3)

water at deltas, and their presence is sporadic and abundance low in other coastal waters. Similarly, Pacific salmon species (chum, pink and sockeye) have recently been documented along the Alaskan coast near Prudhoe Bay (Craig and Haldorson, 1980), and small spawning runs of chum and pink salmon are reported to occur as far east as the Mackenzie River (Scott and Crossman, 1973). Although the occurrence of salmon species this far north is noteworthy, they are not usually encountered along the Beaufort Sea coast and are not an important resource for any domestic fishery. Other species such as sticklebacks are also common to estuarine environments, but are not dominant in coastal marine habitats or of particular importance in Arctic marine food webs (Section 3.1).

3.4.3 ANADROMOUS SPECIES

During the summer, coastal habitats become feeding

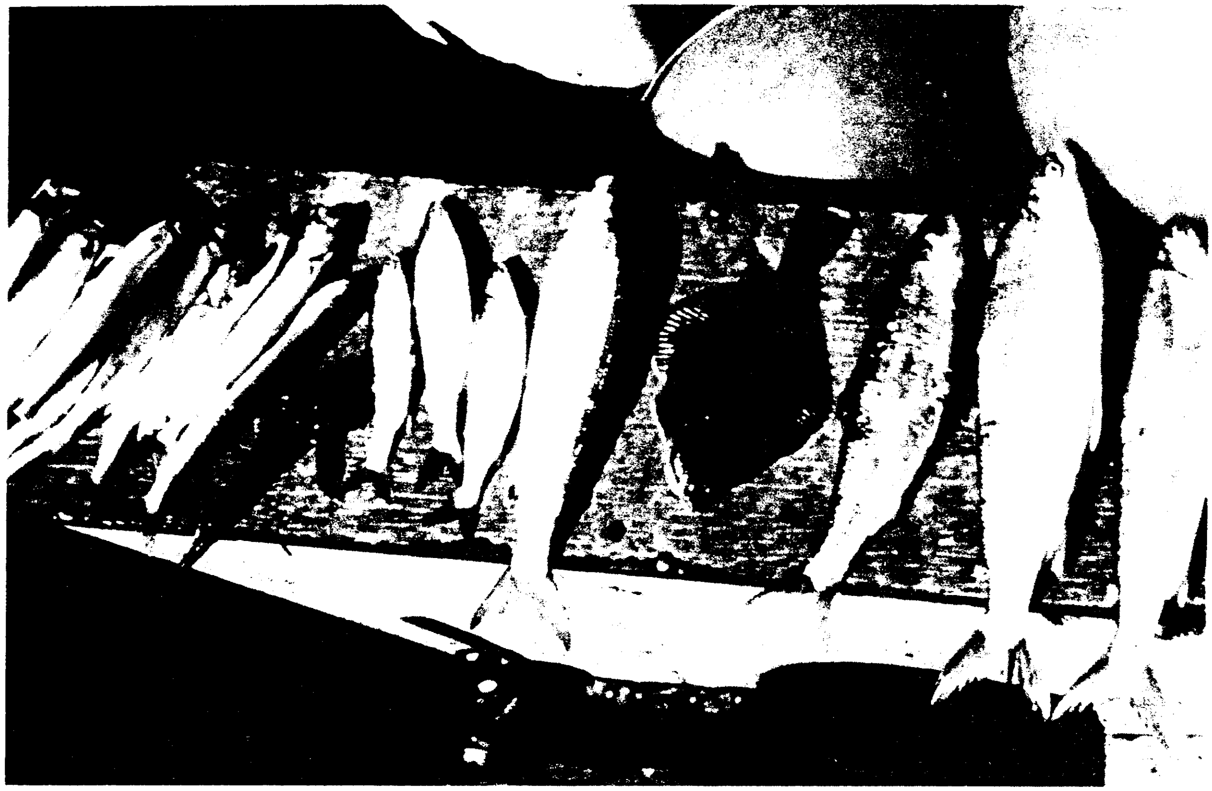


PLATE 3.4-1 *A typical gillnet catch from Tuktoyaktuk Harbour in the fall. From left to right are shown: boreal smelt, fourhorn sculpin (dark fish), 4 least cisco, 1 Arctic flounder, 1 pacific herring, and 2 Arctic cisco. (Courtesy, Dobrocky Seatech Ltd.)*

grounds and migration routes for anadromous species. Over a period of about three or four months, anadromous fish accumulate much of the energy reserves required for spawning and overwintering, although these activities occur later in freshwater habitats usually well away from the coast.

During summer most anadromous species appear to use a narrow corridor within the brackish water immediately next to the shoreline. Shortly after break-up, when land runoff begins to flow into the sea, anadromous species descend into nearshore habitats and (to varying degrees) disperse outward along the Beaufort Sea coast. In almost all fish surveys, most anadromous species appear to restrict themselves to nearshore waters which are less than 5 m deep (Craig and Haldorson, 1980; Byers and Kashino, 1980). The major factor affecting their distribution appears to be the presence of relatively warm brackish water, and Craig and Haldorson (1980) suggested that such water conditions may be necessary for these species to achieve optimal summer growth. These authors also reported that within Simpson Lagoon, Alaska, anadromous fish concentrated along the immediate mainland shoreline and along the edges of the lee sides of barrier islands (Figure 3.4-2). However, in some areas along the Tuktoyaktuk Peninsula, large numbers of fish, particularly broad whitefish juveniles, were observed entering coastal streams and feeding heavily during the summer, rather than remaining exclusively in coastal habitats (K. Chang-Kue, pers. comm.).

However, some species have been observed further seaward. For example, Craig and Haldorson (1980) found anadromous fish 1.5 km offshore when storms affected Simpson Lagoon, while Galbraith and Fraser (1974) reported Arctic cisco 27 km northeast of Herschel Island (Table 3.4-3). Moulton et al. (1980) also observed Arctic char over 1 km from shore in numbers more characteristic of nearshore habitats. Despite these exceptions, anadromous species usually confine themselves to shallow nearshore waters where they migrate along the shore and away from overwintering habitats during the summer months and return in the fall.

The sizes of Arctic anadromous fish populations are not well documented, and coastal population levels are largely a function of the availability of freshwater habitats. McCart (1980) estimated the Arctic char populations of the Firth and Big Fish rivers at 32,000 and 17,000 respectively, and the Sagavanirktok River population of char is probably greater than either of these (A. Sekerak, pers. comm.). Craig and Haldorson (1980) have also provided population estimates for adult Arctic cisco and least cisco in the Colville River. These authors suggested that, on the basis of

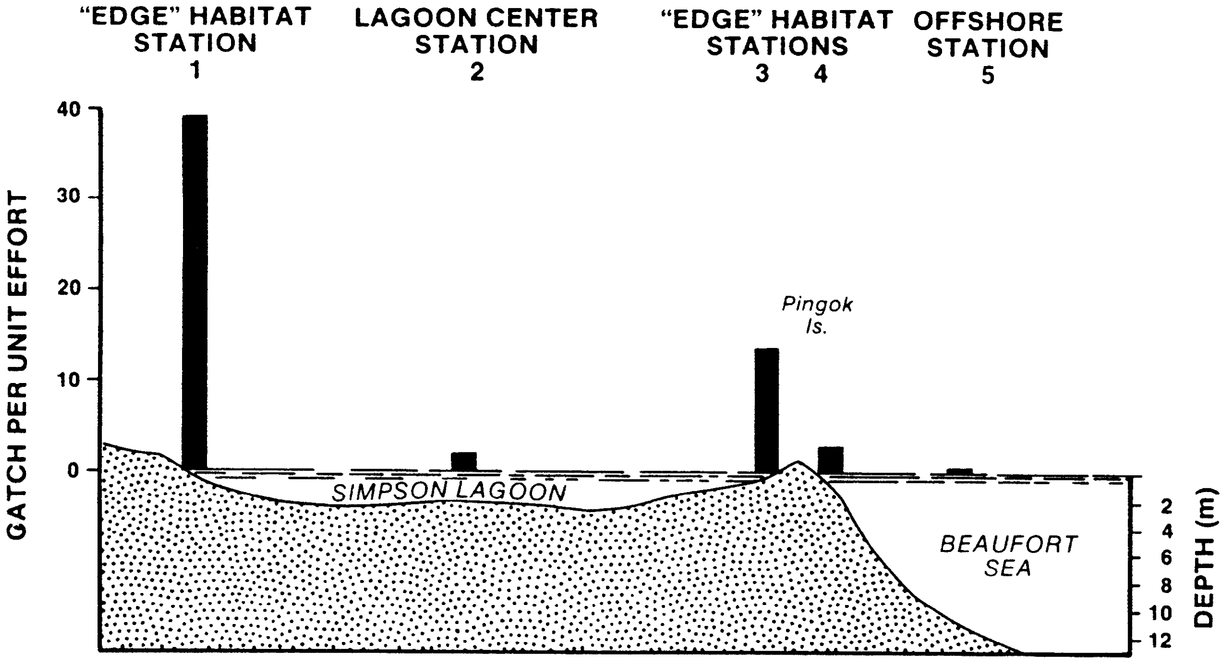


FIGURE 3.4-2 *Cross-section of Simpson Lagoon study area showing relative numbers of fish caught at 5 sampling stations, 1977. Numbers of fish represent a seasonal average for combined species caught in a standardized 24-h gill net set. (Craig and Haldorson, 1980)*

tag recoveries, adult Arctic cisco numbers decreased from 8 x 10^5 to 1 x 10^5 during the period from 1976 to 1979, while least cisco abundance increased from 3 x 10^5 to 1.5 x 10^6 during the same period. However, estimations of the abundance of anadromous fish in coastal environments are complicated by the migration of these species. For example, Craig and Haldorson (1980) suggested that anadromous fish only spend 7 to 12 days in Simpson Lagoon during each spring and fall migration, but over the entire summer one half of the Colville River Arctic cisco population of approximately 120,000 fish in 1978, probably passed through Simpson Lagoon. The maximum number of all adult anadromous fish present in Simpson Lagoon at a given time was estimated to be about 88,000. Thus the fish present at any given time in coastal habitats are likely to be only a portion of the total number of fish passing through those habitats during the summer. These numbers would depend on the migratory patterns of individual species and the distance of a coastal habitat from freshwater sources.

The distances travelled by anadromous fish along the coast and the timing of migrations varies with the species and their life history stage. For example, most mature anadromous fish do not spawn each year, and in some species the spawning segment of the population may either remain in freshwater habitats during the summer, or undertake short coastal migrations in the early summer, returning to spawning rivers early in the open water season (McCart, 1980; Craig and Haldorson, 1980). As a result, immature fish and mature non-spawners tend to be more prevalent in coastal waters compared to the season's spawning population. They migrate greater distances and remain for longer periods away from their native rivers. The fry of many anadromous species reach coastal habitats soon after emergence, but they tend to remain relatively close to native rivers during the summer. For example, Arctic char do not migrate seaward until at least age three (McCart, 1980). Similarly, least cisco young-of-the-year and one year old fish were largely absent from coastal habitats distant from the Colville and Mackenzie rivers where adults were relatively abundant (Craig and Haldorson, 1980; Griffiths et al., 1975, 1977; Kendel et al., 1975). On the other hand, the fry and juveniles of Arctic cisco have been observed along coastal environments at least 70 km from large deltas (Kendel et al., 1975; Craig and Haldorson, 1980). These young fish possibly originated locally from smaller rivers.

The distance anadromous fish travel from natal streams varies with species. Arctic char and Arctic cisco apparently undertake the longest migrations of the anadromous species found in this region. For example, an Arctic char originally tagged in the Sagavanirktok River was recaptured 300 km away (Furniss, 1975). Although this distance is probably larger than normal, studies completed in Simpson Lagoon and elsewhere suggest that Arctic char and Arctic cisco probably travel 90 to 170 km away from their stream of origin during the summer. The latter species has been recorded migrating from the Tuktoyaktuk Peninsula up the Mackenzie River to Arctic

Red River (Department of Fisheries and Oceans, unpubl. data). These migrations likely result in substantial mixing of fish stocks along the coast. McCart (1980) reported that Arctic char from various rivers along the North Slope of Alaska and the Yukon were captured at the same coastal location. This mixing of fish stocks in marine habitats is probably most common with Arctic char since they not only occur in several drainages but undertake longer migrations than do other anadromous species in the region. The majority of Arctic cisco and least cisco likely originate from the Colville and Mackenzie rivers, although cisco are also present in streams west of the Colville River (A. Sekerak, pers. comm.). Other anadromous species, such as whitefish, do not appear to travel far from their natal streams.

Anadromous species utilize coastal habitats almost exclusively for feeding during the open water season, rather than for spawning or overwintering. There is overlap in the diet of most anadromous species, with epibenthic crustaceans, particularly mysids and amphipods, being dominant food. Although anadromous fish appear to depend on relatively few species of prey, food sources are apparently abundant in coastal environments of the Beaufort and northeast Chukchi region. Craig and Haldorson (1980) suggest that an annual immigration of prey species into coastal habitats results from the exchange between nearshore and offshore waters and that this migration may be critical in maintaining their abundance.

As indicated earlier most adult anadromous fish do not spawn in consecutive years. Adult populations generally consist of two components: mature non-spawning individuals which accumulate fat reserves during the summer and then return to freshwater to overwinter, and mature individuals which return to freshwater in order to spawn during the fall. This separation of adult populations has been observed in Arctic char, Arctic cisco, least cisco, broad whitefish and humpback whitefish populations of the region (Craig and Haldorson, 1980; Griffiths et al., 1975, 1977; Kendel et al., 1975). Studies completed in the nearshore Beaufort Sea indicate that spawning individuals usually remain within or near freshwater spawning areas during the summer months.

Most anadromous fish overwinter in freshwater habitats. Some species, such as Arctic char, remain upstream near springs and well away from the coast throughout the winter (McCart, 1980). Ciscos and whitefish may return to river delta overwintering areas after spawning in the fall, and these river delta habitats occasionally include brackish-water environments. Delta overwintering habitats have been identified in the Colville, Sagavanirktok and Mackenzie rivers (Craig and Haldorson, 1980; Kendel et al., 1975; Mann, 1975; Bendock, 1977; Poulin, 1977).

The boreal smelt, in contrast to other anadromous species, appears to need brackish coastal waters near river mouths as overwintering habitat. Overwintering boreal smelt have been observed near the mouths of the Colville, Mackenzie and Kuk rivers (Bendock, 1977; Craig and Haldorson, 1980; Percy, 1975), and may be found at other coastal locations in the Beaufort and northeast Chukchi region. Unlike other anadromous species, the boreal smelt only enters the rivers to spawn during spring.

3.4.4 MARINE SPECIES

In contrast to the available data base for anadromous species, much less is known about the marine species that inhabit the Beaufort and northeast Chukchi seas owing largely to the nearshore emphasis of most studies. The information collected to date suggests that marine fish, as well as anadromous species, use nearshore habitats primarily for feeding during the summer months. Epibenthic invertebrates are the major prey items, although planktonic copepods are also important in the diet of some marine fish. However, unlike the anadromous fish, the occurrence of marine species in nearshore habitats is more sporadic. For example, occasionally large schools of Arctic cod may appear briefly in nearshore waters and be totally absent at other times in the same season.

The presence of marine fish in nearshore habitats often depends on the intrusion of cold saline water in the nearshore area. While some demersal marine species such as fourhorn sculpins and flounders are relatively common in coastal habitats, even when brackish conditions exist, other species such as Arctic cod and snailfish occur sporadically. The latter two species are found in association with true marine conditions, and their numbers increase as the summer progresses and when freshwater inflows decline in coastal areas. Moulton et al. (1980) demonstrated the close association of marine fish in the Beaufort Sea with the submerged layer of saline water that often moves into nearshore habitats. Hydroacoustic records collected during this investigation showed that marine fish were concentrated along the interface between the saline and brackish water layers. Similar associations between marine fish and saline waters were documented by Kendel et al. (1975) and Byers and Kashino (1980). An increasing abundance of marine species in nearshore habitats as summer progresses has been observed in areas near Prudhoe Bay (Craig and Haldorson, 1980) and the Mackenzie Delta (Percy, 1975).

Some marine fish species spawn in nearshore habitats. Fourhorn sculpin, capelin, snailfish and herring are reported to spawn in coastal regions, although spawning areas for most of these species are generally in water greater than 2 m deep and somewhat outside the nearshore corridor used by anadromous species. Of these species, the fourhorn sculpin and snailfish spawn during the winter under the ice. Pelagic marine species such as the Arctic cod may also spawn in coastal habitats. Craig and Haldorson (1980) reported ripe and post-spawning marine fish in Stefansson Sound inside barrier islands. Other investigators suggest that Arctic cod spawn in widespread and non-specific offshore areas in winter (Tarbox and Moulton, 1980; A. Sekerak, pers. comm.).

There is extensive overwintering habitat for marine species throughout the Beaufort and northeast Chukchi seas. The presence of fourhorn sculpin, Arctic cod, snailfish and flounders under the ice in coastal habitats was recently documented by Craig and Haldorson (1980) and Tarbox and Thorne (1980). These species presumably move into deeper water as ice occupies the shallower nearshore habitats. The shallow areas are apparently repopulated when the ice cover eventually disappears in late spring.

The offshore Beaufort and northeast Chukchi seas probably serves as a major area for movements, spawning and overwintering of indigenous marine species, including pelagic fish, such as Arctic cod and demersal species. Frost et al. (1978) found 19 species of demersal marine fish in bottom trawls completed at depths from 40 to 400 m in the western Beaufort and eastern Chukchi seas. Arctic cod was the dominant species collected near the bottom, accounting for 46% of the total catch. Twohorn sculpins, spatulate sculpins, eelpouts and snailfish comprised the remainder. Frost et al. (1978) also noted that the overall abundance of fish in offshore waters was low, averaging only 15 fish per trawl. This is consistent with the results of some studies which also suggested that abundance of fish in offshore areas is generally low (Bray, 1975; Craig and Haldorson, 1980), although this may only reflect the patchy distribution of schooling species (Quast, 1974; Galbraith and Hunter, 1979).

3.4.5 LIFE HISTORY AND DISTRIBUTION OF COMMON ANADROMOUS SPECIES

This section highlights the major life histories and documented distributions of common anadromous fish found in coastal waters of the region. Emphasis is placed on the use of coastal marine environments by each of these species rather than their freshwater habitats. More detailed summaries of the distribution and biology of anadromous species found in the Beaufort and northeast Chukchi seas, including aspects of their freshwater life history, are provided in Hatfield et al. (1972), Craig and Haldorson (1980), Craig and McCart (1975), Bendock (1977), Griffiths et al. (1977), Kendel et al. (1975) and Percy (1975).

3.4.5.1 Arctic Char

Arctic char is one of the most important species in the domestic, commercial and sport fisheries of Arctic communities, and has received a great deal of attention in surveys conducted in the Beaufort Sea. Anadromous Arctic char are distinct from, and larger than, land-locked Arctic char (Plate 3.4-2). Adult char migrate to coastal habitats shortly after breakup and become widely dispersed along the southern Beaufort Sea coast. Most anadromous Arctic char originate from the numerous large spring-fed perennial streams that occur between the Colville and Mackenzie rivers (Craig and McCart, 1974). The most important char-producing watercourses in this region are the Rat, Big Fish, Babbage, Firth, Kongukut, Hulahula, Canning, Sagavanirktok and Colville rivers. Arctic char are uncommon west of the Colville River, largely due to the absence of spring-fed streams (Craig and Haldorson, 1980), and only isolated coastal populations exist to the east of the Mackenzie Delta. The latter populations originate from watercourses near Cape Parry (Hornaday River), Simpson Bay and Read Island, as well as the Sachs and DeSalis rivers on Banks Island (Fenco and Slaney, 1978). Arctic char may migrate considerable distances (150 to 300 km) along the shore, and apparently there is a mixing of stocks from different drainages at sea. Char do not always return to their natal streams. This movement from one freshwater source to another has been summarized by McCart (1980).

Coastal populations of Arctic char usually occur within the narrow corridor of brackish water in protected lagoons rather than in exposed coastal habitats, and are comprised largely of mature females. Most char do not spawn in consecutive years, and coastal populations appear to include both mature spawning and nonspawning individuals. Fish collected from the region range in age from 3 to more than 15 years, reach sexual maturity in from 4 to 9 years, and attain maximum lengths of up to 700 mm. Juvenile char rear almost exclusively in freshwater habitats and do not migrate to coastal areas until at least 3 years old. Therefore, unlike other anadromous species, char do not require coastal rearing habitats for young fish.

While at sea Arctic char feed primarily on epibenthic crustacea, although they do not appear to be very selective and will consume a variety of prey species. Major food items are mysids and amphipods, but insect larvae may form an important component of the diet in areas influenced by freshwater. Griffiths et al. (1975) also reported that larger char (500 mm) will prey on other fish species such as fourhorn sculpins and possibly Arctic cod.

Arctic char return to freshwater spawning and overwintering habitats during the period from July to

PLATE 3.4-2 *Anadromous (sea-run) male Arctic char in spawning colouration caught in the Firth River. (Courtesy, Aquatic Environments Ltd.).*

September. In general, the mature individuals return first, leaving mainly immature fish in coastal environments by September. In some cases the return of immature char to freshwater habitats may not occur until the beginning of freeze-up (Bendock, 1977). Overwintering areas are generally located away from the coast and relatively close to spawning habitats, although in some drainages, spawning and non-spawning individuals may occupy different freshwater overwintering habitats.

3.4.5.2 Arctic Cisco

The Arctic cisco, like Arctic char, is one of the dominant fish species harvested in domestic and commercial fisheries along the Beaufort Sea coast (Craig and Haldorson, 1980). Life history information for this species has been previously summarized by Craig and Mann (1974), Craig and Haldorson (1980), Griffiths et al. (1977), Percy (1975) and Kendel et al. (1975).

The first occurrence of Arctic cisco in coastal waters coincides with spring break-up. Most of the fish present between the Colville River in Alaska and the Tuktoyaktuk Peninsula are believed to originate from spawning and overwintering habitats in the Colville and Mackenzie rivers, but other rivers west of the Colville are also thought to support Arctic cisco in smaller numbers (Craig and Haldorson, 1980). Adult fish (200 to 400 mm) from these two rivers become widely distributed along the southern Beaufort Sea coastline, and may be found up to 200 km away from these rivers. Although mixing of stocks from the Mackenzie and Colville rivers is possible in view of these migration distances, this phenomenon has not been substantiated. The primary use of coastal habitats by Arctic cisco is for feeding. The principal prey items of this species are benthic crustacea, particularly amphipods and mysids (Craig and Haldorson, 1980).

Fry and juvenile Arctic cisco move downstream in the spring, and tend to concentrate in the Colville and Mackenzie deltas, including their outer margins. However, juvenile Arctic cisco originating from the Mackenzie River have been collected as far west as Herschel Island and Shingle Point (Griffiths et al., 1975), while Craig and Haldorson (1980) reported juvenile Arctic cisco as far as 70 km east of the Colville River.

Arctic cisco return upstream in the Mackenzie River during the period from July through September. Spawning is believed to occur in major tributaries of the Mackenzie River. When spawning is complete, both adults and juveniles move downstream between October and November to overwinter in the lower areas of the river and Mackenzie Delta. On the other hand, Arctic cisco from the Colville River migrate directly from coastal habitats to delta areas in September where overwintering of this population is believed to occur. Spawning areas remain unknown (Craig and Mann, 1974; Craig and Haldorson, 1980). Some immature and nonspawning mature fish have been observed under the ice in coastal environments such as Mallik Bay and Kugmallit Bay (Percy, 1975; Galbraith and Hunter, 1979).

Arctic cisco reach maturity at ages from seven to ten years, with males maturing earlier than females. As with Arctic char, members of this species do not spawn each year, and therefore both mature spawners and mature nonspawners may be present in coastal marine waters during the summer. Mature fish which will spawn in the fall tend to return to the river deltas earlier than nonspawning mature fish. These individuals cease feeding in the river deltas prior to their upstream migration to spawning habitats. On the other hand, immature Arctic cisco and mature nonspawners remain widely dispersed along the coast and feed extensively throughout the summer (Griffiths et al., 1975; Craig and Haldorson, 1980). Adult fish up to 14 years old have been collected in several areas, suggesting that adults may spawn several times during their lifetime. However, Craig and Haldorson (1980) reported that there is no direct evidence of previous spawning in fish classified as mature nonspawners.

3.4.5.3 Least Cisco

Unlike Arctic cisco, least cisco are not widely distributed along the Beaufort Sea coast. This species tends to remain near the Colville and Mackenzie rivers, and has only been found to be relatively abundant in surveys completed in these two areas (Bendock, 1977; Kendel et al., 1975; Percy, 1975; Byers and Kashino, 1980; Poulin, 1977).

Older and larger least cisco, mostly mature nonspawners, usually disperse within a short distance along the coast away from the river deltas. These individuals appear to feed extensively on mysids and amphipods, while fish remaining near the river deltas also feed on insects (Bendock, 1977; Craig and Haldorson, 1980).

Least cisco return to the Colville and Mackenzie rivers in August, and mature spawners proceed to upstream locations where spawning habitats are suspected to occur. After spawning, these fish return to overwintering habitats in lower portions of the Colville and Mackenzie deltas. Least cisco reach maturity at ages from four to nine years, but not all mature fish spawn in consecutive years. Most nonspawning adults and juveniles return from coastal feeding areas to concentrate in the delta habitats during winter. However, some individuals have been captured under the ice in other coastal environments such as Kugmallit Bay (Galbraith and Hunter, 1979), Mason and Mallik bays, the outer Mackenzie Delta, and along portions of the Tuktoyaktuk Peninsula (Fenco and Slaney, 1978).

3.4.5.4 Boreal Smelt

The boreal smelt has been reported as occurring in the waters of the Mackenzie Delta and near the mouth of the Colville River. Adults are generally less than 300 mm in length and six years or more of age. They enter the lower reaches of rivers to spawn in spring just prior to and during break-up (Percy, 1975), and return to the marine environment during the open water season of the same year. The presence of fry in the outer Mackenzie Delta and other coastal areas suggests that recently hatched juveniles also move into brackish waters to rear (Fenco and Slaney, 1978).

In coastal areas the boreal smelt feeds mainly on amphipods, isopods and mysids (Percy, 1975; Bendock, 1977; Craig and Haldorson, 1980; Kendel et al., 1975), and in turn, is likely consumed by birds, marine mammals, and other fish species. Despite their widespread occurrence, there is no significant fishery for the boreal smelt in the western Arctic (Percy, 1975). This species appears to overwinter at river mouths, and occurs in large numbers under the ice at the mouths of the Kuk, Colville and Mackenzie rivers (Bendock, 1977; Percy, 1975; Craig and Haldorson, 1980) and in some coastal bays along the Tuktoyaktuk Peninsula (Fenco and Slaney, 1978).

3.4.5.5 Humpback Whitefish

Humpback (or lake) whitefish have been caught near the Colville and Mackenzie rivers (e.g. Percy, 1975; Bendock, 1977; Craig and McCart, 1975), and it is suspected that these two rivers are the major sources of humpback whitefish found along the coast of the southern Beaufort Sea. Colville River fish have been captured as far east as Prudhoe Bay, while fish originating from the Mackenzie River have been caught from Herschel Island to areas east of Tuktoyaktuk (Bendock, 1977; Kendel et al., 1975; Percy, 1975). Due to the relatively high abundance of humpback whitefish in the Mackenzie and Colville rivers, it is an important component of the domestic fishery in these areas. Some other rivers are also believed to support humpback whitefish populations. For example, Fenco and Slaney (1978) reported the presence of humpback whitefish in the Hornaday River near Cape Parry and Amundsen Gulf.

The maximum lengths of humpback whitefish collected during fisheries surveys between the Colville and Mackenzie rivers has ranged from 400 to 500 mm, corresponding to ages from 13 to 18 years, although this species reaches sexual maturity at seven to nine years (Kendel et al., 1975). These larger individuals tend to remain in estuarine habitats with a large freshwater influence during the summer (Kendel et al., 1975). The fry and juveniles of this species rear in delta areas as well as nearshore coastal habitats. During the summer humpback whitefish in outer delta habitats feed mainly on crustacea and small bivalves, while fish in inner delta habitats concentrate on insect larvae (Percy, 1975; Kendel et al., 1975).

Humpback whitefish originating from the Mackenzie River return to the inner Delta area during August, and then begin their upstream migration to spawning habitats (Mann, 1975). The timing of the upstream movement of Colville River fish has not been documented but is probably similar. Overwintering humpback whitefish have been observed in lakes and minor channels of the Mackenzie Delta. These fish were primarily immature, and there was no evidence to suggest that overwintering fish included post-spawners returning downstream during winter (Mann, 1975).

3.4.5.6 Broad Whitefish

Broad whitefish have similar patterns of distribution to the humpback whitefish, and are generally only common in areas of extensive freshwater influence such as the deltas of the Mackenzie and Colville rivers (Kendel et al., 1975; Percy, 1975; Bendock, 1977). Broad whitefish have been reported in the Sagavanirktok River on the Alaskan North Slope (Bendock, 1977). The broad whitefish is a major component of the domestic fishery in the Mackenzie and Colville delta areas (Poulin, 1977; Bendock, 1977). Individuals captured in coastal surveys have ranged from 50 to 500 mm in length, and up to 15 years old.

Fry and juveniles are more restricted to river deltas and areas with freshwater input than are the adults. Important rearing areas for broad whitefish have been identified in the Colville and Sagavanirktok deltas, Mackenzie Bay, Mallik Bay, the south coast of Kugmallit Bay, the Phillips Bay and Shingle Point area, and along the Yukon coast in Stokes Lagoon (Percy, 1975; Kendel et al., 1975).

Broad whitefish do not spawn in consecutive years and the nonspawning mature fish utilize coastal areas extensively for feeding. Major prey items include crustacea, small bivalves and insect larvae. Spawners congregate in delta areas during August to September, and migrate to upstream spawning habitats in October. These fish likely return downstream to overwinter with the immature and nonspawning fish in deep channels within the river deltas.

3.4.5.7 Inconnu

The inconnu is another member of the whitefish family, and is almost exclusively associated with the Mackenzie River Delta and adjacent inland water habitats. In the Canadian Beaufort Sea the species has been collected as far west as Herschel Island and Nunaluk Lagoon on the Yukon coast, but is more abundant toward the Mackenzie River Delta (Percy, 1975; Kendel et al., 1975; Griffiths et al., 1977). The species is important to the domestic fishery in those areas where it is found.

Adult inconnu may attain a length of approximately 1 m and an age of 11 to 14 years in coastal waters near the Mackenzie Delta (Kendel et al., 1975; Percy, 1975). Inconnu use coastal areas for feeding and rearing. Juvenile fish prey largely on small crustacea, while the larger adult fish may consume a variety of other fish including small cisco, boreal smelt, sculpins, sticklebacks, flounders and juvenile inconnu (Percy, 1975; Kendel et al., 1975).

Inconnu return to rivers during the period from July to September and spawn in the fall. They do not spawn in consecutive years and only a portion of the adult population ascends to spawning habitats in the Mackenzie River drainage basin. The mature spawners do not appear to feed extensively in coastal waters during the summer, and after spawning these fish appear to return to lower river habitats where they overwinter with other immature and nonspawning adult inconnu (Poulin, 1977).

3.4.6 LIFE HISTORY AND DISTRIBUTION OF COMMON MARINE SPECIES

3.4.6.1 Arctic Cod

The Arctic cod has a circumpolar distribution, extending south to the Bering Sea, and are found both nearshore and offshore in the Beaufort Sea. They are also a dominant species in the eastern Canadian Arctic (Bain and Sekerak, 1978). In offshore surveys of the western Beaufort and northeast Chukchi seas, Arctic cod accounted for up to 39% of the catch in waters 50 to 150 km offshore and 40 to 400 m deep (Frost et al., 1978). Quast (1974) reported higher densities of juvenile (age 0) Arctic cod with increased depth (surface to mid-water) in the northeast Chukchi in the fall. They were also the dominant species collected in mid-water depths from 65 to 180 m in Amundsen Gulf, in some cases representing up to 90% of the catch (Galbraith and Hunter, 1979).

This study also documented large numbers of (age 0) fish beyond the Mackenzie River plume off the Delta. Large populations of Arctic cod have also been documented in shallow (less than 5 m) brackish nearshore waters near Prudhoe Bay (Bendock, 1977; Moulton et al., 1980; Craig and Haldorson, 1980).

Arctic cod are harvested in a small domestic fishery centred around Point Barrow and Barter Island in Alaska, and some are harvested from Franklin and Darnley bays by people from the community of Paulatuk. However, their greatest importance is as a major trophic link in Arctic marine food webs, where they are principal prey for numerous birds and marine mammals. The trophic importance of Arctic cod is discussed in more detail in Section 3.1.

In contrast to the large and long-lived anadromous species, Arctic cod from offshore areas and near Prudhoe Bay are rarely larger than 250 mm, and only attain maximum ages of about five to six years. Sexual maturity in this species is apparently reached after three years (Craig and Haldorson, 1980; Bendock, 1977).

During the summer months Arctic cod are probably widely distributed throughout offshore areas, but have also been observed feeding in large numbers in the nearshore habitats of Simpson Lagoon. This species feeds primarily on epibenthic and planktonic crustacea, with dominant prey items being mysids, amphipods and copepods (Bendock, 1977; Craig and Haldorson, 1980).

Arctic cod spawn in winter, although the exact dates and locations within the Beaufort and northeast Chukchi seas are not known. Evidence provided by Craig and Haldorson (1980) and Moulton et al. (1980) suggests that spawning occurs under the ice between November and March, and spawning areas appear to occur both in shallow coastal areas (such as Stefansson Sound) as well as in offshore waters (Craig and Haldorson, 1980; Tarbox and Moulton, 1980). This species probably spends most of the winter in offshore regions of the Beaufort and northeast Chukchi seas, although some overwintering adults have been documented under the ice less than 5 km from the coast (Tarbox and Thorne, 1979).

The behaviour of Arctic cod is not well documented, but recent studies suggest that they usually move in large schools and tend to concentrate around open leads in the ice cover (Bain and Sekerak, 1978). They are attracted to physical structures such as ships and docks in nearshore areas (Tarbox and Spight, 1979). Their occurrence in nearshore habitats has also been associated with cold marine water in a stratified water column. For example, Moulton et al. (1980) reported that concentrations of Arctic cod during the summer in Prudhoe Bay were found near the interface between the warmer brackish layer and the dense cold marine water layer. These authors suggested that, although this species prefers cold marine waters, it may take advantage of the greater productivity of upper brackish waters during the summer.

3.4.6.2 Fourhorn Sculpin

The fourhorn sculpin is one of the most common and widely distributed species of marine fish in coastal habitats of the Beaufort Sea. It is a demersal species, usually associated with shallow brackish waters, and has been reported in large numbers in almost all coastal fish surveys. Fourhorn sculpins are not believed to be abundant at depths below 15 to 20 m (Griffiths et al., 1975). The relatively high abundance of this species in some areas was recently demonstrated in a study by Byers and Kashino (1980) who reported that 75% of the biomass of fish (6,000-9,500 kg/km^2) collected in trawl surveys near Tuktoyaktuk was fourhorn sculpin. This species is not utilized in any domestic fishery, but juveniles are occasionally fed on by inconnu, cisco, whitefish, char and gulls (Griffiths et al., 1975; Craig and Haldorson, 1980).

In the Beaufort and northeast Chukchi seas the fourhorn sculpin reaches a maximum length of approximately 300 mm, and although it can reach fourteen years of age, most large fish found in the region are eight to nine years old. Its primary foods are amphipods, isopods and mysids, although juvenile Arctic cod may occasionally form part of their diet (Bendock, 1977).

Spawning occurs on the bottom during mid winter in nearshore habitats. Documented spawning areas include the Yukon coast (Kendel et al., 1975), the Prudhoe Bay area (Craig and Haldorson, 1980) and Mallik Bay in the outer Mackenzie Delta (Percy, 1975). Overwintering has also been documented for nearshore waters, and it is assumed that the fourhorn sculpin moves into slightly deeper waters as shallow habitats freeze solid. They reoccupy these shallow habitats when the ice recedes in the summer.

3.4.6.3 Pacific Herring

In the Beaufort and northeast Chukchi seas, Pacific herring have been reported from Cape Bathurst to Point Barrow, but only appear to be abundant in the eastern Beaufort, particularly along the Tuktoyaktuk Peninsula and in Liverpool Bay. Pacific herring were the second most abundant species observed in surveys conducted prior to 1976 along the eastern portion of the Tuktoyaktuk Peninsula, and were the most abundant fish collected in the Hans Bay region of the Eskimo Lakes (Poulin, 1977). During a recent study, Byers and Kashino (1980) found that herring accounted for 32% of surface gillnet catches near

Tuktoyaktuk, and were particularly abundant inside Tuktoyaktuk Harbour. Further east, in Amundsen Gulf, Hunter (1979) reported that herring were the major species present in Franklin and Darnley bays.

In the Arctic, Pacific herring are believed to spawn during June and July, particularly in areas with macrophyte growth. Liverpool Bay, Eskimo Lakes, eastern Mackenzie Bay and coastal areas of Richards Island were possible spawning and rearing habitats identified by Fenco and Slaney (1978). In the autumn, herring are harvested by the domestic fishery at Tuktoyaktuk and used for human and dog food. A commercial fishery quota of approximately 230,000 kg/yr was established for Cape Parry near Paulatuk, but no commercial fishing for herring has occurred in that area (Fenco and Slaney, 1978; B. Wong, pers. comm.).

3.4.6.4 Capelin

Capelin a widely distributed species of the smelt family, has been reported in areas west of the Mackenzie Delta and is usually not abundant except in August when it spawns in coastal habitats. During August, residents near Point Barrow harvest capelin in a small domestic fishery. McAllister (1962) also collected large numbers of this species in late summer near Herschel Island, while ripe capelin were documented in Simpson Lagoon during August (Craig and Haldorson, 1980). Apart from their sporadic appearance, little else is known about their movements and distribution in the Beaufort and northeast Chukchi region.

3.4.6.5 Snailfish

Snailfish are small, less than 15 cm long, demersal fish usually associated with kelp or rocky substrates (Hart, 1973; Tarbox and Moulton, 1980). The bartail snailfish and the gelatinous snailfish are two species tentatively identified in the region to date. Snailfish have been collected during intensive studies conducted in Simpson Lagoon (Craig and Haldorson, 1980), Prudhoe Bay (Tarbox and Thorne, 1979), and Mackenzie Bay (Slaney, 1973a). Craig and Haldorson (1980) also collected snailfish in trawl surveys carried out from 1 to 7 km offshore, and identified the adhesive eggs of snailfish attached to sampling gear in rocky substrate areas, confirming active spawning near Simpson Lagoon during February. Tarbox and Thorne (1979) also observed snailfish spawning in kelp beds in Prudhoe Bay during March, and subsequently followed the development of the eggs and juveniles later in the year. They reported that snailfish larvae settle out on the bottom and exhibit a strong affinity for saline waters during rearing. Adult snailfish prey largely on amphipods and mysids.

3.4.6.6 Other Marine Species

Arctic flounder, starry flounder and saffron cod have been reported in most coastal areas of the Beaufort Sea. Arctic flounders tend to be more common in the outer margins of river deltas than in other coastal waters within the region (Bendock, 1977; Craig and Griffiths, 1980), and have been reported in large numbers in Liverpool Bay (Government of Canada, 1973). All of these species are believed to spawn and overwinter under the ice in coastal areas, but details of their life history in this region are poorly known. Flounders are reported to consume bivalves as well as epibenthic crustacea, and therefore represent one of the few groups of fish, including whitefish, which feed at least in part on infaunal organisms.

3.5 LOWER TROPHIC LEVELS

The rigorous physical and chemical constraints imposed by the Arctic environment play a dominant role in influencing the seasonal and spatial distribution of members of lower trophic levels. The first part of this section describes the physical oceanographic characteristics and processes in the Beaufort and northeast Chukchi seas which affect the distribution, abundance and species composition of lower trophic level communities (Section 3.5.1), as well as the chemical factors (Section 3.5.2) which act in conjunction with the physical environment to limit rates of primary photosynthetic production by plant communities. The remainder of the section summarizes available information on the bacterial, phytoplanktonic, zooplanktonic, epontic and benthic communities.

3.5.1 PHYSICAL CHARACTER OF THE BEAUFORT AND CHUKCHI REGION

This section summarizes the major physical conditions and processes which affect the lower trophic communities of the Beaufort and northeast Chukchi seas. A more detailed description of the physical environment is provided in Chapter 1 of this volume. The annual oceanographic cycle in the region is dominated by a period of ice cover lasting at least eight to nine months. Comprehensive discussions of the variability in ice conditions within this region are provided in Markham (1975), Marko (1975), and Shapiro and Barry (1978). Three zones of winter ice cover generally occur (Figure 3.5-1):

- Landfast ice: a continuous sheet of relatively smooth, new (first year) ice anchored at the shore and extending offshore to depths of approximately 20 m (Cooper, 1974). Grounded pressure ridges are commonly found within the landfast ice and contribute to its stability.

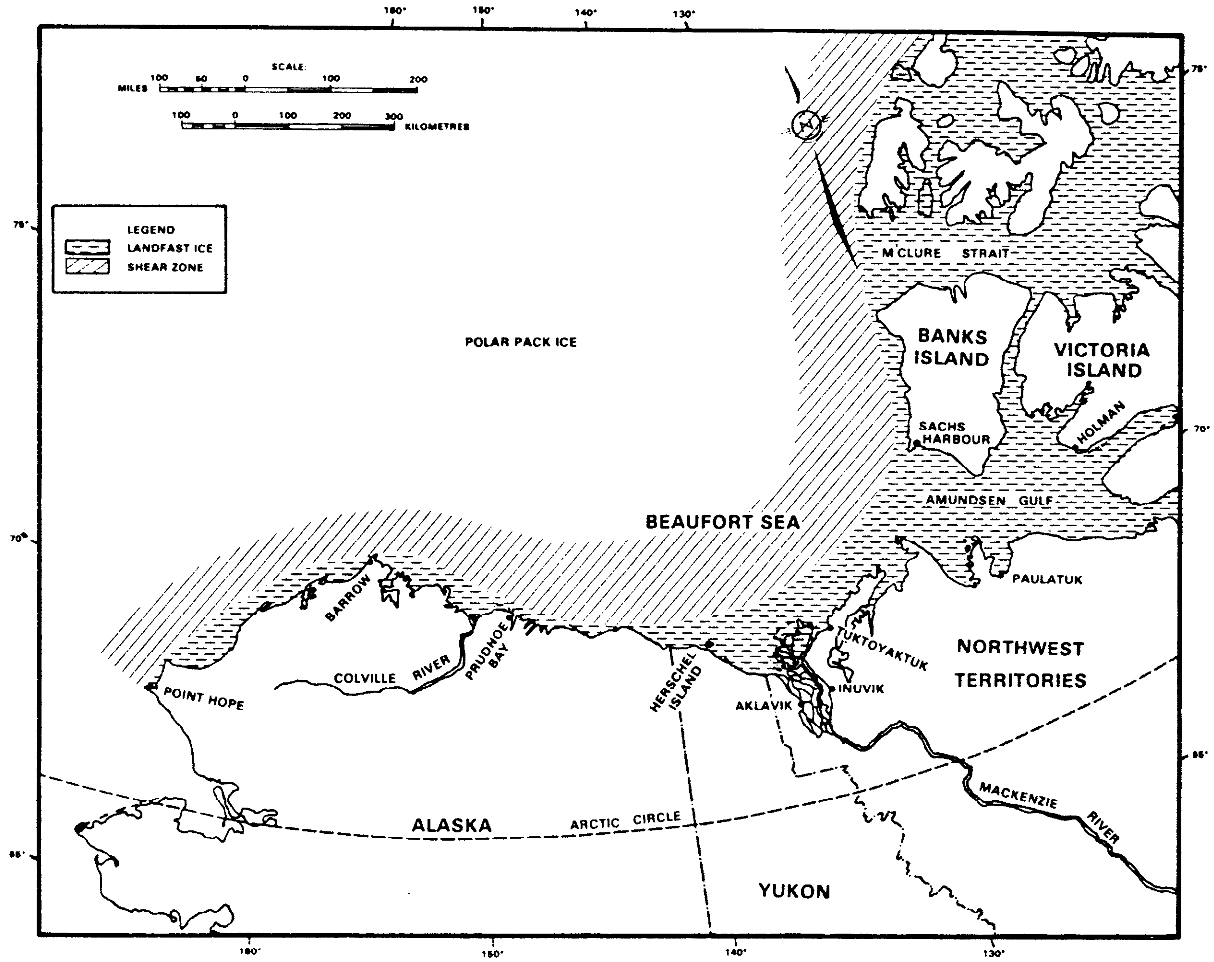


FIGURE 3.5-1 *Generalized sea ice zones of the Beaufort Sea and western Arctic.*

- Shear (transition) zone ice: a heavily ridged and highly irregular discontinuous ice cover between the outer edge of the landfast ice and the offshore polar pack ice. It is composed of new and multi-year ice.

- Polar pack ice: an extensive permanent ice zone extending from the transition zone into the Arctic Basin, and composed of multi-year ice circulating in a clockwise gyre. Large leads and fracture lines can develop within this zone, especially in the spring.

During the brief ice-free season, freshwater discharge from coastal rivers and streams creates brackish conditions in the shallow nearshore zone. With the exception of the Colville River estuary, most estuaries in the Alaskan Beaufort and northeast Chukchi seas are relatively small in comparison with the extensive brackish water area associated with discharge of the Mackenzie River. During the winter months, waters off the Mackenzie Delta continue to be influenced by river discharge, by depressing salinities beneath the ice cover (Barber, 1968; Bengeyfield et al., 1974). Winter oceanographic conditions elsewhere in the region are characterized by colder more saline waters which approach 33 ⁰/oo after the smaller freshwater tributaries freeze. Hypersaline conditions (greater than 50 ⁰/oo) can occur during winter in shallow nearshore waters along the Alaskan coast due to cryoconcentration, reduced freshwater inflow and restricted circulation (Griffiths and Dillinger, 1980).

Ice thickness in winter may reach 2 to 3 m, and in shallow areas the entire water column freezes down to and into the upper layer of sediment. Pressure ridges between large ice plates further offshore may have "keels" extending to 15 m below the surface (Reimnitz and Barnes, 1974), and bottom scouring occurs as these keels move across the substrate during movement of the pack ice. Similarly, the landfast ice in shallow water also moves during spring break-up, scouring many of the nearshore areas.

The spring runoff of warmer fresh water from snowmelt results in flooding of the landfast ice at river mouths and eventually the formation of open water areas. In the Beaufort and northeast Chukchi region, this process generally occurs from mid May through June (Gill, 1974). During the brief summer open water period, landfast ice disperses and open water may extend 500 km or more from the coast. Annual variability in the extent of open water is largely due to differences in prevailing winds. In some years northerly winds have been known to drive the polar pack ice to within 50 km of the coast.

Water temperatures near the freezing point (as low as -2.5°C for marine water) prevail throughout the water column during the winter months. During the open water season, vertical mixing of the warmer freshwater discharge can occur to depths of 15 m (Wacasey, 1974), while temperatures below this zone generally remain cold and fluctuate only slightly throughout the year. Surface water temperatures have reached 18°C off the Mackenzie Delta (McDonald and Cambers, 1977) and 16°C in shallow enclosed areas such as Simpson Lagoon, Alaska (Griffiths and Craig, 1978).

The transition from the total darkness and extreme cold of winter to the 24 hour daylight regime and moderate temperatures of summer, in conjunction with seasonal differences in nutrient availability (Section 3.5.2), results in annual cycles in the abundance, species composition and primary productivity of different plant communities. Seasonal differences in the structure and abundance of various plant communities subsequently affect the distribution, abundance and secondary production of benthic, epontic and pelagic invertebrates (zooplankton) due to the herbivorous food habits of most Arctic marine invertebrates (Section 3.1).

In summary, the annual cycles of members of lower trophic levels in the Beaufort and northeast Chukchi seas are closely correlated with five distinguishable but continuous seasons characterized by the following physical processes:

- Winter extends approximately from October to March or early April and is characterized by an increasing thickening of sea ice with grounding of pressure ridges and shallow landfast ice, little or no solar radiation, increasing water salinity in most areas except the Mackenzie estuary, and limited vertical circulation of water under the ice.

- Spring extends approximately from April to May and is characterized by slower thickening of sea ice, increasing solar radiation, high salinity water and weak under-ice currents.

- Late spring extends approximately from late May to July and is characterized by melting of the landfast ice with some scouring of nearshore substrates, a large influx of often turbid freshwater river runoff from melting snow, intense solar radiation often interrupted by ground fog, and very highly stratified areas of open water.

- Summer extends approximately from July to September and is characterized by break-up and the eventual disappearance of sea ice in some areas, less intense solar radiation, water salinities approaching oceanic levels, and periodic wind-driven mixing of the water column including storm wave-induced erosion and deposition of sediments in coastal areas.

- Fall extends approximately from September to October and is characterized by the formation of slush ice along the shore, rapidly decreasing solar radiation, increasing salinity of oceanic waters as more ice forms, and sporadic wind-driven water recirculation which becomes less common as sea ice becomes more extensive.

3.5.2 NUTRIENTS

The major nutrients affecting plant growth are nitrites/nitrates, phosphates and silicates, although carbon dioxide and a number of trace elements must also be present in adequate quantities. This section briefly describes various nutrient supply mechanisms and the seasonal availability of nitrogen, phosphorus and silicon in the Beaufort and northeast Chukchi seas. The role of these nutrients in controlling or limiting the growth of phytoplankton, epontic flora, benthic microalgae and macrophytic algae is also summarized where this information is available.

3.5.2.1 Nutrient Supply Mechanisms

Nutrient concentrations in the water column are a complex function of consumption, *in situ* nutrient regeneration rates, upwelling of deeper waters, resuspension of sediments, and input from terrestrial sources (Figure 3.5-2). Once the supply of available nutrients surrounding individual plant cells is depleted below critical concentrations, growth does not occur, irrespective of the availability of light and carbon dioxide. When local diffusion processes are insufficient to support continued growth, an additional influx of nutrients must come from one or more of the aforementioned sources.

Arctic waters usually become stratified during late spring and summer when less dense ice-melt water and river drainage water form a surface layer. This water increases in temperature, further decreasing the density of the upper water column and reinforcing the vertical stratification. The nutrient supply near the surface is rapidly exhausted by phytoplankton growing in the relatively intense light. This nutrient supply is primarily replenished from deeper waters when localized wind-generated currents disrupt the stratification and cause vertical exchange with deeper waters below the photic zone or with

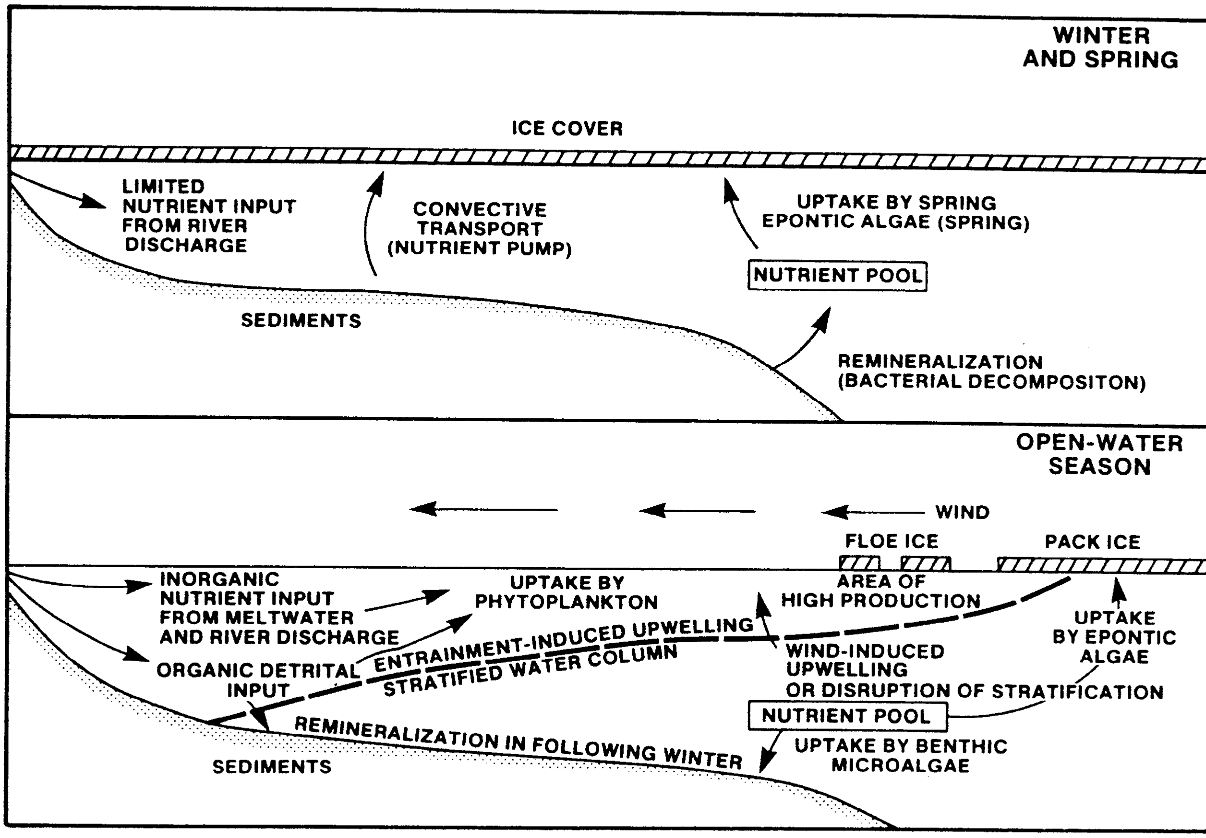


FIGURE 3.5-2 *Major nutrient supply mechanisms and pathways in Arctic marine coastal environments*

sediments under shallower waters. Examples of the vertical structure of nearshore and offshore waters of the Beaufort Sea, and resultant effects on nutrient availability and phytoplankton standing stock, are provided in Table 3.5-1. These data clearly illustrate the marked differences in concentrations and subsequent effects on phytoplankton growth which can occur in nearshore areas (Station 73-529) and highly stratified offshore sites (Station 73-542). The combination of a short season of intense light and the predominance of stable water stratification during this period makes the Arctic Ocean and adjacent waters the least productive of the world's oceans (Dunbar, 1970; Platt and Subba-Rao, 1975).

Nutrient replenishment of the photic zone of stratified water columns may occur through various upwelling phenomena. Wind-induced divergence of the surface water may cause open ocean upwelling (Smith, 1968; Dragesund, 1971), while in estuaries, outflowing fresh water entrains nutrient-rich deep water and causes an increased nutrient supply at the surface. Although these phenomena remain poorly documented in most Arctic waters, wind-driven upwelling may be a factor contributing to the high productivity observed at ice edges.

For example, along the Bering Sea shelf 65% of the annual primary productivity occurs in spring, and most of this production is associated with the edge of the pack ice in May (Alexander and Cooney, 1979). When the ice edge is located over the continental shelf most of the production from the associated bloom enters benthic food chains, but when the ice edge is over deeper water most of the production goes into the pelagic food web. These authors suggest that high production at the edge of large areas of pack ice occurs because ice, broken into small floes by wind, allows high light penetration, but at the same time, the restricted fetch inhibits mixing and thus minimizes dispersal of the bloom populations.

Another mechanism of nutrient replenishment of surface waters is convective upward transport of nutrient-rich deeper water toward the lower ice surface. At the end of winter, the ice covered oceanic and nearshore Arctic waters have high concentrations of inorganic nutrients as a result of heterotrophic remineralization throughout the winter in the absence of planktonic uptake. Once the growth of epontic algae on the lower ice surface commences in spring, this community immediately begins to deplete the nutrient supply in the surface waters. The ice is still increasing in thickness at this time, and may provide the power for the hypothetical nutrient pump described by Schell (1975, 1979). As the ice freezes, a zone of very cold dense water is formed around each growing crystal. This cold saline water has a higher

TABLE 3.5-1

VERTICAL DIFFERENCES IN THE STRUCTURE AND NUTRIENT REGIME OF NEARSHORE AND OFFSHORE BEAUFORT SEA WATERS (ADAPTED FROM DATA PROVIDED IN GRAINGER (1975) AND GRAINGER AND LOVRITY (1975))

NEARSHORE STATION 73-529 (22/07/73)
Secchi Depth + 0.3 m

DEPTH (m)	TEMP (°C)	SALINITY (‰)	PO_4-P (μg-at/L)	NO_3-N (μg-at/L)	Si (μg-at/L)	Chl. a (mg/m³)
0	7.7	9.0	0.21	0.1	19.2	1.40
3	7.5	9.2	0.36	0.0	18.8	1.39
5	7.5	9.3	0.15	0.0	19.3	1.80
10	7.0	9.6	0.27	0.0	19.5	1.24

OFFSHORE STATION 73-542 (27/07/73)
Secchi Depth = 2.2 m

DEPTH (m)	TEMP (°C)	SALINITY (‰)	PO_4-P (μg-at/L)	NO_3-N (μg-at/L)	Si (μg-at/L)	Chl. a (mg/m³)
0	7.1	12.0	0.13	0.0	17.7	0.59
5	5.0	14.3	0.13	0.1	19.1	0.80
10	-0.2	29.5	0.61	2.1	12.1	0.16
20	-0.2	30.5	0.65	2.1	9.5	0.00
30	-0.1	30.9	1.09	2.4	14.0	0.00

density than the surrounding water and sinks, in the process displacing an equal volume of water upward toward the epontic algal community.

3.5.2.2 Nutrient Regeneration and Availability

(a) Nitrogen

Nitrogen is the nutrient which most frequently limits growth of marine phytoplankton communities, particularly in coastal Arctic waters (Ryther and Dunstan, 1971; Schell, 1975). In marine environments, nitrogen exists in ionic forms as nitrates (NO_2 -), nitrites (NO_2 -) and ammonia (NH_3), but only nitrate and ammonia are commonly used by marine organisms. Of these two forms of available nitrogen, ammonia is preferentially utilized by most algal species (Eppley et al., 1969). However, ammonia is also volatile and rarely found in high concentrations in marine waters.

The role of ammonia as a limiting factor on phytoplankton productivity has been examined in nearshore waters of the Alaskan Beaufort. Horner et al. (1974) reported that the highest ammonia concentrations (and other nutrients) near Prudhoe Bay were found under the sea ice in late winter and spring. They also reported that inorganic nitrogen sources, including ammonia, were rapidly depleted to levels that are limiting to many neritic diatom species in the early part of the summer. Ammonification, the process by which heterotrophic bacteria release ammonia from organic nitrogen compounds such as amino acids, urea and complex organic detritus, is one of the *in situ* pathways of nitrogen regeneration. Schell (1974) found that ammonification occurred naturally in the cold hypersaline estuarine areas of the western Beaufort Sea between Point Barrow and Prudhoe Bay, and subsequently reported ammonification rates of amino acids naturally present in the Beaufort Sea from 0.04 to 0.49 μg-at NH_3/L/day (Schell, 1975).

Nitrate is not volatile and is therefore the common inorganic form of nitrogen available to marine phytoplankton. The primary sources of nitrate within the photic zone are the nitrification of ammonia by bacteria, release from detritus by bacterial decomposition, and the upwelling of nitrate-rich deep water. Nitrification is the energy yielding process whereby bacteria oxidize ammonia to nitrite and nitrite to nitrate. This process occurs throughout the year in oceanic waters, and the lack of active uptake below the photic zone leads to accumulations of nitrate-rich waters which can become available to phytoplankton in areas of upwelling. Rates of nitrification measured in coastal and marine waters of the Beaufort Sea have ranged from 0.068 to 0.15 μg-at NO_3^-/L/day (Schell, 1975). In addition, storm-driven erosion of the tundra transports nitrogen into nearshore waters. During the late spring and summer, the inorganic forms of nitrogen are taken up almost immediately by phytoplankton communities in nitrate-depleted coastal waters, whereas the more refractory peat nitrogen forms the basis of the detrital nitrogen supply which is remineralized during the following winter (Alexander et al., 1975).

Nitrate concentrations in the Alaskan and Canadian portions of the Beaufort Sea have been reported in a number of sources including English (1961), Alexander (1974), Grainger (1974, 1975), Horner et al. (1974), Schell (1974, 1975), Alexander et al. (1975), and Grainger and Lovrity (1975). One of the most comprehensive studies of seasonal and spatial differences in nutrient concentrations was completed in conjunction with the Beaufort Sea Project and earlier programs of the Arctic Biological Station. Grainger (1975) reported that highest (open water) nitrate levels in surface waters occurred in the vicinity of the Mackenzie River outlets, while lowest concentrations were found at the surface at offshore stations farthest from the river mouths. He also suggested that relatively high surface nitrate concentrations (to 9.9 μg-at NO_3^-/L) observed in some areas, such as Kugmallit Bay during May, probably reflected a combination of winter remineralization processes and contributions from the Mackenzie River. The highest nitrate levels were found in deep waters below the photic zone where concentrations approached 16 μg-at NO_3^-/L.

(b) Phosphorus

Phosphorus is another nutrient which can commonly limit the growth of marine phytoplankton communities. The biologically useful form of phosphorus is the phosphate ion, which is nonvolatile but which may undergo abiological transformations in and near anoxic zones such as the upper layer of marine sediments. Arctic fresh water generally has a low phosphate content (Schindler et al., 1974; Sekerak and Graves, 1975). For example, the range of phosphate found in the Mackenzie drainage area by Reeder et al. (1972; cited in Grainger, 1975) was less than 0.10 to 0.95 μg-at/L, while concentrations recorded in the Colville River (Alexander et al., 1975) were even lower (0.02 - 0.18 μg-at/L). Although near-limiting levels of phosphate (0.2 - 0.8 μg-at/L) are also present in coastal Alaskan waters adjacent to the Colville River, it has been suggested that nitrogen becomes limiting to phytoplankton growth before phosphorus (Alexander et al., 1975; Schell, 1975).

In the Canadian Beaufort highest surface phosphate concentrations have been found near Mackenzie and Kugmallit bays (Grainger, 1975), but the range of values observed in both nearshore and offshore areas was small relative to the distinct trends noted for nitrate during the same investigation. Unlike nitrate, phosphate concentrations in the surface waters at stations farthest from the river mouths remained relatively high. Nevertheless, Grainger (1975) reported some evidence of phosphate depletion in the upper 20 m of the water column at the same stations where nitrate was almost totally exhausted. Surface phosphate concentrations in the region rarely exceed 1 μg-at/L, but may exceed 2.0 μg-at/L at depths from 50 to 200 m (Hufford, 1974; MacDonald et al., 1978). Some contribution of phosphate from the Mackenzie River was also suggested by the investigations of Grainger (1975), although the watercourse is clearly more important as a source of nitrate.

(c) Silicon

Silicon is an essential element for the siliceous tests of diatoms which are generally the dominant members of the phytoplankton community. Unlike nitrate and phosphate, the biologically utilized form (silicate) is not a direct metabolite, but can become limiting to cell development at concentrations less than 3 μg-at/L (Alexander et al., 1975). Concentrations of silicate in the region are generally at least 5 to 10 times this level, and it has been suggested that nitrates would become limiting before the availability of silicate affected phytoplankton communities in this region (Alexander et al., 1975; Grainger 1975; Schell 1975). For example, silicate concentrations in surface waters of the U.S. Beaufort shelf, southern Beaufort Sea and Amundsen Gulf have ranged from less than 2 to 40, 10 to 33, and 2 to 35 μg-at/L, respectively (Hufford, 1974; Grainger 1975; MacDonald et al., 1978). Schell (1975) reported that silicate concentrations in lagoons from Point Barrow to Prudhoe Bay varied from 21.0 to 57.6 μg-at/L. As was the case with nitrates, a positive relationship between the influence of the Mackenzie River plume and high silicate availability was observed by Grainger (1975).

3.5.3 BACTERIA

Aquatic bacteria are important in nutrient recycling processes in freshwater and marine environments. As indicated in Section 3.5.2, bacteria play a fundamental role in phosphorus and nitrogen regeneration in the upper layers of marine sediments. Some of these micro-organisms oxidize organic matter to produce carbon dioxide, while others synthesize vitamins which are subsequently utilized by algae. Some species, called oleoclastic bacteria, can also degrade certain petroleum hydrocarbons and assume a relatively major role in the weathering of oil (Fingas et al., 1979). Aquatic bacteria are important food sources for microzooplankton and benthic detritivores, and still others are pathogens to various flora and fauna. They generally occur throughout the water column and within bottom sediments of the Beaufort and northeast Chukchi region in concentrations similar to those of more temperate coastal waters (Bunch and Harland, 1976; Kaneko et al., 1978).

In the Beaufort and northeast Chukchi region, Boyd and Boyd (1963) were the first authors to attempt enumeration of coastal bacteria. Plate counts from Point Barrow samples in early March were extremely low (1 to 2 bacteria per ml), but increased to about 500 bacteria per ml during June. Bacterial counts were similar on both freshwater and marine agar media, and these authors suggested that many of the bacteria from this area were of terrestrial origin. However, their incubation techniques were not appropriate for the psychrophilic bacteria which have subsequently been shown to predominate in most cold marine waters and sediments (Bunch and Harland, 1976; Kaneko et al., 1977).

Kaneko et al. (1978) reported that most of the bacteria isolated from the western Beaufort Sea during summer were psychrotrophs (that is, they tolerate cold temperatures), while most of the winter bacterial populations were psychrophiles (that is they grow best at cold temperatures). These authors found that 90% of water and 80% of sediment colonies required salt for growth in both summer and winter. They also concluded that total bacteria populations in the Beaufort region were present at concentrations as high as those found in temperate oceans.

Bunch (1974) used growth media similar to Boyd and Boyd (1963) but incubated water samples from the Beaufort Sea at 5°C instead of 22°C. This study suggested that a large freshwater bacterial biomass was carried by the Mackenzie River, but that these cells did not persist or multiply once they were transported into the marine environment. However, the indigenous marine bacteria in the southern Beaufort Sea and Eskimo Lakes appeared to be relatively uniform and tolerant of low salinities.

Bunch and Harland (1976) conducted a microbiological program in the southern Beaufort Sea during the summers of 1974 and 1975, and reported that total viable counts ranged from 1,000 to 30,000 cells/ml. The maximum bacterial population in the water column coincided with the phytoplankton bloom which occurred after break-up; bacterial biomass then declined along with primary productivity. Incubation of replicate samples at different temperatures indicated that the heterotrophic flora were predominately psychrophilic.

Griffiths et al. (1978) investigated bacterial concentrations and relative microbial activity off Point Barrow and Prudhoe Bay, Alaska in summer 1975, winter 1976 and summer 1976. Both population size and activity in water and sediment samples were lower during the April (winter) sampling period. Samples of melted sea ice showed levels of relative microbial activity similar to those in the adjacent seawater. Seawater samples that were diluted 50% with sterile fresh water showed no significant change in the bacterial uptake of glutamic acid, thereby confirming the salinity tolerant (euryhaline) nature of the local microflora. Griffiths et al. (1978) suggested that an order of magnitude difference between summer and winter glutamic acid uptake rates probably reflected variability in nutrient concentrations rather than the 3°C range in water temperature. Microbial activity per square metre in the sediments of inshore stations was found to be approximately 400 times greater than within the entire overlying water column (3 m deep).

Kaneko et al. (1977) investigated bacterial diversity between Point Barrow and Prudhoe Bay, Alaska, during two summer and one winter field programs. The authors isolated the bacteria in pure culture, characterized the colonies, and then grouped them into phenotypic clusters. Almost all strains were found to be psychrophilic. During both summers bacterial diversity in the water samples decreased as population size increased, moving eastward from Barrow and offshore from Prudhoe Bay. However, no geographic trends in bacterial diversity within sediment or ice samples were observed. Concentrations of bacteria in the water column were always higher in summer (greater than 10,000/ml) than in winter (less than 10,000/ml). Nutritional studies also indicated that populations of bacteria in the water had extensive growth requirements which were presumably supplied by phytoplankton exudates. On the other hand, populations in the sediments were relatively abundant throughout the year (10,000/g) and generally more diverse than those in the water column, likely due to the greater availability of nutrients. Bacterial concentrations were less than 10,000/ml in sea ice.

The literature regarding the abundance of oleoclastic bacteria in the Beaufort and northeast Chukchi region is conflicting. Earlier studies indicated little or no petroleum-degrading micro-organisms. For example, Robertson et al. (1973) did not find any oleoclastic bacteria in estuarine areas of the Colville River, Alaska. Bunch and Harland (1974) subsequently isolated a psychrotrophic mixed culture from the Eskimo Lakes using an enrichment procedure. These flora were found to be oleoclastic but not very abundant. Bunch and Harland (1974) reported that these bacteria degraded petroleum at temperatures down to 2°C, but optimum growth of individual colonies occurred at 20 to 25°C. They also suggested that the relatively low abundance of oleoclasts in the Beaufort region might be partly due to the absence of petroleum contamination in this ecosystem. The latter observation was confirmed by the studies of Wong et al. (1976).

In a subsequent report using improved enrichment techniques, Bunch and Harland (1976) found oleoclastic species to be ubiquitous to both offshore and nearshore Beaufort waters, although they were only found in nearshore sediments. Mixed cultures were able to degrade Norman Wells crude oil at 0.0°C. These authors also investigated the effect of petroleum hydrocarbons on the metabolism of dissolved organic compounds by indigenous bacteria. They found that mineralization of glutamic acid by the indigenous microflora was generally unaffected, or in some instances enhanced by the presence of weathered or unweathered crude oil. Bunch and Harland (1976) further suggested that *in situ* activity of non-oleoclastic heterotrophs might not be affected by a moderate influx of petroleum to the Beaufort Sea ecosystem.

Atlas et al. (1978) conducted small experimental spills of Prudhoe Bay crude oil near Point Barrow to investigate microbial degradation of oil in ice, water and sediment ecosystems. They found that oleoclastic micro-organisms were present in all Arctic marine ecosystems, and numbers of bacteria generally increased after oil contamination. However, these authors also reported that petroleum biodegradation progressed slowly following initial abiotic weathering.

3.5.4 PHYTOPLANKTON

As discussed earlier (Section 3.5.1), the environment of the Beaufort and northeast Chukchi seas is characterized by seasons of little or no light, remineralization and rapid nutrient depletion, low and high freshwater discharge, and vertical stratification of the water column in summer. Each of these factors contributes to marked seasonal differences in the structure, abundance and productivity of algal communities. There are three distinct algal communities in the Arctic marine environment (epontic, planktonic and benthic), and each is affected to a greater or lesser extent by the aforementioned factors. The first community to develop in the spring is that of the epontic algae, followed by the planktonic forms which are relatively abundant in the upper water column (photic zone) from late spring through summer. The benthic algae (microalgae and attached macrophytes) are generally present throughout the year, but most do not become photosynthetically active until the ice cover disappears in late spring or early summer. The present section only discusses available information describing the species composition, abundance and productivity of planktonic algae. Benthic and epontic algae are discussed in Sections 3.5.6 and 3.5.7, respectively.

3.5.4.1 Species Composition and Abundance

The species composition and standing crop of phytoplankton communities in the Beaufort and northeast Chukchi seas have been the subject of substantial investigation in recent years. Beaufort Sea phytoplankton were first collected during the 1913-1918 Canadian Arctic Expedition, and diatoms present in the samples were subsequently described by Mann (1925). Bursa (1963) studied the taxonomic composition of phytoplankton from nearshore and offshore habitats near Barrow, Alaska, and reported that the nearshore community was characterized by many coccolithophorids (Chrysophyceae) and unidentified flagellates. On the other hand, offshore waters contained more oceanic forms such as the diatoms *Chaetoceros concavicornis* and *Leptocylindrus danicus* and the flagellate *Dinobryon balticum*. In subsequent studies completed in the same area, Horner (1969, 1972) demonstrated that spring (June-July) phytoplankton blooms contained both centric and pennate diatoms, with centric diatoms increasing in abundance near the end of July. During the fall (August-September), centric diatoms and chrysophytes were common, and although dinoflagellates were observed throughout the open water season, they were most abundant during the fall. Horner et al. (1974) described the species composition of nearshore and offshore phytoplankton communities near Prudhoe Bay. Nearshore communities were characterized by a predominance (50-70%) of pennate diatoms, while centric diatoms were more common in deeper more saline waters.

Hsiao (1976) described the species composition of nearshore and offshore phytoplankton communities of the Beaufort Sea in considerable detail. In general, diatoms dominated nearshore phytoplankton communities, whereas flagellates were more abundant at offshore stations. Hsiao (1976) suggested that higher water temperatures, higher nutrient concentrations and lower light intensities favour the growth of diatoms in nearshore areas, while the greater abundance of flagellates in offshore waters was a reflection of poor growth conditions for other algal groups, in conjunction with the tolerance of flagellates to high light intensities and relatively low nutrient levels.

Alexander et al. (1975) examined the standing crop of major phytoplankton species in the nearshore Beaufort Sea close to the Colville River delta, and reported that phytoplankton abundance was greatest at depths from 2 to 4 m. Hsiao (1976) subsequently found that the standing crop of southern Beaufort Sea phytoplankton in the euphotic zone decreased with increasing distance from shore. The highest standing crop was observed in the nearshore waters near Herschel Island, and, on average, nearshore standing crop concentrations were 10 times greater than values observed at offshore stations.

Abundance of phytoplankton in the region has been more commonly expressed in terms of chlorophyll *a* concentrations. Studies completed from a free-floating ice station in the Arctic Ocean indicated that maximum chlorophyll *a* concentrations occurred in late July when light intensities were highest (English, 1961). Alexander (1974) reported that chlorophyll *a* concentrations in the western Beaufort Sea were highest below the surface and in shoreline areas where salinity was relatively low. On the other hand, Horner et al. (1974) examined the distribution and levels of chlorophyll *a* near Prudhoe Bay and found that, in general, the chlorophyll *a* concentration was higher in deeper (greater than 5 m) more saline water than in brackish surface water. Grainger (1975) subsequently measured chlorophyll *a* concentrations at various stations throughout the Beaufort Sea. Highest levels were recorded in Mackenzie and Kugmallit bays, while lowest values occurred offshore, northeast of the Tuktoyaktuk Peninsula. The highest values were also generally observed in the upper 5 m of the water column.

The species composition and abundance of phytoplankton communities in Arctic waters are highly dependent on seasonal and local differences in the physical-chemical environment, and these differences, in conjunction with biological factors such as grazing pressure, contribute to dynamic seasonal patterns of succession. The results of studies conducted in the Beaufort and northeast Chukchi seas to date suggest that several factors influence the species composition, abundance and productivity of phytoplankton communities.

In nearshore areas dominant environmental factors are the high concentrations of suspended sediment which markedly reduce light penetration into the water column, relatively low salinities and warm temperatures, and an adequate supply of nitrate and silicate associated with freshwater discharge. In most cases the limiting factor to phytoplankton growth in these areas would be light intensity.

In offshore areas the dominant controlling factors are the stratified nature of the water column which effectively prevents nutrient replenishment from deeper waters, low light intensities in areas of persistent ice cover, and low nutrient availability following initial uptake by spring phytoplankton blooms. In general, the major limiting factor to phytoplankton growth in offshore waters is nutrient availability, in particular nitrate. Diatoms generally tend to be most abundant in areas with high nutrient levels, low light intensities, and relatively warm temperatures (Sverdrup et al., 1942; Ryther, 1956; Raymont, 1963; Hulbert, 1970), whereas growth of flagellates tends to be favoured in areas with higher light intensities and lower nutrient concentrations (Raymont, 1963; Fogg, 1965). In general, Arctic phytoplanktonic communities are dominated by diatoms, with occasional occurrences of flagellates and other forms. Pennate diatoms predominate early in the open water season, and centric diatoms become more important later in the summer and early fall.

3.5.4.2 Primary Productivity

The Arctic Ocean is considered the least productive of the world's oceans (Dunbar, 1970; Platt and Subba-Rao, 1975), with annual primary productivity ranging from 1 to 10 g $C/m^2/yr$ (English, 1961). The productivity of the Beaufort Sea is higher, but still less than 20 g $C/m^2/yr$ (Alexander et al., 1974). By comparison, productivity estimates for the Bering Sea, Atlantic Ocean shelf, and Atlantic offshore waters are 121, 150 and 100 $gC/m^2/yr$, respectively (McRoy and Goering, 1974; Platt and Subba-Rao, 1975).

Primary production studies in the northeast Chukchi and Beaufort seas have been completed by Alexander (1974), Alexander et al. (1975), Duval (1977), Horner et al. (1974) and Hsiao (1976). A series of productivity investigations conducted in the Colville River estuary and nearshore Beaufort Sea between April and May, 1974 were discussed by Alexander (1974) and Alexander et al. (1975). Under-ice productivity during this period was approximately 10 mg $C/m^2/h$, and it was estimated that total annual production in the area was 5 g $C/m^2/yr$. Alexander (1974) also reported that productivity of surface waters in Simpson Lagoon, Harrison Bay and the nearshore Beaufort Sea outside the barrier islands was 1.8, 0.6 and 0.4 mg $C/m^3/h$, respectively. Differences in production with depth and season were also examined. Maximum planktonic productivity (14 mg $C/m^3/h$) occurred in early August at a depth of 2 m. Very low levels of primary production were also observed in the Colville River estuary (less than 2 mg $C/m^3/h$) (Alexander et al., 1975) and near Prudhoe Bay (0.1-2.4 mg $C/m^3/h$) (Horner et al., 1974).

Higher rates of primary productivity have been documented in the northeast Chukchi Sea and eastern portions of the Beaufort Sea. For example, Carey (1978b) estimated that the annual productivity of the northeast Chukchi Sea in 1976 and 1977 were 18 and 28 g $C/m^2/yr$, respectively, while the same author reported annual production levels of 9 and 18 g

$C/m^2/yr$ for the western Beaufort in these years. The relatively high productivity of the eastern (Canadian) Beaufort in comparison to Alaskan waters was substantiated by the studies of Hsiao (1976). Mean surface primary production measured by this investigator during the Beaufort Sea Project was 1.39 mg $C/m^3/h$ in offshore areas and 6.74 $C/m^3/h$ in nearshore waters. Duval (1977) also investigated nearshore open water primary productivity north of Kugmallit Bay and reported surface production levels from 5.4 to 18.4 mg $C/m^3/h$ during August to early September. The studies of Hsiao (1976) and Duval (1977) both suggest that nearshore production in the Canadian Beaufort may be as much as twenty times greater than levels recorded in coastal Alaskan waters from Prudhoe Bay to Point Barrow. This apparent difference in productivity is probably related to the direct contribution of nutrient-rich waters of the Mackenzie River, remineralization of organic detritus (peat) transported downstream by this river, and nutrients entrained from deeper waters by the freshwater wedge in the Canadian Beaufort.

3.5.5 ZOOPLANKTON

The species composition and general abundance of zooplankton in the Beaufort and northeast Chukchi seas have been the subject of numerous investigations, with the most comprehensive studies having been completed in the Canadian Beaufort. Zooplankton are responsible for much of the secondary production that occurs in marine waters since many species are herbivorous and feed (graze) directly on phytoplankton, thereby forming a fundamental trophic link between primary producers and vertebrates (Section 3.1). Some zooplankton species found in the Beaufort and northeast Chukchi seas complete their life cycle in one year, although life cycles of two or even three years have also been reported. Most herbivorous zooplankton species reproduce during the late spring and summer when phytoplankton abundance is highest. However, a few species such as the copepod *Calanus hyperboreus* produce young in winter. In such species development is retarded until the phytoplankton bloom commences in spring.

3.5.5.1 Species Composition

Over 100 species of zooplankton have been identified in the Beaufort and northeast Chukchi seas, but as in other marine waters of the world, copepods are normally dominant both in terms of numbers of species and biomass. The copepods *Calanus, Pseudocalanus, Microcalanus* and *Oithona* are the most abundant forms. Other components of the zooplankton community include ostracods, mysids, amphipods, decapods, cumaceans, euphausiids, combjellies, jellyfish, arrow worms and pteropods. During some months and in some areas, the larval stages of benthic invertebrates may also be abundant in the area. Many species found in this region are also common in temperate waters.

There are considerable differences in the species composition of zooplankton throughout the Beaufort and northeast Chukchi seas. Grainger (1965) described three relatively distinct assemblages of zooplankton in the northwest Arctic Ocean and Beaufort Sea depending on depth and proximity to the shoreline. Copepods which are characteristic of nearshore brackish waters along the coastlines of the Beaufort and Chukchi seas include *Arcartia clausi, Eurytemora herdmani* and *Limnocalanus macrurus.* Freshwater zooplankton such as *Daphnia, Diaptomus* and *Bosmina* are also relatively abundant near the mouth of the Mackenzie River (Grainger, 1975), and may be present in other estuarine areas within the region.

A different zooplankton assemblage is found in the upper layers of the water column (to depths of 200-300 m) in offshore regions of the Beaufort Sea and Arctic Ocean. These areas commonly support the jellyfish *Aglantha digitale* and *Aeginopsis laurentii,* the combjelly *Beroe cucumis,* and several copepod species, the most prominent of which are *Pseudocalanus minutus, Calanus glacialis, C. hyperboreus, Microcalanus pygmaeus, Metridia longa* and *Oithona similis.* Grainger (1965) reproted that the diversity of the zooplankton community increased substantially in waters deeper than 200 to 300 m, although most species were present in low numbers. Species characteristic of deep water regions of the Beaufort Sea include the copepods *Gaidius tenuispinus, Heterorhabdus norvegicus, Scaphocalanus magnus* and *Chiridius obstusifrons.*

3.5.5.2 Distribution and Abundance

Within the major habitat types described by Grainger (1965), there may also be substantial local variability in the species composition and abundance of zooplankton, as well as seasonal differences in community structure and standing stock. For example, Grainger (1975) reported that spatial differences in the species composition of zooplankton in shallow coastal areas of the southeastern Beaufort Sea were primarily due to the variable extent of the Mackenzie River plume and resultant local differences in salinity and temperature. This author also noted that zooplankton abundance within this coastal region was highest in some sheltered inshore bays (such as Mason Bay, Tuktoyaktuk Harbour, and Liverpool Bay), but that the diversity of communities in these areas was also very low. As indicated earlier the dominant species in these nearshore sheltered environments are *Acartia clausi, Eurytemora herdmani, Pseudocalanus minutus* and *Limnocalanus macrurus* with freshwater forms (including *Diaptomus,* *Daphnia, Cyclops,* and *Bosmina)* becoming more prevalent near and in the mouth of the Mackenzie River. Similar species of zooplankton occur in the coastal Alaskan portion of the Beaufort Sea, and to a lesser extent the northeast Chukchi Sea, but the data base describing zooplankton in these areas is not as extensive as in the Canadian Beaufort (OCSEAP, 1978). Johnson (1956) reported that *Oithona* spp. and *Oncaea* spp. were the most abundant copepod genera observed in both eastern and western portions of the Beaufort Sea during the 1950 and 1951 cruises of the U.S.S. BURTON ISLAND. However, the number of species found in the western Beaufort was higher, while at the same time, the larvae of benthic organisms (especially barnacles) were abundant in Alaskan waters but relatively rare in the eastern Beaufort Sea.

The abundance and species composition of zooplankton communities also vary with depth in virtually all marine waters, although detailed information regarding the vertical distribution of zooplankton in this region is lacking. Grainger (1965) stated that the copepod *Acartia longiremis* prefers low salinites and relatively high temperatures; consequently, this and perhaps other species with similar habitat preferences may be most abundant near the surface. However, in other parts of the Canadian Arctic such as Lancaster Sound, maximum zooplankton abundance frequently occurs between depths of 10 to 50 m (Sekerak et al., 1976).

Substantial variability in the numbers and types of zooplankton occur throughout the year as a result of seasonal differences in reproduction and development. Most herbivorous species reproduce during spring and summer, and the period when juvenile and larval forms are present in the water column coincides with the season of maximum phytoplankton productivity and abundance. For example, Envirocon (1977) reported that the abundance of nauplii and copepodite larval stages in the Mackenzie estuary near Pullen Island increased almost threefold from July through August. One to three years are required for completion of the life cycles of copepods, although the rate of development of some species varies with environmental factors such as temperature and food availability. Seasonal changes in the abundance of Arctic zooplankton were described by Heinrich (1962), who reported that maximum abundance occurred from August to early September, approximately one month after the peak in phytoplankton standing crop. However, the relatively high variability observed in the spatial distribution of zooplankton in this region limits resolution of any seasonal distribution patterns. Data for nearshore areas of the Beaufort Sea suggested that standing crop may be highest in mid August (Duval, 1977; Erickson, 1981).

3.5.6 BENTHIC FLORA AND FAUNA

Benthic flora are the microscopic algae (diatoms) and larger seaweeds that live on the seafloor. These flora along with benthic invertebrates represent an important link in the marine food chain (Section 3.1). The benthic invertebrates have representation from several phyla and occupy a great variety of aquatic habitats, often as members of complex communities. Traditionally, benthic invertebrates have been grouped into two broad categories -infauna and epifauna - based upon their different relationships with the substrate/water interface (Plate 3.5-1).

Infaunal organisms are generally found within the bottom sediments, and some exhibit preferences for a narrow range of sediment grain sizes. Infaunal organisms are usually sedentary, and once established, may persist in the same location from year to year. Examples of the infauna include oligochaetes, polychaetes, bivalve molluscs, echiuroids, and sipunculids.

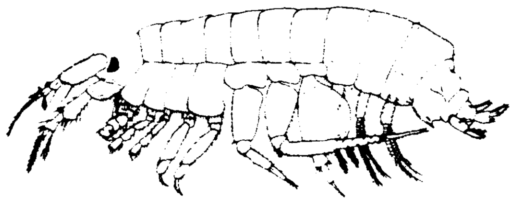
Epifauna generally inhabit the upper surface of the substrate, although some may burrow for brief periods. This group is further divided into sessile or mobile forms. Sessile epifauna are attached to solid surfaces which usually consist of rock or cobble, but can also include wood, metal, kelp or other materials (Plate 3.5-2). This type of hard substrate, with its associated fauna, is generally uncommon in the Beaufort and northeast Chukchi region. Examples of invertebrates in this group include barnacles, hydroids, anemones, bryozoans and mussels. The mobile epifauna category is dominated by crustaceans (including amphipods, mysids, isopods, cumaceans, and decapods), although echinoderms and gastropod molluscs are also prominent members of this group (Plate 3.5-3). The mobile epifauna are well represented in the Beaufort and northeast Chukchi seas, and form a substantial portion of the diet of many fish species (Section 3.1).

Prior to 1970 most benthic studies conducted in the Alaskan and western Canadian Arctic were primarily concerned with taxonomy and zoogeography. These investigations have been summarized by Wacasey (1975) and Curtis (1975). More recently, environmental studies funded by the petroleum industry have compiled site-specific data regarding species diversity and biomass of benthic invertebrates, as well as their relationships to the physical environment. Several government agencies and academic institutions have also completed synoptic surveys which provide a broad overview of benthic resources in the Beaufort and northeast Chukchi seas.

3.5.6.1 Zoobenthos

The spatial distribution of benthic invertebrates in

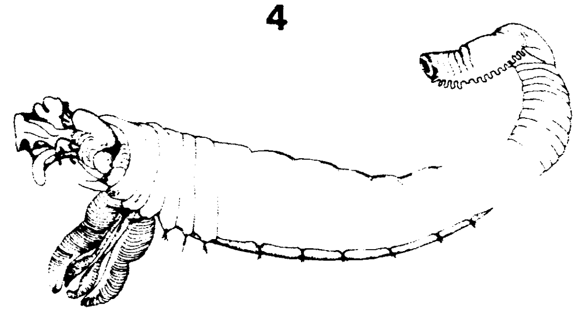
1



PONTOPOREIA AFFINIS

0 1 mm

4



TEREBELLIDES STROEMII

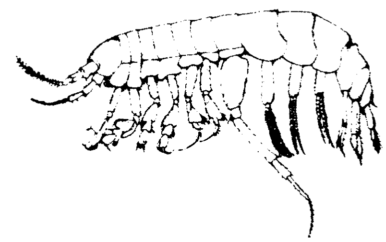
0 2 4 mm

2

MACOMA INCONSPICUA

0 1 mm

5



ACEROIDES LATIPES

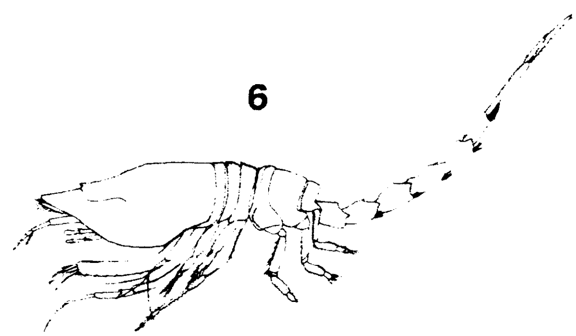
0 1 2 mm

3

CYTODARIA KURRIANA

0 1 2 mm

6



BRACHYDIASTYLIS RESIMA

0 1 2 mm

PLATE 3.5-1 *Drawings of typical epifauna and infauna found in Tuktoyaktuk Harbour. 1, 4 and 6 are crustacea which generally live on the substrate (epifauna). 2 and 3 are clams and 4 is a polychaete worm, all of which live in the substrate (infauna). (Courtesy, Arctic Laboratories Ltd.).*

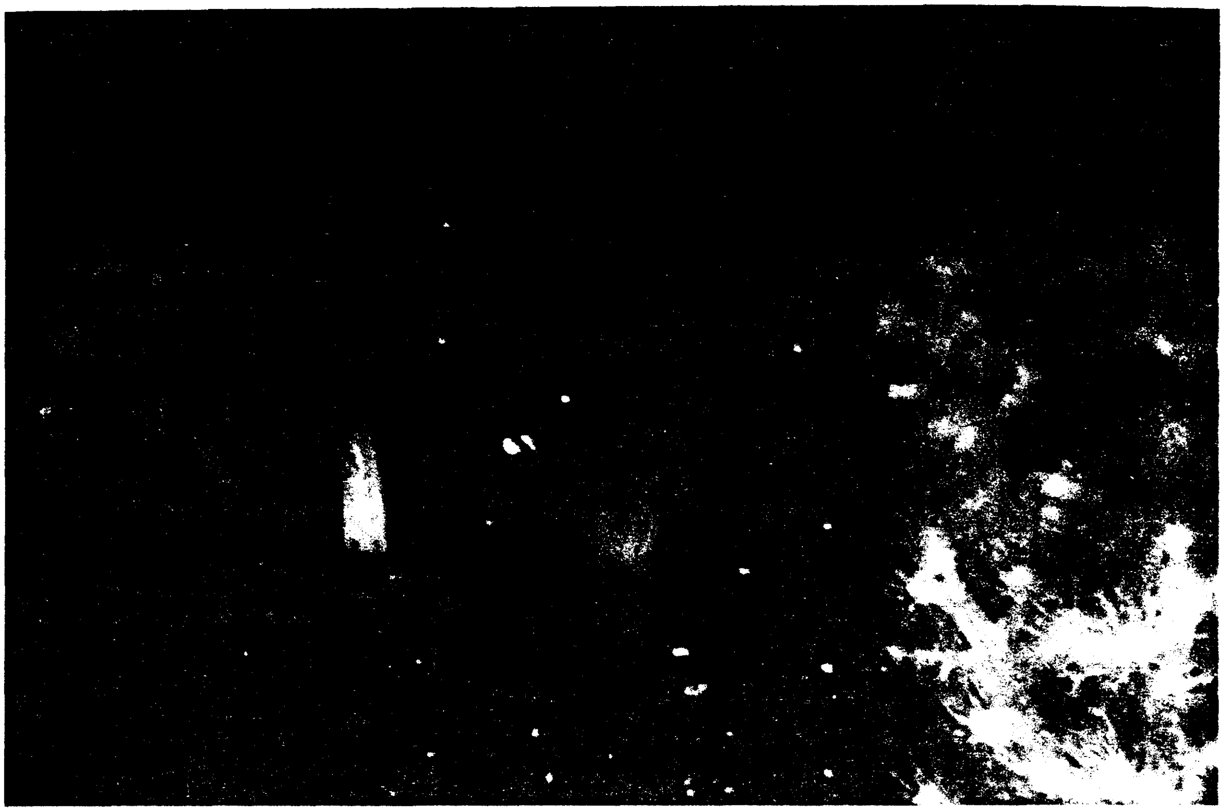


PLATE 3.5-2 *Taken underwater at Herschel Island, this photo illustrates several larger species of benthic animals which grow in gravelly areas of the Beaufort Sea. Shown are several anemones on the left, and the soft coral Gersemia rubiformis which looks like a plant. (Courtesy, Arctic Laboratories Ltd.).*

PLATE 3.5-3 *This underwater photograph shows two isopod crustacea. They are about actual size and can range to 12 cm (6 inches) in length. (Courtesy, Arctic Laboratories Ltd.).*

the western Arctic is governed by substrate suitability, water depth, ice scour, oceanographic regimes and food availability. The seafloor characteristics of the Beaufort Sea can be described as essentially unconsolidated fine-grained sediments, with exposed bedrock and large boulders occurring very infrequently (Mohr et al., 1957; Lee, 1973). The particle size composition (sands, silts and clays) of these sediments is highly variable owing to the reworking of the sediments by yearly ice scour (Reimnitz and Barnes). Localized areas with exposed pebbles, cobbles and/or boulders have been found off Point Barrow in waters deeper than 30 m (MacGinitie, 1955), in Stefansson Sound at depths from 6 to 9 m (Dunton and Schonberg, 1979), near Point Hope (Sparks and Pereyra, 1966) and in the vicinity of Herschel Island (Heath, 1981a) and Banks Island (Heath, 1981b).

Four large-scale benthic surveys have provided an overview of zoobenthos for the region. Wacasey (1975) sampled infaunal invertebrates in the eastern Beaufort Sea between Herschel Island and Cape Dalhousie, Northwest Territories. Broad (1979) described the nearshore invertebrates between Point Barrow and Barter Island, Alaska, while Carey (1978a) examined more offshore communities in the same region. Frost et al. (1978) described epifaunal invertebrates between Point Barrow and Demarcation Bay, Alaska.

Wacasey (1975) described four depth zones in the southern Beaufort Sea based on their physical environments and zoobenthic diversity and biomass (Figure 3.5-3). Table 3.5-2 summarizes data collected between May and September in four years, although it should be emphasized that infaunal biomass figures are somewhat misleading due to inclusion of some epifauna in grab samples. Wacasey reported 337 species from 82 stations, with four taxonomic groups comprising 74% of the total number of species. Polychaetes, amphipods, gastropod molluscs and bivalve molluscs were represented by 101, 67, 33 and 36 species, respectively.

Broad (1979) sampled benthos from 22 stations along the coast of Alaska from Point Barrow east to Barter Island (Kaktovik) and to depths of about 11 m. During August, mobile epifaunal crustacea were

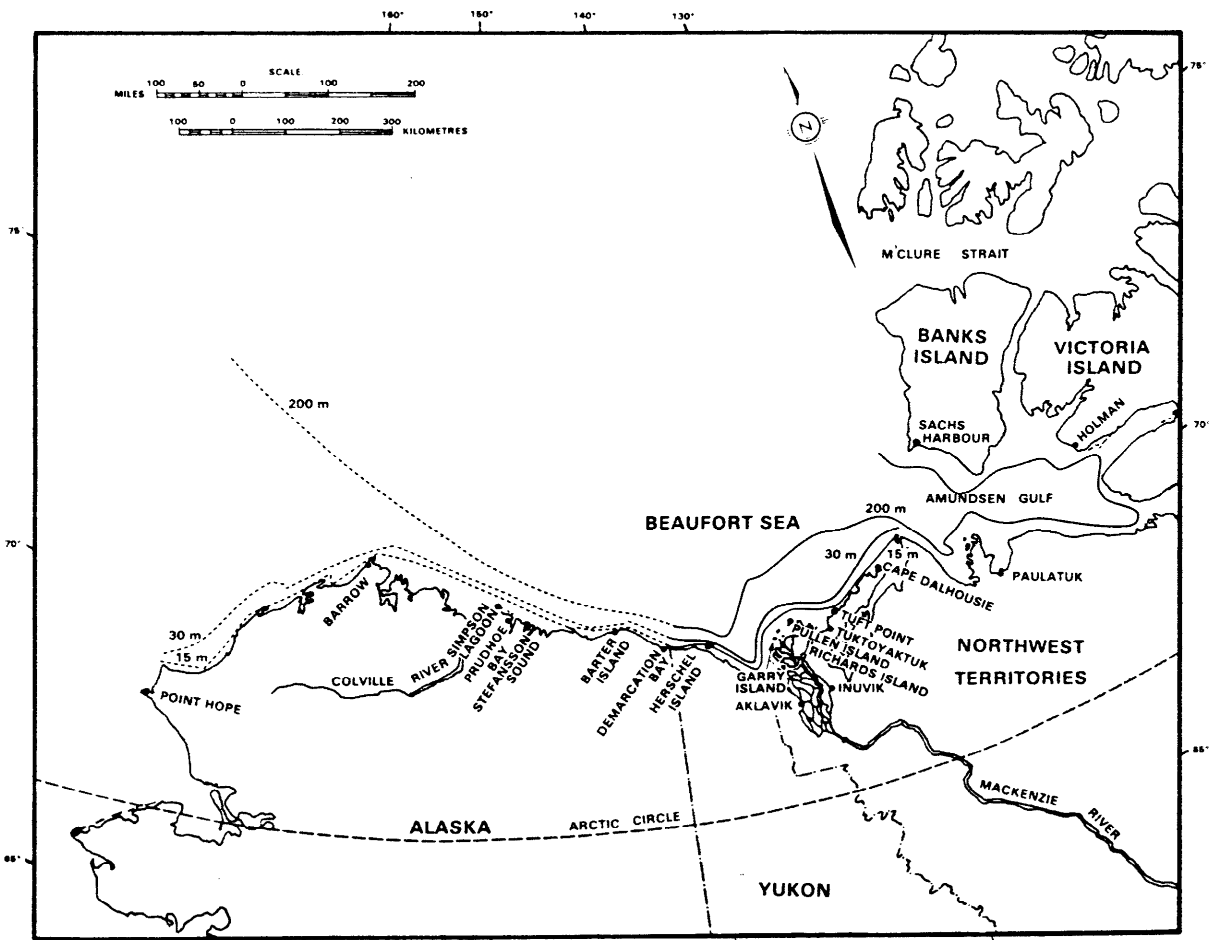


FIGURE 3.5-3 *Depth zones related to zoobenthos distribution (adapted from Wacasey, 1975) and locations of some zoobenthic studies in the Beaufort Sea. Four major depth zones have been described in the southern Beaufort, based on their physical environments, zoobenthic diversity and biomass.*

TABLE 3.5-2

DEPTH ZONES AND ZOOBENTHOS DISTRIBUTION IN THE SOUTHERN BEAUFORT SEA (from Wacasey 1975)

ZONE	DEPTH RANGE (m)	TEMP. RANGE (°C)	SALINITY RANGE (‰)	No. SPECIES PER STATION	AVERAGE BIOMASS (g/m^2)
Estuarine	0-15	May -1.2 July 16.6	0.1 to >40	1-32 (usually <20)	2
Transition	15-30	May -1.8 July 6.3	11.6 to 31.3	20-40	5
Marine	30-200	Sept. -1.6 July -0.1	30.1 to 32.8	3-81	14
Continental Slope	200-900	Sept. -0.3 July 0.4	34.3 to 34.8	31-53	4

found throughout the entire inshore zone. However, infaunal invertebrates were generally more abundant and diverse beyond the 2 m isobath than in the shallower depths. A similar distribution and species composition was found along the Chukchi coast north of Point Hope during an earlier survey (Broad, 1978). However, variability in both biomass and number of infauna between grabs at the same station indicated a generally patchy distribution. Polychaetes, amphipods, bivalve molluscs and gastropod molluscs were again the major groups observed in this area.

Frost et al. (1978) recorded 238 species, or groups, of epifaunal invertebrates during a summer trawl survey in the northeast Chukchi and Beaufort seas at depths from 40 to 400 m. Major groups were gastropods, amphipods, polychaetes, echinoderms, bivalve molluscs, ectoprocts and shrimps, while miscellaneous taxa included sponges, anemones, flatworms, nemerteans, bryozoans and tunicates. Echinoderms were the overwhelmingly dominant phylum, in many cases comprising more than 75% of the total biomass. Two major faunal assemblages were found to occur on the Alaskan shelf at these depths. Brittle star *(Ophiura sarsi)* communities, along with soft corals and sea cucumbers, predominated on mud bottoms off Point Barrow and to the west. In rocky areas east of Harrison Bay (150°W) a different community, compromised of scallops *(Delectopecten groenlandicus)*, crinoids *(Heliometra glacialis)*, sea cucumbers (*Psolus* sp.), sea urchins *(Strongylocentrotus droebachiensis)*, several brittle star species and shrimps *(Sabinea septemcarinata)* were found.

Carey et al. (1974) and Carey (1978a) conducted sampling programs across the Alaskan Beaufort Sea shelf to depths of 3,800 m, and concluded that benthic infauna were most abundant in shallow nearshore zones (20 m) and on the outer continental shelf. Minimum numbers of infauna were found at depths from 15 to 25 m, corresponding closely with the boundary between landfast ice and moving pack ice along the Beaufort coast. Standing stock and biomass of infauna also decreased markedly in very deep water. Standing stocks decreased from 10 g/m^2 (wet preserved weight) at stations shallower than 1,000 m, to 1 to 5 g/m^2 at depths between 1,000 and 3,000 m, and 0.1 to 0.7 g/m^2 at depths greater than 3,000 m.

Carey (1978a) reported that the density and biomass of benthic communities on the outer continental shelf varied with season, possibly indicating an annual reproductive cycle with a large peak in recruitment. In general, numbers of infauna at most stations increased throughout the spring, peaked in May, and then declined during the summer and fall. However, the annual range in infaunal abundance at the shallowest station (25 m) was small, and no seasonal trends were observed.

In addition to these major overview investigations, numerous site-specific studies conducted in the last ten years have supplemented the data base regarding the structure and abundance of benthos in the region, particularly at depths less than 20 m. Details regarding the location, date and depth range of these site-specific studies are summarized in Table 3.5-3.

(a) Infauna

Benthic fauna tend to select a particular type of substrate due to specialized requirements for feeding, burrowing, and respiration. Carey et al. (1974) suggested that the annual ice scour which randomly reworks the sediments was a primary cause of the patchy distribution of coastal shelf infauna. Carey and Ruff (1977) found a relative decrease in the abundance of polychaetes in gravels on the outer continental shelf off Prudhoe Bay and a complementary increase in mollusc populations. On the other hand, polychaetes were generally more abundant at stations with finer sediments. However, Bengeyfield et al. (1974) reported a low correlation between benthos abundance and substrate composition in the shallow (less than 13 m) estuarine zone off the Mackenzie Delta where infauna were sparse. In a study related to island construction at Issungnak O-61, the density and number of species present were inversely related to sediment particle size (Crippen and McKee, 1981). In the latter investigation a greater correlation was observed between abundance and depth. Subsequently, Chin et al. (1979) found a similar trend during their nearshore study at Prudhoe Bay, where the distribution of benthos was more closely related to both depth and bottom salinity than sediment composition.

Sampling programs at several locations throughout the region have resulted in the delineation of a "nearshore" zone (0-2 m) which is characterized by a sparse and unevenly distributed infauna primarily comprised of oligochaete worms and chironomid larvae (Broad, 1979). These are probably transient summer populations which, like many epifaunal organisms, take advantage of certain productive nearshore habitats.

TABLE 3.5-3
SUMMARY OF RECENT ZOOBENTHOS STUDIES IN THE BEAUFORT-N.E CHUKCHI REGION

INVESTIGATOR	LOCATIONS*	DATES	No. STATIONS	DEPTH RANGE	GEAR & EFFORT
Broad (1978), (1979)	Point Barrow to Barter Island, Alaska	Aug. 1977	44	2-11.5 m	Smith-McIntyre (0.1 m^2 min. 3 grabs per station) Wildco dredge (1.0 mm mesh; one 5 min. tow per station)
Bengeyfield (1976)	Garry Island to Tuktoyaktuk, N.W.T.	July - Aug. 1975	19	1.2-11.2 m	Ekman grab (0.02 m^2; min. 5 grabs per station) Epibenthic trawl (3.2 mm mesh; one 20 min. tow)
Bengeyfield et al. (1974)	Garry Island to Pullen Island, N.W.T.	March 1973; Mar-Apr 1974	22	1.8-12.7 m	Ekman grab (5 grabs per station)
Beak (1978)	Netserk, Isserk artif. Islands, N.W.T.	Summer 1977	27	7-15 m	Ponar grab (0.05 m^2; 4 to 7 grabs per station)
Crippen and (1981) McKee	Issungnak artif. Island, N.W.T.	Aug-Sept. 1980	20	19 m	Ponar grab (3-6 grabs per station)
Carey et al. (1974)	Prudhoe Bay - Colville Delta, Alaska	1971-72	40	21-2600 m	Smith-McIntyre (5 grabs per station) Shrimp trawl (1.3 cm mesh; 5-30 min.)
Carey (1978a)	Point Barrow to Barter Island, Alaska	1971-74 Aug-Sept. 1977	51	4.5-3800 m	Smith-McIntyre (5 grabs per station)
Chin et al.(1979)	Prudhoe Bay Alaska	Aug 1978	36	0.8-7.0 m	Sediment corer (0.01 m^2; 5 samples per station; Diver observations
Crane & Cooney (1975)	Simpson Lagoon - Harrison Bay, Alaska	Aug 1971	67	<20 m	Ponar grab; Benthic Trawl
Envirocon Ltd. (1977)	Isserk artif. Island, N.W.T.	July-Aug 1977	16	10-15 m	Ponar grab (10 grabs per station)
Frost et al. (1978)	Point Barrow to Demarcation Bay, Alaska	Aug-Sept. 1977	23	40-400 m	Otter trawl (0.6 cm mesh)
Griffiths & Dillinger (1980)	Simpson Lagoon, Alaska	Open water 1977 Open Water 1978 Nov. 1978-Apr. 1979	Variable	1.0-7.5 m	Otter trawl (0.6 cm mesh); Faber net (0.1 cm mesh); Drift net (0.1 cm mesh); Diver observations, baited traps, Wildco dredge
Jones & DenBeste (1977)	Tuft Point, N.W.T.	July-Sept. 1976	12	<10 m	Ekman grab Bottom trawl
Slaney (1973a)	Pelly Island to Richards Island, N.W.T.	July-Sept. 1972	28	1.0-5.0 m	Petersen grab (0.09 m^2; min. 3 grabs per station; beam trawl (6 mm mesh); 25 cm^2 quadrat
Slaney (1973b)	Tuktoyaktuk Harbour, N.W.T.	Aug. 1972	3	4.0-12.5 m	Petersen grab (0.09 m^2 10 grabs per station)
Slaney (1975)	Garry Island to Richards Island, N.W.T.	July-Sept 1974	23	0.6-13.0 m	Ekman grab; beam trawl (5.1 mm mesh)
Slaney (1977)	Aynak L-30 artif. island Tuft Point, N.W.T	July-Aug 1976	15	<8.2 m	Ekman grab (5 grabs per station) sled trawl
Wacasey (1975)	Herschel Island to Cape Dalhousie, N.W.T.	July 1971 July 1973 Aug-Sept. 1974 May-Sept. 1975	82	1.3-441 m	Ponar grab (5 grabs per station); epibenthic dredge; Pisces submarine (observations)

*See Figure 3.5-3 for general locations.

Infaunal biomass in the nearshore zone is generally low. Wacasey (1975) reported a mean biomass of about 2 g/m^2 in his estuarine zone in the southern Beaufort Sea (Table 3.5-2), while Broad (1978) found in the order of 3 g/m^2 in the western Beaufort Sea and northern Chukchi Sea. This biomass increased to almost 6 g/m^2 in the southern Chukchi Sea due to the greater predominance of polychaetes and bivalve molluscs (Broad, 1978).

(b) Epifauna

Although infauna are characteristically sparse in the entire shallow water zone, epifauna are often abundant in inshore areas during the open water period. The extensive series of barrier lagoons along the North Slope of Alaska probably support high standing stocks of amphipods and mysids throughout the open water period. For example, Griffiths and Dillinger (1980) reported epifaunal biomass ranging from 0.029 to 3.78 g/m^2 (dry weight) in Simpson Lagoon, with the most abundant species being *Mysis littoralis, M. relicta* and *Onisimus glacialis.* Isopods and amphipods appeared to be year-round residents in the lagoon, while mysids repopulated the area after spring break-up. Certain localized habitats within the Beaufort-Chukchi region appear particularly productive in terms of epifauna. For example, Slaney (1973a) reported between 320 and 1,072 amphipods per m^2 in a spit-protected bay on Hooper Island off the Mackenzie Delta in August. Wacasey (1975) subsequently identified Mason Bay on Richards Island as a productive area within the estuarine zone, although he did not state whether infauna or epifauna were the major contributors to the biomass.

The epifauna of inshore regions of the western Beaufort Sea and Chukchi Sea north of Point Hope have been found to be similar to those documented for the Canadian Beaufort (Broad, 1978), with the most commonly encountered species being the crustaceans *Mysis relicta, Onisimus litoralis, Gammarus setosus* and *Saduria entomon.* Epifauna in the estuarine zone of the southern Beaufort Sea include *Mysis relicta, M. femorata, Onisimus glacialis* and *Saduria entomon* (Wacasey, 1975). However, the shallow water epifauna found south of Point Hope in the Chukchi Sea are considerably different from communities observed farther north. *Neomysis* spp. replace *Mysis* spp. as the common mysids, while shrimp and starfish are found at depths of less than 2 m (Broad, 1978). The presence of these epifauna, as well as more infaunal polychaetes and bivalve molluscs in shallow water, is indicative of a less vigorous and more temperate marine environment than in the Beaufort Sea region.

Direct comparison of benthic distributions and abundance in the northeast Chukchi, western Beaufort and southern Beaufort seas is difficult since researchers have used different methods of sampling, reporting of species groups, and biomass analysis. Nevertheless, several trends are apparent from the studies which have been conducted in these regions:

- Infaunal biomass in most depth zones appears to decrease from the northeast Chukchi Sea toward the Mackenzie Delta, although biomass may increase again east of the Delta (Carey, 1978b).

- Infaunal diversity and biomass generally increase with distance offshore, at least as far as the continental shelf (200 m). Infauna are generally lower in shallow estuarine areas or in the main ice scour zone (15 - 30 m).

- Essentially the same dominant epifaunal species are found along the entire coastline of the study area.

- Mobile epifauna occupy the nearshore areas during the open water season and are often present in large numbers. There appears to be an active emigration of mobile epifauna to deeper water for overwintering.

- Sessile epifauna on hard substrates are limited in distribution in the Chukchi-Beaufort region. They occur most frequently between Point Hope and Point Barrow, Alaska.

(c) Reproduction

Many benthic species in the Arctic do not have a pelagic larval stage (Thorson, 1950). Mobile young are either released from eggs or egg masses on the bottom, or from eggs carried and brooded by the adult. Species with this mode of reproduction are well adapted to Arctic conditions with a poor phytoplankton supply during the extended winter. However, other species produce pelagic larvae which have relatively small amounts of yolk, and these forms must feed on phytoplankton to survive and develop (Thorson, 1950). Recruitment in a population having direct development is largely from local stocks due to the restricted dispersal potential as compared to those species with planktonic larvae (Chia, 1970).

MacGinitie (1955) observed a high incidence of direct development and breeding among zoobenthos at Point Barrow, Alaska. Only a few gastropod larvae were captured in the plankton, while snail egg capsules and masses from several species were abundant in the region. Other groups which carry their eggs or brood them in some manner included certain species of chaetognaths, polychaetes, tunicates, bivalve molluscs, mysids, cumaceans, isopods, amphipods, decapods and pycnogonids.

In Simpson Lagoon, Alaska, the most abundant epifauna breed in late fall or early winter after ice formation, and brood their young until the following spring. This category of epifauna includes *Mysis litoralis, M. relicta, Pontoporeia affinis, Gammarus setosus* and probably *Onisimus glacialis* (Griffiths and Dillinger, 1980). In this type of reproductive cycle, young are released at the time of the spring blooms of epontic and benthic diatoms. The ubiquitous isopod *Saduria entomon* breeds throughout the year, but the peak reproduction occurs in summer (Bray, 1962; Robilliard and Busdosh, 1979). The life cycles of only a few Arctic species have been studied and these investigations suggest that the life spans of mysids and amphipods are two to three years, and from two the four years for *Saduria entomon*. Studies completed by Griffiths and Dillinger (1980) also indicate that breeding is generally restricted to older individuals.

3.5.6.2 Macrophytic Algae

The standing crop of macrophytic algae decreases from east to west in the North American Arctic, with the north coast of Alaska being almost barren of these plants (Mohr et al., 1957; Lee, 1973). The principal reason for this trend is the large proportion of substrate that is composed of soft sediment, which is generally unsuitable for the growth of macrophytes. Kelp and other large algae are occasionally found in the Beaufort and northeast Chukchi region, but are usually restricted to areas where there is a rocky substrate (MacGinitie, 1955; Mohr et al., 1975; Beehler et al., 1979; Broad, 1978; Dunton and Schonberg, 1979; Hsiao, 1976).

MacGinitie (1955) observed two species of macrophytic algae in Elson Lagoon near Point Barrow, while Mohr et al. (1957) collected three species of brown algae and seven species of red algae from about 12 m of water 80 km southwest of Point Barrow. The substrate in the latter area was essentially rocky with a minor amount of sand.

More recently Dunton and Schonberg (1979) conducted a comprehensive survey of the large kelp community in Stefansson Sound. The cobble and boulders found in this area provide a firm substrate for permanent attachment of macrophytic algae. Large areas of hard substrate such as this are uncommon in the Beaufort Sea. Scattered small stones and mollusc shells are normally the largest objects available for attachment. Dunton and Schon erg (1979) documented two types of habitats in Stefansson Sound: large rocky areas that supported a diverse flora, and regions of scattered rocks with isolated plants. The algal community of the boulder patches was dominated by the brown kelp *Laminaria solidungula* which formed the overstory. *Alaria esculenta* and *L. saccharina* were less common, but were also present in some areas. Red algae grew beneath the kelp overstory and were also observed in areas where the kelps were absent. Common red algae included *Phycodrys rubens, Neodilsea integra, Phyllophora truncata,* and the encrusting form *Lithothamnion* sp. The biomass of kelp in this area was extremely high (average of 3.3 kg/m^2), and approximately of the same order of magnitude as in temperate zone kelp communities on both coasts of North America (Dunton and Schonberg, 1979). The two species of *Laminaria* accounted for 95% of this biomass.

Beehler et al. (1979) also reported small scattered kelp patches at six stations near Prudhoe Bay where water depths ranged from 3.9 to 6.6 m. Both attached and unattached plants, mostly *Laminaria solidungula* and *L. saccharina,* were observed by divers beneath the ice. Kelp was more abundant farther offshore where water depths increased to about 5 m. The relatively minor currents measured beneath the ice in these areas indicated a relatively static distribution of macrophytic algae during the winter. However, longshore currents and onshore winds probably redistribute many of these plants during the open water season.

Hsiao (1976) reported that *Laminaria* sp. and *Phylolophora* sp. were collected by divers in Liverpool Bay near the Eskimo Lakes for use in oil toxicity experiments. In 1981, underwater video equipment.(Heath, 1981b) recorded scattered clumps of *Laminaria* sp. and rock-encrusting *Lithothamnion* sp. offshore from the Rufus River on Banks Island. This latter area is of interest for use as a rock borrow-site, for offshore island construction.

3.5.6.3 Benthic Microalgae

As indicated earlier in Section 3.1, benthic microalgae are important primary producers in the marine food webs of the Beaufort and northeast Chukchi region. Benthic microalgae include diatoms, flagellates, filamentous green, brown and red algae, and blue-green algae. Layers of algae, ranging in thickness from microscopic films to visible mats and colonies, form on virtually any substrate in the photic zone, and often contribute substantially to the total primary productivity of estuarine and inshore environments.

Matheke and Horner (1974) discussed the species composition and primary productivity of benthic microalgae near Point Barrow between February and August. Study sites were located in 5 m of water in areas with a silt-clay bottom mixed with fine sands. The benthic microalgal community was sparse and composed of motile unattached diatoms during the period when ice cover was present (February to June). Brown patches of filamentous diatoms, mainly *Amphipleura rutilans,* began covering the surface sediments after break-up of the landfast ice. This mat persisted throughout the summer and contributed significantly to the maximum benthic primary productivity (57 mg C/m²/h) measured *in situ* during August. This rate was eight times the maximum productivity of the epontic algae in May, and twice that of the phytoplankton maximum in August. The areal extent of this microalgal community was unknown, but since small-scale patchiness was reported by the investigators, estimation of the contribution of benthic microalgal production to the total production of the region was not possible.

There have been no investigations of the productivity of benthic microalgae in the Canadian portion of the Beaufort Sea. Extremely turbid conditions exist in much of the southern Beaufort Sea during the summer, and this likely precludes, or at least limits, extensive benthic algal growth. However, prominent mats of benthic diatoms and filamentous green algae have been observed, in certain localized clear-water habitats such as in the lee of spits and offshore islands, or in embayments away from the Mackenzie River plume (Slaney, 1973a). These habitats have also generally supported higher numbers of epifaunal invertebrates and fish. Benthic microalgae form an important food source for shallow water amphipods, mysids, and isopods (Bray, 1979; Schneider and Koch, 1979), although the overall contribution of benthic microalgae to the carbon budget of secondary producers in the southern Beaufort Sea remains unknown.

3.5.7 EPONTIC COMMUNITIES

Epontic organisms are flora and fauna living within the bottom few centimetres of ice and on the underice surface. The importance of epontic biota to high latitude ecosystems includes: a significant contribution to the annual production of organic matter resulting from an extension of the growing season (Horner, 1976, 1977); and the increase in availability of this organic matter to herbivores resulting from its presence at a time when planktonic algae are rare (Horner, 1977), as well as from its high concentration (Alexander, 1974). The use of the relatively abundant epontic fauna by carnivores (including fish, seals, and birds) is not well documented, but they may be an important trophic link in many Arctic marine food webs (Section 3.1).

For the Beaufort Sea the most detailed studies of the standing stock and productivity of epontic algae, and the physiology of the epontic community have been conducted in fast ice approximately 1 km offshore from Point Barrow. The results of these investigations have been described by a number of authors (Horner, 1972, 1976, 1977; Horner and Alexander, 1972a, 1972b; Clasby et al., 1973; Alexander, 1974; Alexander et al., 1974; Matheke and Horner, 1974). Additional, but less intensive, sampling (single SIPRE ice cores) was completed at seven nearshore stations between Wainwright and Prudhoe Bay on the northern Alaskan coast (Horner, 1972; Horner et al., 1974).

The only investigation of offshore epontic communities was that by Meguro et al. (1966, 1967) who described microalgal biomass, nutrient concentrations and species present in SIPRE cores (surface-operated) taken in pack ice roughly 8 to 16 km from Point Barrow during late July 1964. A limited examination of ice flora in Prudhoe Bay was conducted by Coyle (1974) in conjunction with phytoplankton studies. Bengeyfield et al. (1974) observed a pennate diatom colony 20 km east of Pullen Island off the Mackenzie Delta in mid April when surface salinity was 8 parts per thousand.

Some observations of epontic fauna during periods of deteriorating landfast ice and ice break-up (late June to late August, 1975 to 1977) at Cooper Island, Alaska were included in a study of bird feeding ecology (Divoky, 1978). SCUBA observations of underice fauna in Stefansson Sound were described by Dunton and Schonberg (1979).

3.5.7.1 Epontic Flora

(a) Community Description and Species Composition

Microalgae (Plate 3.5-4) are present in low abundance throughout sea ice from the time it forms (Horner, 1977), although the highest concentrations occur during spring and early summer in the soft crystalline bottom few centimetres of ice (Meguro et al., 1967; Horner and Alexander, 1972b; Thomson et al., 1975, 1978). A layer of brown microalgae can be several centimetres thick when it reaches a maximum density during May. These microalgae are either consumed by fauna that graze on the undersurface of the ice, or are sloughed off into the water column where they apparently cease photosynthesis and become a potential food source for detritivores.

The epontic community is dominated by colonies of both motile and sessile pennate diatoms which occur within brine cells in the interstices of the matrix of vertically-oriented ice crystals (Meguro et al., 1967; Horner and Alexander, 1972b). Common pennate diatoms comprising the ice flora include *Nitzschia frigida, N. cylindrus, Navicula pelagica, N. marina, N. quadripedis, N. transitans, Achnanthes taeniata,* and *Fragilariopsis.* However, the dominant species at a given location can vary from year to year, or from week to week, and over relatively short distan-

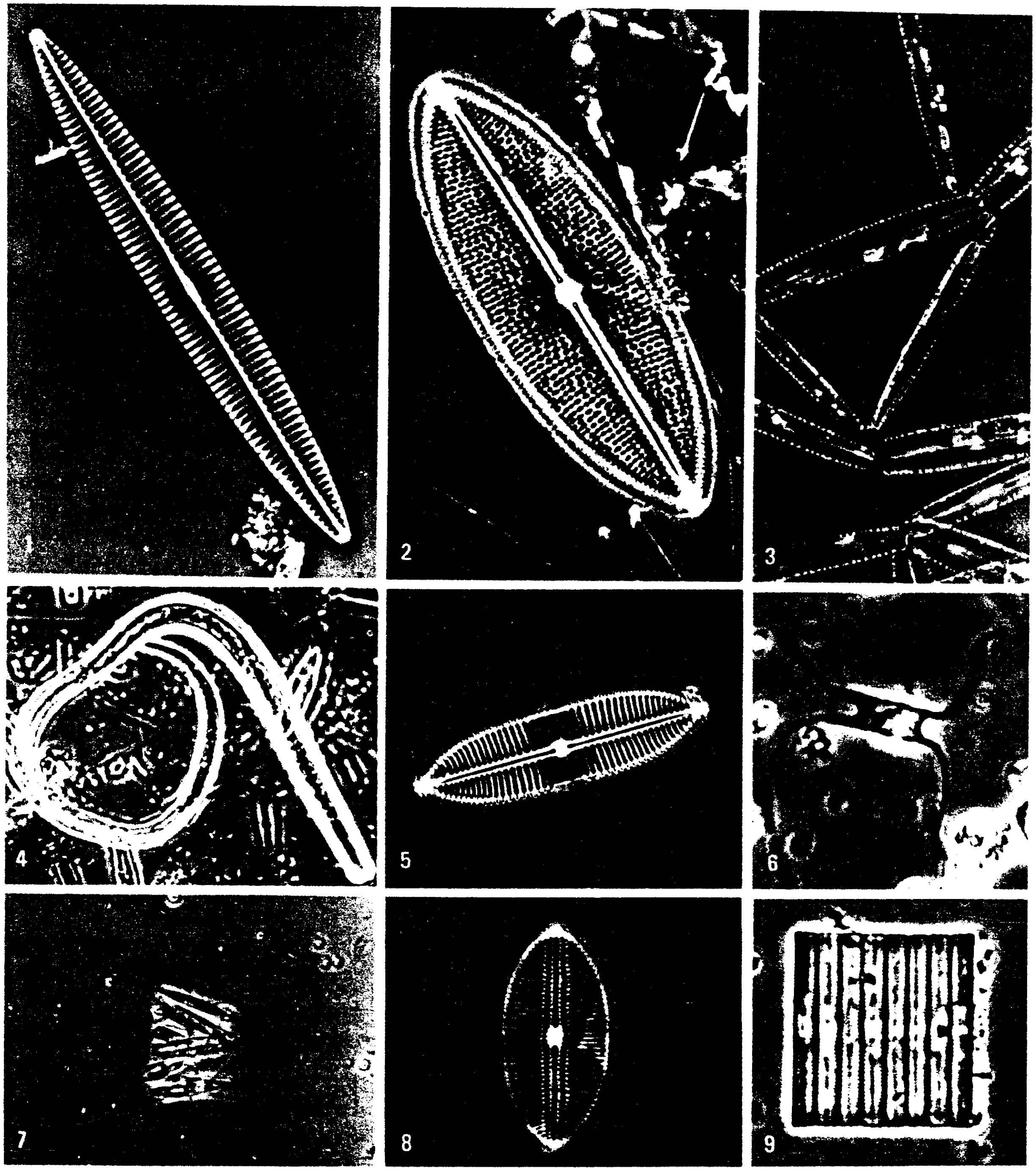


PLATE 3.5-4 *Typical group of epontic microbiota found in/under ice at McKinley Bay in 1980. Pennate (rod-shaped) diatoms (1, 2, 3, 5, 7, 9) made up the bulk (50-80%) of the population. The centric diatom Chaetoceros fragilis is shown in 6 and a nematode worm is illustrated in 4. (Courtesy, Arctic Laboratories Ltd.).*

ces at a given time (Alexander et al., 1974; Hsiao, 1979). Centric diatoms usually form only a small part of the epontic diatom community, but some species can occur either regularly in small numbers (such as *Chaetoceros* spp., *Thalassiosira* spp.), or occasionally in relatively high numbers (including *Melosira* spp., *Chaetoceros atlanticus, C. septentrionalis, Porosira glacialis* and *Coscinodiscus lacustris).* Dinoflagellates, flagellates and cryptomonads comprise the remainder of the epontic microalgal community.

(b) Standing Stock and Biomass

The abundance of epontic microalgae varies with season, depth of snow over the ice cover, and area (both in a regional sense and locally, due to differences in available light and nutrients). The two common measures of epontic microalgal abundance are standing stock (cells/L) and biomass, expressed in terms of chlorophyll *a* concentration per m^2 of ice surface. Seasonal differences in the abundance of epontic microalgae near Point Barrow were described by Horner et al. (1974). Standing stock of microalgae increased from 6.0 x 10^5 cells/L in January to 4.3 x 10^7 cells/L in late May through early June, with the algae being visible on the bottom of the ice by late April. They also found that, by the second week in June, the layer of algae had disappeared due to melting ice, brine channel drainage and currents. However, considerable differences in the standing stock of ice floras have been observed during the same month. For example, Coyle (1974) found that cell counts varied from 0.18 x 10^6 cells/L to 83 x 10^6 cells/L in three samples of bottom ice collected in May near Prudhoe Bay.

As in the case of standing stock, marked seasonal and local differences in the chlorophyll a content of sea ice have been observed in the vicinity of Point Barrow, Alaska. Alexander et al. (1974) reported that chlorophyll *a* concentrations in the bottom layer of ice varied from 0.87 to 8.26 mg/m^2 in April, 1972, and reached a maximum of 23 mg/m^2 on May 23. During the May to June bloom period, mean chlorophyll *a* concentrations measured in the coastal Beaufort and Chukchi seas have ranged from 2.8 to 30.5 mg chl *a*/m^2 (Alexander et al., 1974; Horner, 1972; Horner et al., 1974). These levels are relatively consistent with bloom chlorophyll *a* values recorded elsewhere in the Canadian Arctic and subarctic.

Horner (1972) and Horner et al. (1974) reported a high degree of local and regional variability in the biomass of ice flora at the same time of year. Local variability in the abundance of ice flora may result from differences in the depth of the overlying snow cover, while regional differences in abundance may be associated with the timing of the bloom in various areas (Horner et al., 1974). An inverse relationship between snow depth and chlorophyll concentration in sea ice has been documented by Alexander et al. (1974).

Investigation of epontic floral abundance in the offshore Beaufort has been limited to a single study completed off Barrow in July, 1964 (Meguro et al., 1966, 1967). These authors reported an average biomass of 24 mg chl *a*/m^2 in 14 SIPRE cores taken over a period of three days.

(c) Primary Productivity

Theoretical annual primary productivity of the epontic community has been estimated in a number of reports, but the only experimental measurement of production in the Beaufort and northeast Chukchi region to date were the C^{14} studies completed at Barrow, Alaska (Horner, 1972; Clasby et al., 1973; Alexander et al., 1974; Horner et al., 1974). Production rates of epontic microalgae based on laboratory or *in situ* incubation of samples collected with a SIPRE corer, as well as those based on diver-operated *in situ* incubations, are summarized in Table 3.5-4.

Alexander (1974) estimated that the annual productivity of epontic flora in coastal regions near Barrow was 5 g C/m^2/yr. This author also estimated that production by epontic microalgae accounted for 25 to 30% of the total annual primary production of the area. On the other hand, Horner et al. (1974) indicated that production by epontic flora accounted for 6% of the total annual productivity of offshore lagoons near Prudhoe Bay. However, virtually all estimates of this type are based on limited data.

3.5.7.2 Epontic Fauna

(a) Community/Habitat Description and Species Composition

A variety of microscopic fauna have been observed in core samples taken in the soft bottom layer of sea ice. At Barrow, heliozoans, hypotrichous ciliates and nematodes (Plate 3.5-4) were common epontic fauna, while turbellarians, polychaete larvae and harpacticoid copepods occurred sporadically (Horner and Alexander, 1972a, 1972b; Horner et al., 1974). However, gammarid amphipods appear to be the most common macroinvertebrates on the undersurface of the ice (Plate 3.5-5). For example, *Gammaracanthus loricatus* was reported to occur on the underside of ice cakes during break-up of landfast ice in the Beaufort Sea (Divoky, 1978). Near Point Barrow, Alaska, divers observed several amphipod species, including *Onisimus litoralis, Gammarus wilkitzkii* and *Gammaracanthus loricatus,* on and in small holes in the undersurface of the ice (Horner and Alexander, 1972a; Alexander et al., 1974). During other SCUBA studies completed in November 1978 and March 1979 in Stefansson Sound near Prudhoe Bay, Dunton and Schonberg (1979) reported the presence of the amphipods *Weyprechtia hueglina, Gammarus setosus, Gammaracanthus loricatus* and *Melita formosa* under a thick soft layer in the sea ice.

The smaller gammarid amphipods *Onisimus pseudalibrotus litoralis* and *O. glacialis* are abundant in the Beaufort Sea during the open water season (Wacasey, 1975). Elsewhere in the Canadian Arctic these species are commonly found singly, or in groups, within small holes in the ice undersurface, as well as on and just under the ice surface. It is probable that these amphipods occupy similar habitats in the Beaufort and Chukchi seas, although this has not been

TABLE 3.5-4

RATES OF PRIMARY PRODUCTIVITY BY EPONTIC ALGAE MEASURED IN THE BEAUFORT SEA

		PRIMARY PRODUCTIVITY (mg C/m³(or m²)/h)=				
LOCATION	**DATES**	**MEAN**	**MIN.**	**MAX.**	**n**	**REFERENCE**
BARROW	May 13-31 1971	11.3	1.6	32.4	13	1
	June 2 - July 3 1971	3.9	0.1	28.2	18	1
	Jan. 28 - March 27 1972	0.1	0.0	0.2	12	1
	April 3 - May 1 1972	0.6	0.0	2.2	5	1
N. ALASKA**	June 2-3 1972	42.2	0.1	133.0	4	1
PRUDHOE BAY	May 10, June 4 1971	11.9	0.1	23.6	2	2
BARROW	May 7 - June 8 1972	2.0*	0.3*	4.6*	6	3
	April 6-30 1973	1.2*	0.3*	1.9*	7	3
	May 7 - June 8 1973	5.5*	0.4*	14.9*	8	3

1 = Horner (1972); 2 = Horner et al. (1974); 3 * Alexander et al. (1974)
* Results of diver-operated in situ incubations expressed as mg C/m²/h
** Wainwright, Harrison Bay, Smith Bay, Dease Inlet

PLATE 3.5-5 *Amphipods (probably Onisimus glacialis) on the under-ice surface. Amphipods appear to be the most common macro-invertebrates on the undersurface of ice. (Courtesy, LGL Limited).*

documented. In a similar manner, mysids and copepods have been observed in small numbers on the under-ice surface in the eastern Arctic, and may also be present at some times of the year in the Beaufort-Chukchi region.

(b) Abundance and Biomass

There are no available data on the numbers and biomass of epontic fauna in the Beaufort and northeast Chukchi seas. All studies completed to date have been directed at qualitative descriptions of the taxonomic composition of these communities.

3.5.7.3 Trophic Relationships

A general description of trophic interrelationships within the Beaufort and northeast Chukchi marine ecosystem was provided in Section 3.1. This section summarizes additional information on the trophic relationships within epontic communities, as well as the role of epontic fauna in supporting vertebrate populations.

The epontic community depends on the photosynthetic production of its microalgal component, but also shows considerable heterotrophic activity. The heterotrophic component includes a number of microscopic organisms such as bacteria, fungi, colourless flagellates and ciliated protozoans (Horner, 1976, 1977). The existence of an active microbial population within epontic communities is confirmed by the relatively high abundance of bacteria observed in some investigations (Horner, 1976), as well as by the uptake of labelled organic substrates found during other studies (Horner and Alexander, 1972a). The documented interrelationships between grazing activity and micro-organisms (such as flagellates ingest diatoms; ciliated protozoans graze on diatoms, bacteria and other organic material) provides additional evidence for the existence of an efficient system of *in situ* nutrient regeneration and inorganic carbon cycling. Other nutrient sources to the epontic community include drainage from the ice above and exchange with the water below (Meguro et al., 1967; Alexander et al., 1974).

A substantial portion of the epontic algal standing stock is probably ingested by metazoan grazers (polychaetes, copepods, amphipods) occurring in the under-ice community, although quantitative data on feeding rates of these organisms are lacking. The remainder of the algal biomass may be sloughed off into the water column during the late spring or early summer, or may persist above a thin layer of clear hard ice which restricts access by grazing fauna (Meguro et al., 1966, 1967). Clasby et al. (1973) reported that near the end of the epontic algal bloom, chlorophyll *a* content of the water under the ice increased by an order of magnitude, but this was not accompanied by an increase in primary productivity. This suggests that ice algae do not continue to grow after they are sloughed off into the water column. Matheke and Horner (1974) also suggest that epontic algae do not subsequently become part of the benthic diatom community, although they probably still represent a food source for pelagic and benthic scavengers (Alexander, 1974; Horner, 1977).

A predatory trophic level probably exists within some epontic communities. For example, *Gammaracanthus loricatus* is a known predator of *Gammarus setosus* (Green and Steel, 1975), while *Onisimus glacialis* has also been observed attacking live prey (W. Griffiths, pers. comm.). The frequency of occurrence and importance of this trophic level within the epontic community are both unknown, but most predation of epontic macrofauna is probably limited to predators that occur in the subice community.

The use of epontic biota by members of higher trophic levels (fish, birds, and mammals) is also not well documented. Epontic amphipods formed a small part of the diet of murres and guillemots feeding at ice-edges in the central Arctic in 1976 (Bradstreet, 1977), and were eaten by Arctic terns, Sabine's gulls and red phalaropes during landfast ice break-up periods at Cooper Island, Alaska (Divoky, 1978). Under-ice amphipods may also comprise a very significant portion of the diet of ringed seals, at least during the haul-out season (Finley, 1978). An additional trophic pathway between epontic biota and vertebrates is through Arctic cod *(Boreogadus saida)* which are thought to feed on epontic fauna (Andriashev, 1970; McAllister, 1975). This fish is subsequently important in the diets of kittiwakes, murres and guillemots in the central Arctic (Bradstreet, 1976, 1977), kittiwakes and apparently Arctic terns and guillemots in the eastern Chukchi and Beaufort seas (Divoky, 1978), ringed seals (McLaren, 1958; Finley, 1978), and beluga whales (Davis and Finley, 1979).

3.6 RESOURCE USE

The harvest of fishery and wildlife resources is important to the cash economy of communities along the coasts of the Beaufort and Chukchi seas, and provides social, nutritional and cultural benefits for the Inuit. Although resource harvesting patterns have changed since the Inuit settled in permanent villages and acquired modern fishing, hunting and trapping equipment, harvests continue in many of the coastal marine areas and on the nearshore sea ice of the northeast Chukchi and Beaufort seas.

The six Canadian settlements where residents harvest marine fishery and wildlife resources of the Beaufort Sea are: Inuvik, Aklavik and Tuktoyaktuk comprising the "Mackenzie economy" of the Mackenzie River Delta, and Sachs Harbour, Paulatuk and Holman in the Amundsen Gulf region or the "Rim economy." Settlements in the "Mackenzie economy" exhibit a high level of industrial and commercial activity, with harvests directed mainly toward fishery resources and white whales for domestic use (Brakel, 1977). The relatively limited export of Arctic fox and polar bear furs is the main commercial use of marine wildlife. In contrast, the export of seal skins, white Arctic fox pelts and polar bear hides provide the primary source of cash income for residents in the "Rim economy" (Brakel, 1977), and commercial and domestic fishing activity is relatively limited.

The five communities along the Alaskan coast whose residents harvest marine fishery and wildlife resources of the Beaufort and northeast Chukchi seas are: Point Lay, Wainwright, Barrow, Nuiqsut and Kaktovik. Residents of these settlements harvest mainly ringed and bearded seals, bowhead and white whales, and walruses. In addition, residents from at least two communities outside the Beaufort - northeast Chukchi area (such as Coppermine, Northwest Territories, and Point Hope, Alaska) harvest resources in some coastal areas within the region.

The following section presents a brief discussion of the resource utilization of fish, marine waterfowl, marine mammals, polar bears and Arctic foxes by residents of coastal communities in Canada and Alaska adjacent to the Beaufort and northeast Chukchi seas. Greater emphasis is placed on discussion and presentation of harvest statistics from the Canadian sector of the study area due to the proximity of this region to potential offshore hydrocarbon development activities. A discussion of inland fisheries, and hunting and trapping of terrestrial mammals in this region is presented in Section 4.6, while additional details of the socio-economic value of the harvests in the Beaufort Sea region are provided in Volume 5.

3.6.1 SEALS AND WALRUS

3.6.1.1 Seals

Ringed seals are the most abundant and widespread species of marine mammal in the Beaufort-northeast Chukchi region, and are harvested throughout the year by residents of most coastal communities. This species provides a stable food source and source of income for both Alaskan (NPR-A Task Force, 1978a) and Canadian communities (Davis et al., 1980). Bearded seals are also harvested by residents of most settlements in the region, although in the Canadian Beaufort they are not as abundant or important to the harvest as ringed seals (Burns, 1967; Stirling et al., 1977). Spotted seals range as far east as the Colville River during open water periods, and are harvested by Alaskan Inuit during summer and fall.

Estimates of the harvest of seals in the Canadian Beaufort between the years 1970 to 1980 are presented in Table 3.6-1, while estimated average annual harvests of seals in northern Alaska are included in Table 3.6-2. The estimated number of seals harvested in the Canadian Beaufort are considered minimum estimates of the actual kill since they are based on Fur Export Returns which do not account for seals shot but lost through sinkage (losses approach 50%) (Davis et al., 1980; Burns, 1967), and seals harvested but retained for domestic purposes. Sealskin trading records are particularly unreliable indices of the actual kill. Anders (1967) estimated that the number of landed seals exported at Pangnirtung might range from 35 to 75%. The extent of areas used for hunting seals in Canadian and Alaskan portions of the Beau-

TABLE 3.6-1

SEAL* HARVESTS IN THE BEAUFORT SEA AND AMUNDSEN GULF
(Adapted from Brakel, 1977 Fur Export Tax Returns and Traders Fur Record Books, N.W.T. Wildlife Service, Yellowknife)

Community	1978 Population**	Number of Seals 1971-72	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80
Aklavik	800	n/r	n/r	16	n/r	n/r	n/r	n/r	n/r	17
Inuvik	4,150	268	7	61	n/r	n/r	4	n/r	n/r	n/r
Tuktoyaktuk	750	53	26	37	1	4	18	n/r	8	13
Paulatuk	148	179	1	146	n/r	61	72	n/r	n/r	154
Sachs Harbour	167	200	95	n/r	n/r	n/r	298	n/r	1	70
Holman	350	1,096	2,198	3,213	2,876	2,394	4,971	992	2,052	792

n/r = no record or unknown

*harvests include primarily ringed seals, but bearded seals, harp seals and "other seals" recorded in marine mammal harvests are also included in estimates.

**Fenco and Slaney, 1978.

TABLE 3.6-2 ESTIMATED ANNUAL HARVESTS OF SEALS, WALRUSES AND WHITE WHALES ALONG THE NORTH COAST OF ALASKA (J. Burns, pers. comm., cited in LGL and ESL, 1982)				
		Harvested Species approximate mean annual harvest		
Community	1977 Population*	Seals**	Walruses	White Whales
Point Lay	54	50	20	15
Wainwright	398	250	96.8 (1973-1977) range: 31-253	10 (1973-1977) 2 (1978) 37 (1979)
Barrow	2,220	1,500 (1973) 1,000 (1974-1977)	53.6 (1973-1977) range: 15-136	(1976-1979) range: 2-4
Nuiqsut	n/r	n/r	n/r	n/r
Kaktovik	134	60 (1973-1977)	n/r	n/r

n/r = no record or unknown
*NPR-A Task Force, 1978a
**Includes bearded, spotted and ringed seals
Local information sources of unknown accuracy

fort - Chukchi region are shown in Figure 3.6-1, while core areas for hunting marine mammals in the Canadian Beaufort are presented in Figure 3.6-2.

In the Canadian Beaufort Sea the harvest of ringed seals is particularly important to the community of Holman Island, although Paulatuk and Sachs Harbour also report harvests of this species. Bearded seals are also harvested, but comprise only a small percentage (about 2-4%) of the seal harvest of these communities (Usher, 1965). Between the seasons 1971-72 and 1979-80, the annual average harvest of seals from Holman Island was 2,287. The average price paid to seal hunters for a ringed seal skin in the Northwest Territories during the 1979-80 season was $19.15, representing only a minor increase from past years.

Depending on the season, a variety of techniques are used to hunt seals. These methods have been described by a number of authors, including Usher (1965), Anders (1967), Bissett (1967, 1968), Nelson

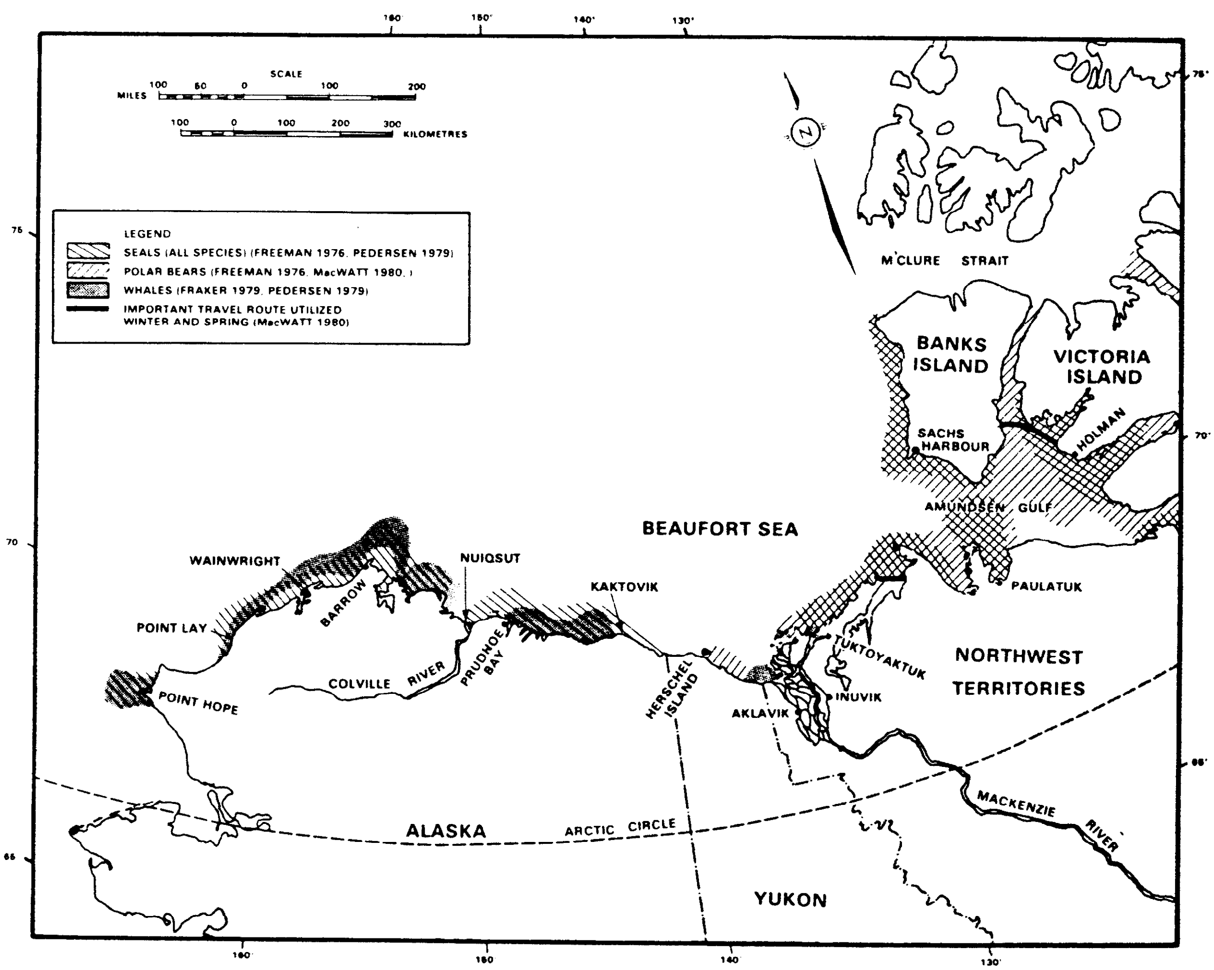


FIGURE 3.6-1 *Extended harvesting areas for seals and whales in the Beaufort-northeast Chukchi region and for polar bears in the Canadian Beaufort*

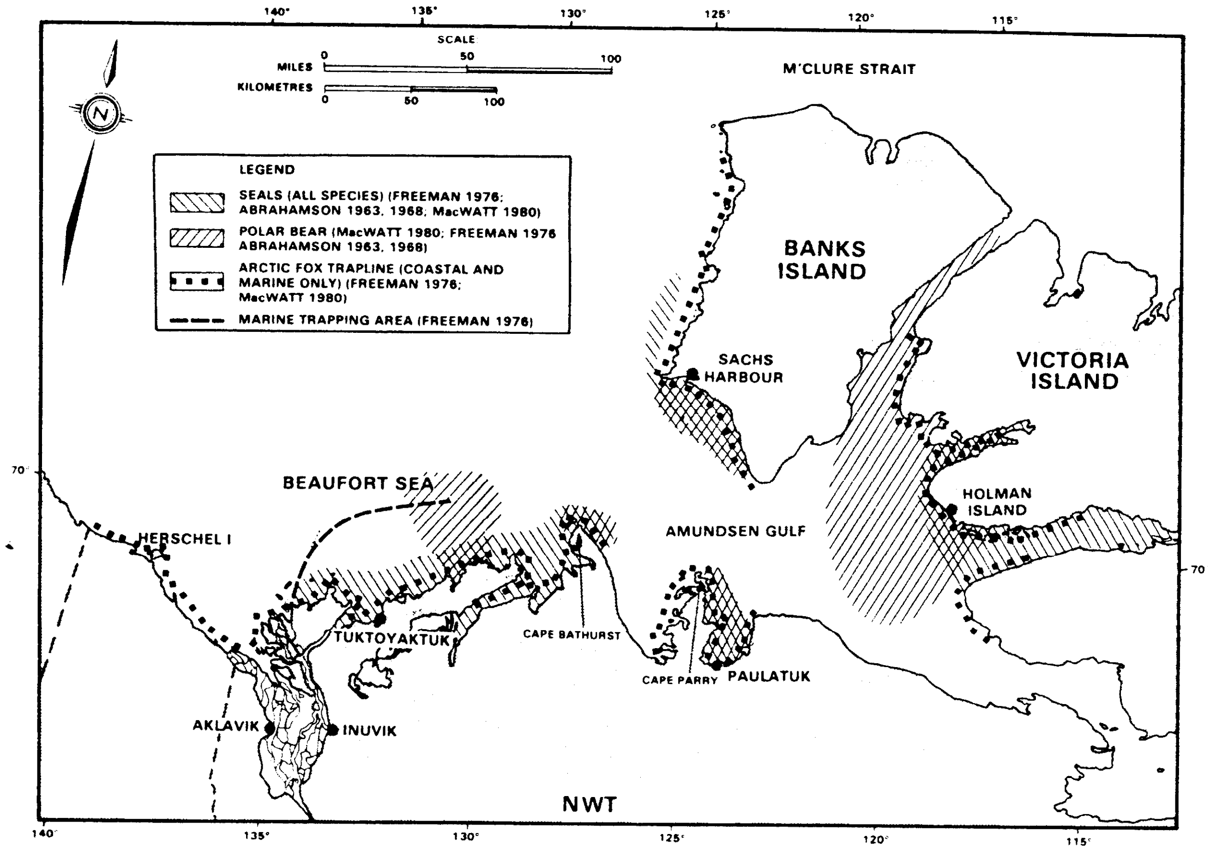


FIGURE 3.6-2 *Core hunting areas for polar bears, seals and Arctic fox in the Canadian Beaufort Sea region. Most hunting occurs on the landfast ice, extending to the edge of the transition zone.*

(1969) and Treude (1977). Although seals are often shot during the winter when they surface at their breathing holes in landfast ice, most harvesting occurs during late spring when the seals are hauled-out on the ice to moult. The seals are shot from snowmobiles or after a concealed approach by the hunters behind a white screen (Kemp et al., 1977). In the open water season, seals are hunted and shot from boats. Although seal products formerly provided meat for dogs, oil for heat and light, and materials for clothing, the current basis for the harvest is primarily the commercial export of skins. The demand for seal products has decreased with the advent of the snowmobile. Since then the use of dog teams has declined (Freeman, 1976), and fuel oil and clothing are now imported (Brakel, 1977).

3.6.1.2 Walrus

Although the Pacific walrus is abundant in the Bering and southern Chukchi seas, it only occurs in the northeast Chukchi Sea and western Beaufort Sea during summer, and rarely ranges to the eastern Beaufort Sea. Consequently, within the Beaufort - Chukchi region, this species is only harvested by Alaskan Inuit with Barrow, Wainwright, and Point Lay in Alaska regularly reporting a walrus harvest. The harvest statistics from these communities are summarized in Table 3.6-2, while areas utilized during this harvest are shown in Figure 3.6-3. The reported size of the walrus harvest is considered a minimum estimate since walruses shot but not retrieved are not consistently recorded. The most common method of hunting is to drive the walruses into shallow lagoons where they are shot (NPR-A Task Force, 1978b; Burns, 1965).

3.6.2 WHALES

3.6.2.1 Bowhead Whale

The bowhead whale is considered an endangered species under U.S. legislation and by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In addition, the bowhead has been given a protected stock status by the International Whaling Commission (IWC), although they are still subject to a small subsistence hunt by Alaskan Inuit. It is illegal to hunt the bowhead in Canadian waters.

The western Arctic population of bowhead whales was heavily exploited by commercial whalers in the 19th century. The demand for baleen or whalebone increased after about 1880 as manufacturers valued it for corset stays, skirt hoops and umbrellas, and by the turn of the century the price of baleen reached $5

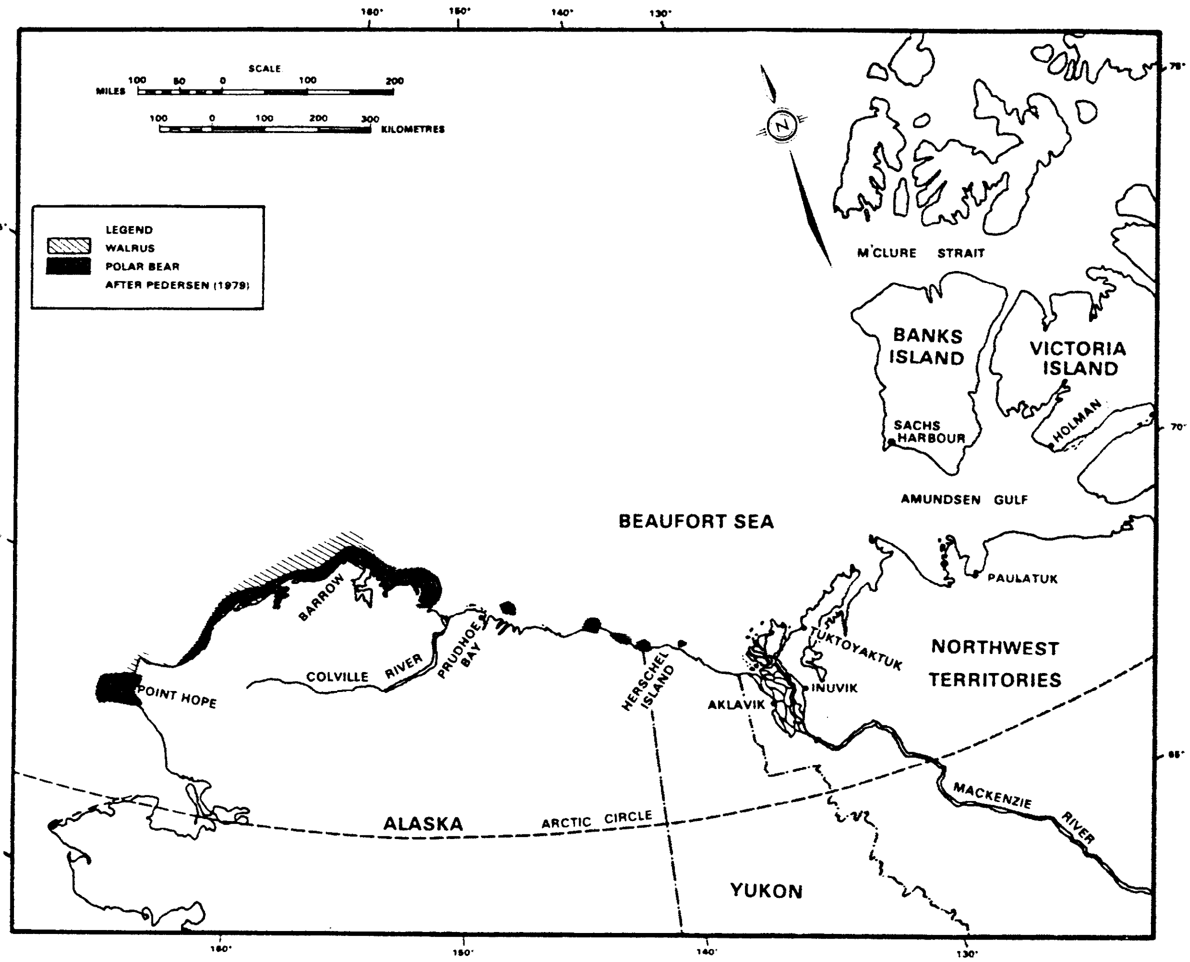


FIGURE 3.6-3 *Polar bear and walrus hunting areas in the Alaskan Beaufort and Northeast Chukchi Seas.*

per pound ($11.00/kg). A single adult bowhead was worth more than $10,000 at that time (Marquette and Bockstoce, 1980). Bockstoce (1980) estimated that commercial whalers killed more than 19,000 bowheads of the western Arctic population during the years from 1848 to 1915. Although this population was drastically reduced, the decline in the baleen market in 1915 prevented further depletion or extinction of this stock of bowheads. The current 'best estimate' of the size of the western Arctic population of bowhead whales is 2,264 (Braham et al., 1979), and Breiwick et al. (1981) calculated the present stock to be less than 10% of its original abundance.

After the collapse of the commercial whaling industry in 1915, the Alaskan Inuit resumed a small subsistence hunt for the bowhead whale. From 1910 to 1969 whaling was characterized by a relatively low, but steady, level of harvest. The Alaskan Inuit took an average of 11.7 bowheads annually during this 60 year period (Marquette and Bockstoce, 1980). During 1970 to 1977, however, a rapid increase in hunting effort and in the number of whales taken and struck but lost (Marquette, 1979) prompted the IWC to introduce an annual quota regulating the harvest of the bowhead whale in Alaska (Table 3.6-3). The mean number of bowheads struck annually between 1970 and 1977 was 54, while the average number struck between 1978 and 1980 was 25. The estimated survival rate of whales struck but not landed has not been documented. The location of the bowhead hunt is dependent on local ice conditions and the routes of migrating whales. During the spring the bowheads are hunted from small boats in open leads near Wainwright and Barrow, while during the fall they are hunted by residents of the eastern communities of Kaktovik, Nuiqsut and Barrow, Alaska (NPR-A Task Force, 1978a) (Figure 3.6-1).

3.6.2.2 White Whale (Beluga)

The western Arctic population of white whales migrates through the Chukchi Sea to the Canadian Beaufort and Amundsen Gulf each year. This population is hunted during the spring migration by residents of Point Lay, Wainwright and Barrow, Alaska, and later by residents of Inuvik, Aklavik and Tuktoyaktuk in the Northwest Territories, when the

TABLE 3.6-3

NUMBER OF BOWHEAD WHALES HARVESTED BY ALASKAN INUIT (1970-1980) AND HARVEST QUOTAS SET BY THE INTERNATIONAL WHALING COMMISSION (1978-1983)
(Adapted from Tillman, 1980 and W. Marquette, pers. comm., 1981)

Season	Landed	Struck but Lost	Total Struck	Quota Landed (or)	Total Struck (whichever occurs first)
1970	25	–	*25		
1971	24	–	*24		
1972	38	–	*38		
1973	37	10	47		
1974	20	31	51		
1975	15	28	43		
1976	48	43	91		
1977	29	82	111		
1978	12	6	18	12	18
1979	12	15	27	18	27
1980	15	16	31	18	26
1981				17	32
1982					
1983					

*1981-83 harvest not to exceed 45 landed or total of 65 struck, whichever occurs first.

whales come into the Mackenzie estuary (Section 3.2.1.2). In addition, during the summer the Inuit hunt white whales in nearshore lagoons along the northwest coast of Alaska. These whales probably belong to a stock distinct from the Mackenzie estuary whales.

The estimated annual harvest of white whales by Alaskan communities is presented in Table 3.6-2, while areas used by Alaskan Inuit during the hunt are shown in Figure 3.6-1. Between the years 1977 through 1979, the Alaskan communities landed an average of about 65 white whales annually (Seaman and Burns, 1980, cited in Fraker and Fraker, 1981). Many hunters harvest white whales incidentally with bowhead whales during the spring migration, although during the summer the white whales are caught with nets or driven into shallow lagoons and shot (Seaman and Burns, 1980, cited in Fraker and Fraker, 1981).

The numbers of white whales harvested by Canadian Inuit in the Mackenzie estuary between the years 1972 and 1981 are presented in Table 3.6-4, while areas used for hunting this species are shown in Figure 3.6-1. During these years, the Canadian communities along the Beaufort Sea landed an annual average of 132.8 white whales (Fraker and Fraker, 1982). Whales are hunted and shot from motorized boats or freighter canoes while they are in the shallow waters of the estuary.

The current 'best estimate' of the size of the population of white whales which ranges into the Mackenzie estuary each year is 7,000 (Fraker and Fraker, 1979). Based on present annual harvest statistics and estimated loss rates of 33% for the Mackenzie estuary and 67% for Alaska, Fraker (1980) estimated that the annual kill in Alaska and Canada totals about 300 whales, or 4.3% of the adult population. The difference in loss rates is attributable to different hunting techniques used in the two regions. Archaeological records indicate that this species has been harvested in the East Channel of the Mackenzie Delta for at least 500 years (McGhee, 1974, cited in Fraker, 1980).

The whale hunt is of social and cultural importance to the Inuit, and provides them with a source of meat, muktuk and oil (Plates 3.6-1 and 3.6-2). White whale products are used primarily for domestic purposes, although some intrasettlement trading also occurs (Brakel, 1977). Whaling in the Mackenzie estuary typically begins in late June when the whales arrive and continues intensely for about three weeks. There are approximately 100 families involved in the harvesting and processing of whales and whale products in this area. The Aklavik hunters and their families move to four traditional whaling camps on 'Niakunak' Bay, while hunters and their families from

TABLE 3.6-4

THE HARVEST OF WHITE WHALES IN THE MACKENZIE ESTUARY (1972-1981)
(Adapted from Fraker & Fraker, 1982)

	Number of White Whales										Mean Harvest	
Location	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1972-1979**	**1972-1981**
Tuktoyaktuk Community	45	87	40	50	51	54	53	49	23	62	53.6	51.4
Kugmallit Bay Camps	31	63	50	60	59	32	28	31	14	30	44.2	39.8
Kendall Island Camps	4	7	2	3	12	30	10	12	24	22	10	12.6
'Niakunak Bay' Camps	33	20	30	29	32	24	30	28	29*	35**	28.2	29.0
Total Harvest	113	177	122	142	154	140	121	120	90	149	136	132.8

*Includes 8 whales taken near Aklavik - July 14
**Includes 13-15 whales taken by Holman Island families with the help of Aklavik hunters

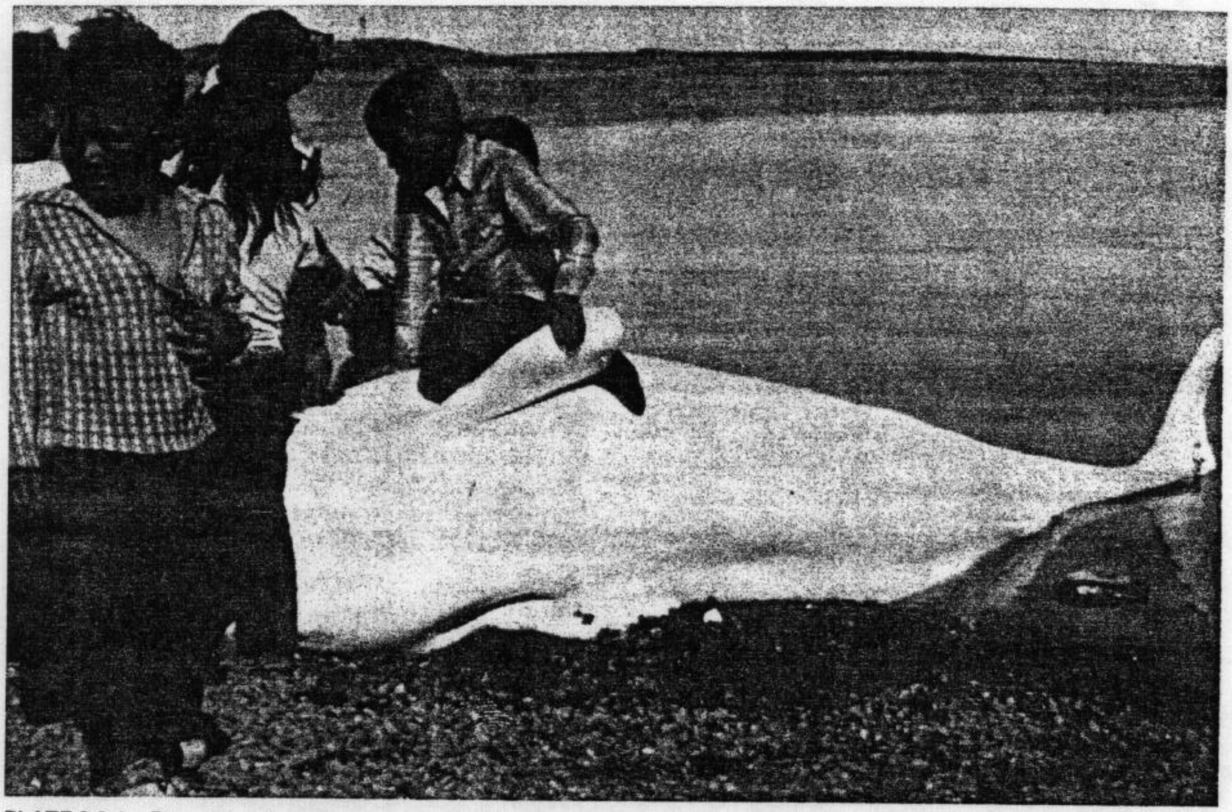


PLATE 3.6-1 *The white whale hunt is of considerable social and cultural importance to the Inuit and provides them with a source of meat, muktuk and oil.*

PLATE 3.6-2 *Laying out of muktuk (white whale blubber) to dry.*

Inuvik move to three camps on Kugmallit Bay and two on Kendall Island. Hunters from Tuktoyaktuk usually make day-trips to the whaling grounds in Kugmallit Bay (Fraker et al., 1978).

Hunting success is generally greater in Kugmallit Bay, with landings from there making up 60 to 80% of the total catch. However, few whales enter Kugmallit Bay in years when the ice fractures there later than usual in relation to the timing of the spring migration (such as in 1979 and 1980) (Fraker and Fraker, 1981). Hunting success also depends on hunter effort, the number of whales reaching accessible shallow water areas and calm weather. For example, poor weather conditions and fewer than normal white whales reaching Kugmallit Bay in 1980 were believed to have resulted in a catch of only 90 that year. However, the 1981 catch of 149 whales was the third most successful harvest in ten years. In 1981 warm spring weather encouraged large numbers of white whales to reach Kugmallit Bay. Between 1974 and 1978, an average of 3.42 males were landed per female, while in 1979, 1980 and 1981, the ratio was 1.57, 0.95 and 1.05 males per female, respectively (Fraker and Fraker, 1981, 1982). Fraker and Fraker (1981) suggested the change in the sex ratio of the harvest was probably the result of a decreased selectivity for the larger males by the hunters, and was not a result of an actual change in the sex ratio of the population.

3.6.2.3 Other Whales

Gray whales may be harvested incidentally during the bowhead hunt by residents from Barrow. M. Fraker (pers. comm., cited in LGL and ESL, 1982) suggests that one to four gray whales are landed near that community in most years.

3.6.3. POLAR BEARS

Polar bears are hunted during the winter and spring on the sea ice by residents of coastal communities in both Canada and Alaska. The harvest of this species in Canada has been regulated on a community quota system administered by the Northwest Territories government since 1967 (Usher, 1975). Tuktoyaktuk, Paulatuk, Holman Island and Sachs Harbour have had annual quotas and special Red Tags amounting to 26, 17, 20, and 22 bears, respectively, for the years 1978 through 1981. Bears reported and exported by residents of Aklavik and Inuvik are taken through permits (tags) of the other communities. Quotas are reviewed each year by the Northwest Territories government. The number of polar bear hides exported by Canadian communities in the southeastern Beaufort Sea and Amundsen Gulf are presented in Table 3.6-5, while extended and core areas used to hunt bears in the regions are illustrated in Figures 3.6-1 and 3.6-2.

The sale of polar bear hides is important to the cash economy of Tuktoyaktuk, Paulatuk, Sachs Harbour and Holman. Individual settlements divide the allocated permits within the community between sport and commercial hunting. The average price received by residents of the Northwest Territories for a polar bear hide was $1,018.31 in 1979-80 (26.5 times the amount received for an Arctic fox pelt or 53 times that for a ringed seal skin).

The harvest of this species is less intensive in Alaskan communities since the sale of polar bear hides is prohibited in Alaska (NPR-A Task Force, 1978b). However, the sale of products made from hides is permitted. The minimum estimates of the average annual harvest of polar bears from the north coast of Alaska was 27 (range: 14-38) between the years 1973 and 1979 (Alaska Dept. Fish and Game records). Areas in Alaska used to hunt polar bears are indicated on Figure 3.6-3.

TABLE 3.6-5

EXPORT OF POLAR BEAR PELTS BY CANADIAN COMMUNITIES IN THE SOUTHEASTERN BEAUFORT SEA (1970-1981)

	Number of polar bear furs exported											Annual** Quotas
Community	1970-71*	1971-72	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1978-1981
Aklavik	n/r	n/r	n/r	n/r	1	1	n/r	1	n/r	n/r	1	0(5)†
Inuvik	6	1	n/r	2	2	16	6	5	15	n/r	n/r	0
Tuktoyaktuk	4	12	21	11	21	13	15	22	16	19	20	26
Holman	9	8	10	15	17	6	15	11	7	17	14	20
Paulatuk	8	11	10	13	22	2	10	1	2	17	2	17
Sachs Harbour	2	18	16	9	22	16	19	9	20	21	14	22

n/r = no recorded exports. Fur Export Tax Returns, GNWT, Yellowknife

*July 1 - June 30

**N.W.T. Quota includes Red Tag Quota.

† In 1980-81 Aklavik had a quota of 5.

3.6.4 ARCTIC FOX

Arctic foxes are trapped by residents of all coastal communities adjacent to the Beaufort and northeast Chukchi seas and communities on the Mackenzie Delta. Although the Arctic fox is essentially a terrestrial mammal throughout its range, residents of several coastal communities in the Beaufort-Chukchi region, trap this species for its white fur during winter and spring when they occur offshore on the landfast ice (Section 3.2.4). The harvest of this species by residents of communities of the Mackenzie Delta is discussed in Section 4.6.1.

The sale of white fox pelts provides an important source of cash income for some coastal communities. A small number of furs may also be retained and used within the communities for production of native crafts. Fox trapping methods are described by Usher (1971).

In the Canadian sector of the Beaufort-northeast Chukchi region, white Arctic foxes are particularly important to the cash economy of Sachs Harbour and Holman, although residents of Paulatuk, Tuktoyaktuk and Inuvik also report substantial Arctic fox exports (see Section 4.6.1). The number of furs exported by these communities are presented in Table 3.6-6, while the locations of the coastal and marine traplines are shown in Figure 3.6-2. Although the communities tend to retain their relative share of export income, the pattern of exports is erratic and may change by a factor of 2 or 3 between years owing to fluctuations in the levels of Arctic fox populations (Section 3.2.4). Average fur prices in the Northwest Territories for white fox pelts also fluctuate between years. The average 1979-80 price for white fox furs was $38.38, or about twice that paid for a ringed seal skin.

Trapping of Arctic foxes along the north coast of Alaska is less intensive than in the Canadian Beaufort Sea. The estimated average annual harvest for the Alaskan sector of the Beaufort - northeast Chukchi region probably ranges from 400 to 600 foxes (H. Melchoir pers. comm.). This estimate was based on conversations with trappers, fox dealers and export returns. Arctic fox harvests in Alaska also reflect natural fluctuations in the Arctic fox populations in these areas, as well as fluctuations in the market value.

3.6.5. BIRDS

Residents of coastal settlements adjacent to the Beaufort and northeast Chukchi seas harvest several species of ducks and geese during the spring, summer and fall. Depending on location, most hunting effort is directed toward snow geese, brant, white-fronted geese and Canada geese, and to various species of diving and dabbling ducks such as eiders, oldsquaw, pintail, scaup and scoters. Brant, common eider, king eider and oldsquaw are the primary species taken along the north coast of Alaska during spring and fall by virtue of their coastal migration routes (Section 4.2). Many of the ducks harvested in northern Alaska are taken within a few kilometres of Barrow, with the majority (over 85%) being king eiders (Thompson and Person, 1963; Johnson, 1971; Timson, 1976). Thompson and Person (1963) and Johnson (1971) present data suggesting that the annual duck harvest from Barrow may be within the range from 4,000 to 8,000. Since brant migrate at higher altitudes and pass Alaska in a short time period, they do not constitute a major part of the annual harvest of these communities. Residents from Wainwright and Nuiqsut also hunt ducks and geese, although no estimates of the annual harvest are available.

TABLE 3.6-6

EXPORT OF ARCTIC FOX PELTS BY CANADIAN COMMUNITIES OF THE SOUTHEASTERN BEAUFORT SEA AND AMUNDSEN GULF

(Fur Export Tax Returns, N.W.T Wildlife Service, Yellowknife)

Community	Number of Furs Exported										
	1970-71*	1971-72	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	Mean
Aklavik	93	56	85	87	59	62	65	15	12	8	57.8
Inuvik	1,098	491	173	1,405	984	911	1,154	790	1,088	22	707.3
Tuktoyaktuk	476	2,067	852	574	1,062	904	1,715	388	641	594	967
Holman	1,376	2,215	703	3,892	1,923	356	1,432	2,740	596	1,887	1,816
Paulatuk	n/r	223	310	870	758	8	305	209	33	483	400
Sachs Harbour	2,811	2,687	2,000	6,007	3,258	3,757	5,922	4,803	1,299	1,036	3,397

n/r = no recorded exports

*July 1 - June 30

In the Canadian Beaufort Sea, large numbers of moulting, staging, and brood-rearing waterfowl occur during the summer and fall near Herschel Island and Nunaluk Spit, the outer Mackenzie Delta, coastal bays along the Tuktoyaktuk Peninsula and in Liverpool Bay. The most numerous species available to hunters in these areas include scaup, scoter, oldsquaw, brant, snow geese and white-fronted geese. Residents from Aklavik, Inuvik and Tuktoyaktuk harvest the majority of these waterfowl, although residents of Holman Island hunt eiders in Minto Inlet during spring, and Inuit from Paulatuk hunt staging snow geese on the Parry Peninsula in late May and early June. The number harvested each year varies depending on weather, numbers available and hunting effort. Nevertheless, Usher (1975) estimated that residents of Aklavik and Inuvik take a combined annual average of 1,500 ducks and a highly variable number of geese annually (examples being 150 in 1965-66, and 3,250 in 1973-74), while residents of Tuktoyaktuk harvest between 600 and 1,000 ducks and 1,000 and 2,500 geese annually (Usher, 1975).

3.6.6 FISH

Residents of Beaufort and northeast Chukchi sea coastal communities harvest several species of freshwater, anadromous and marine fish for both domestic and commercial purposes. The major species harvested in coastal fisheries include Arctic char, Arctic and least cisco, humpback and broad whitefish, inconnu, northern pike, and Pacific herring (Brakel, 1977; Corkum and McCart, 1981). However, the importance of fish, particularly in the Mackenzie Delta, has declined as the number of sled dogs (major fish consumers) has decreased and, as wage employment and food imports have increased (Brakel, 1977). Other aspects of fish harvesting in this region, including more detail on catch statistics for the important inland fishing areas, are discussed in Section 4.6.2 of this volume dealing with harvests of freshwater fish in the onshore Beaufort zone.
zone.

Most domestic and commercial fishing is concentrated in areas such as the Colville and Mackenzie river deltas, in small river outlets and in coastal lakes. In contrast, little fishing is done in Beaufort Sea coastal waters even though most species captured occur in marine coastal waters in the summer. Harvests of primarily anadromous species occur during the fall migration to spawning and overwintering freshwater habitats.

Small commercial fisheries in the Canadian Beaufort supply local markets and export some whitefish to the prairie provinces. Overall, the commercial fishery remains small compared to the domestic fishery because of the competitive advantages of fisheries elsewhere which have fewer logistic difficulties. There are presently no major commercial fishing operations in the Canadian Beaufort region. The last major one was an Arctic char fishery located at the Hornaday River east of Paulatuk.

The Paulatuk operation began in 1968 with a quota of 5,000 lb (2,270 kg), and had been increased to 15,000 lb (6,800 kg) dressed (R. Barnes, pers. comm., cited in LGL and ESL, 1982). It supplied markets mainly in Inuvik and provided a major source of income for several families in Paulatuk (Brakel, 1977). However, this fishery was recently closed due to declines in fish stocks (Corkum and McCart, 1981). In addition to char, the community is reported to have caught Arctic cod and Pacific herring, but few details are available on the extent of this catch (Fenco and Slaney, 1978).

Near the Mackenzie Delta, a small fishery for whitefish on Holmes Creek (80 km north of Inuvik) has been subsidized by the Northwest Territories government since 1972, but only provides a minor source of income for about three families (Brakel, 1977). Similarly, about eight fishermen may independently sell small numbers of whitefish, lake trout and char locally to Inuvik and Aklavik. Data from 1979 indicated that in addition to approximately 100,000 kg of fish from domestic harvests, about 22,000 kg were either sold locally or exported (Corkum and McCart, 1981).

In 1963 an experimental fishery was initiated for Pacific herring near the Baillie Islands off Cape Bathurst. However, despite sufficient quantities landed (approximately 8,000 kg), the project proved uneconomical. The feasibility of a commercial herring roe fishery along the Tuktoyaktuk Peninsula and in Liverpool Bay is presently being studied (Dept. Fisheries and Oceans, Inuvik, pers. comm., 1981).

In most Canadian Beaufort Sea communities domestic fishing is far more important than commercial fishing. However, the intensity of domestic harvests varies with different areas. In the Mackenzie Delta area, domestic fishing is more economically important than the other types of marine harvesting. Species harvested include whitefish, ciscos, char, pike, inconnu, lake trout, and herring; the latter being restricted to coastal areas of the Tuktoyaktuk Peninsula. Fishing is most intensive during the open water period, although some ice-fishing is also done (Brakel, 1977). Most fishing is centred in the Delta and near Tuktoyaktuk, but a small amount of fishing occurs along the Yukon coast and west of Tuktoyaktuk. Although estimates are limited by the lack of catch records, whitefish represent the greatest proportion of fish harvests.

Recent data from 1979 and 1980 indicate that domestic harvests in the Delta are in the order of 100,000 kg annually. Broad and humpback whitefish are the dominant species, accounting for at least 50% of the domestic harvests for all areas of the Delta (Corkum and McCart, 1981). Other major species include Arctic and least cisco, inconnu, pike, and burbot, which together represent over 25% of the fish captures. Minor species captured in a few locations include, Arctic grayling, Arctic char, lake trout, chum salmon, longnose sucker, and Pacific herring.

In comparison to the Delta area, communities such as Paulatuk and Sachs Harbour rely less heavily on fish for domestic needs, but as in other areas, no reliable harvest records exist. Brakel (1977) reports that in Paulatuk the domestic fishery has shifted from the economically lucrative char to whitefish and burbot, but some char (900 - 1,350 kg) are still harvested for domestic use (R. Barnes, pers. comm., cited in LGL and ESL, 1982). Domestic fishing for char and lake trout is done from Sachs Harbour (Banks Island) and for char and whitefish from Holman Island (Victoria Island). These communities do not rely much on domestic catches, for example only about 50 kg/yr of these fish are harvested in Sachs Harbour (Fraker et al., 1979).

In Alaska, marine fish are of domestic and commercial importance to residents of Point Lay, Wainwright, Barrow, Nuiqsut and Kaktovik. Although some fishing occurs in coastal waters, most occurs on inland lakes and in rivers (LGL and ESL, 1982). For Point Lay and Barrow there are no records on the numbers or species of fish taken. At Wainwright salmon, trout, and whitefish are taken during late summer, and boreal smelt are caught through the ice later at the mouth of the Kuk River (LGL and ESL, 1982; Bendock, 1977).

Residents of Nuiqsut mostly fish inland, except in the Colville River delta where large numbers of cisco and whitefish are harvested. A non-native commercial fishery in the Colville delta lands about 54,000 cisco and 3,500 whitefish annually (Alaska Dept. Fish and Game, cited in Craig and Griffiths, 1978), and Craig and Griffiths (1978) suggest that the native harvest in that area may be up to two times the commercial harvest.

3.7 SPECIAL AREAS

This section briefly describes areas adjacent to the Beaufort and northeast Chukchi seas which have a legal status or which are publically recognized as conservation and/or important wildlife areas. These areas include existing and proposed sanctuaries and parks, protected wildlife habitats, polynyas and areas selected by the Inuvialuit under native claims agreements. Special areas in Canada and Alaska are discussed separately. For a description of special areas bordering on M'Clure Strait the reader is referred to Volume 3B, Section 2.6.

3.7.1 CANADA

3.7.1.1 National Parks and Significant Areas

Parks Canada has divided the country into 39 terrestrial and 9 marine 'natural regions,' and within each of these areas a national park may eventually be established. The Beaufort Sea area includes portions of four terrestrial and one marine natural regions. Within each natural region Parks Canada may identify 'Natural Areas of Canadian Significance' (NACS) that are representative of the natural region in terms of both abiotic (landform, geology etc.) and biotic components. 'National Sites of Canadian Significance'(NSCS) are small areas within the natural region that contain unique or rare natural components. Figure 3.7-1 shows the locations of existing NACS and NSCS areas in the Beaufort Sea region as well as other locations that are under study to determine whether they merit NACS or NSCS status.

The northern Yukon, including part of the coastal area and most of Herschel Island, has been proposed as a National Park. In addition, the Yukon coastal area, including the proposed park site, has been given legal status, having been withdrawn from further development for the present time by Order-in-Council (Plate 3.7-1). This area includes the Canadian segment of the calving grounds of the Porcupine caribou herd (Section 4.1.1.1), and coastal zones which support thousands of migrant and staging waterfowl (Section 4.2). Industry fully recognizes the natural significance of this vast region, and would take this into consideration when planning any future developments.

Parks Canada is currently considering the area near Nelson Head (Plate 3.7-2) and the Thomsen River drainage basin on Banks Island (Figure 3.7-1) for park status. Nelson Head is of geological interest, since it contains several series of cliffs, while the Thomsen basin supports a large herd of muskoxen and is a staging area for thousands of brant and lesser snow geese (Section 3.3). Parks Canada is also reviewing a small area on the Tuktoyaktuk Peninsula for National Landmark status to protect a group of pingos which are considered a unique landform. Three other areas adjacent to the Mackenzie River and Delta, as well as the region south of Cape Parry to Cape Bathurst, are being examined by Parks Canada to determine whether they should be given NACS (Natural Area of Canadian Significance) status (Figure 3.7-1).

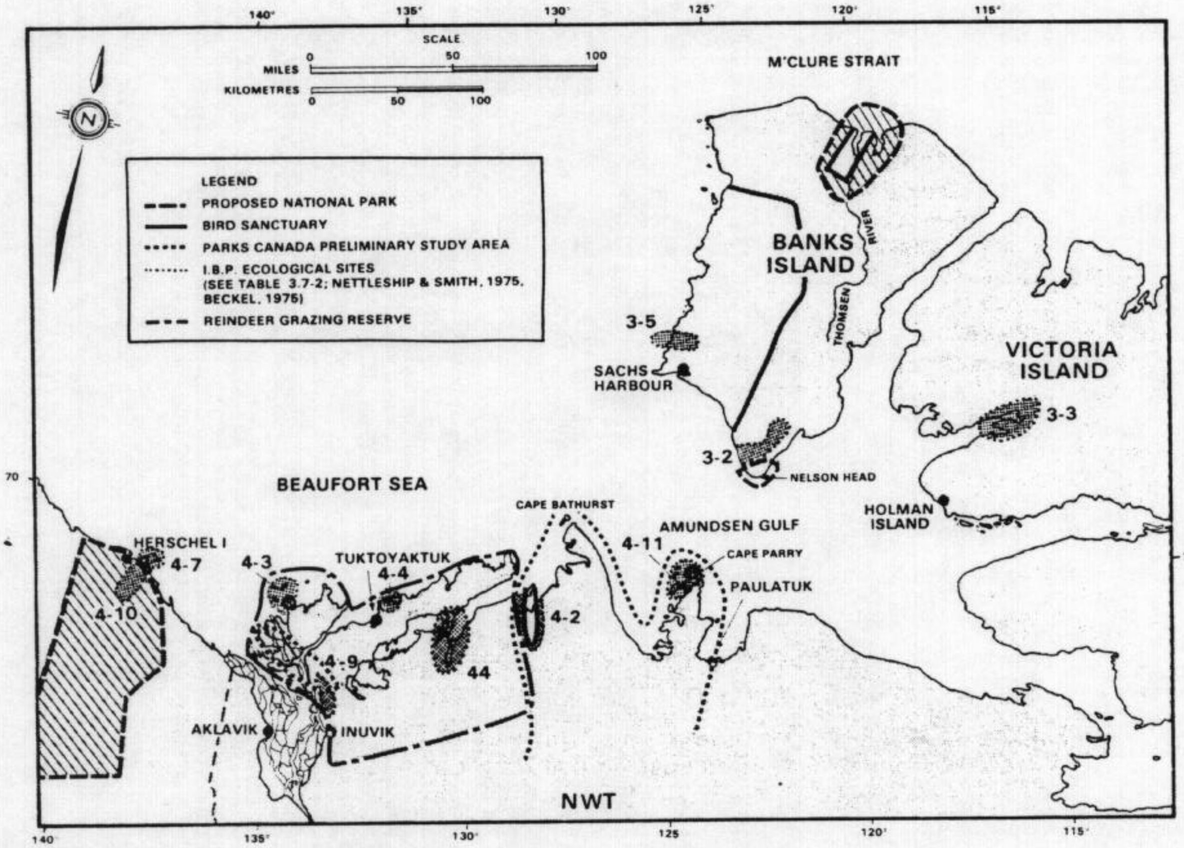


FIGURE 3.7-1 *Location of special areas in the Canadian Beaufort Sea region.*

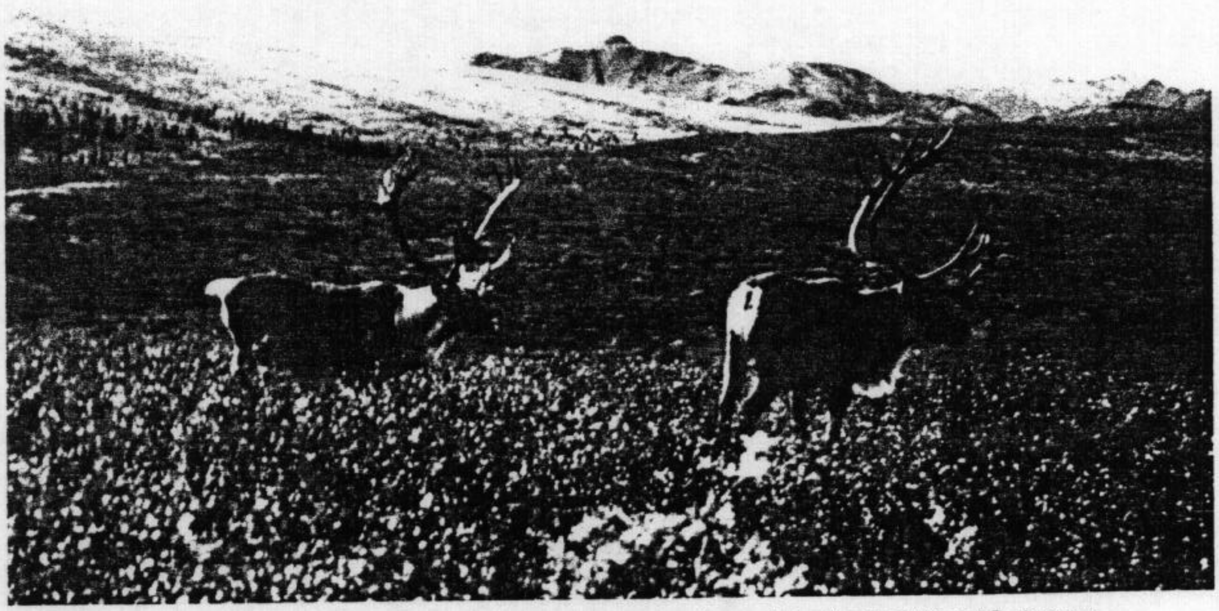


PLATE 3.7-1 *Highlands of the northern Yukon — part of the area under consideration for National Park status.*

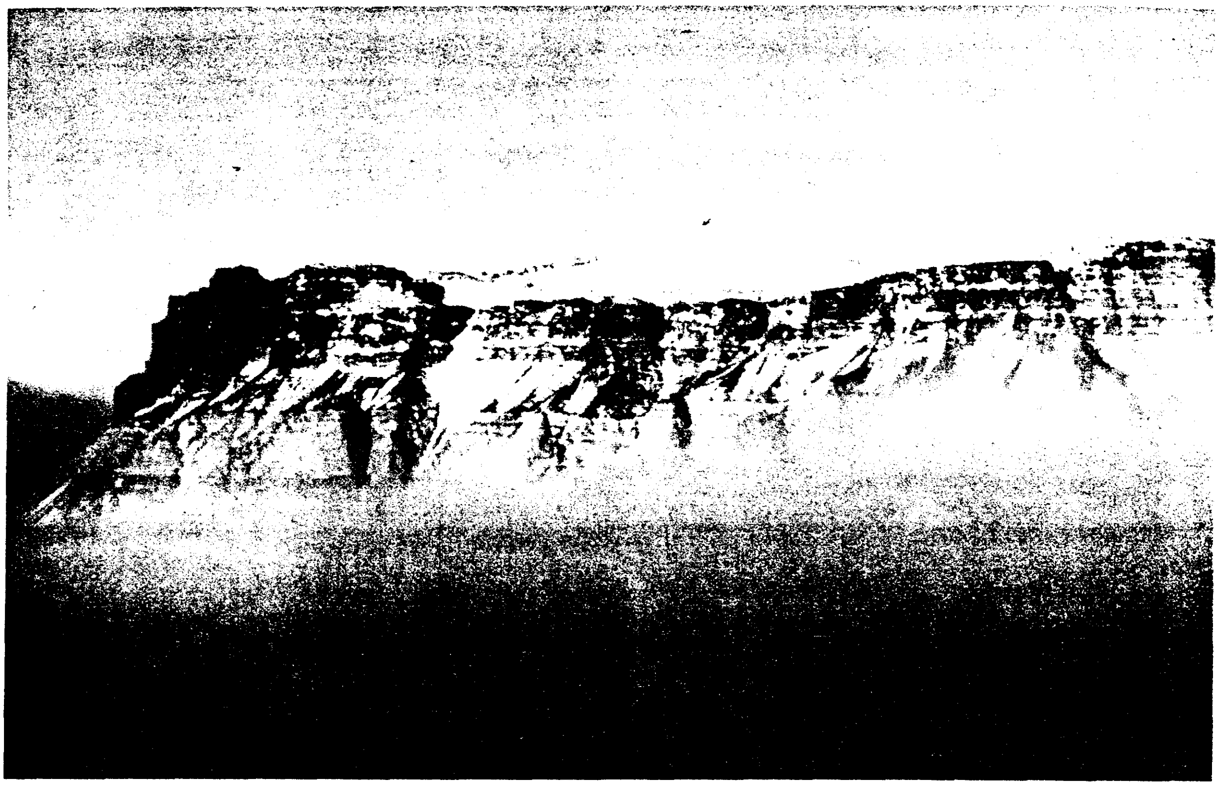


PLATE 3.7-2 *The cliffs of Nelson Head on Banks Island, part of the area being considered for National Park status.*

3.7.1.2 Migratory Bird Sanctuaries

There are four migratory bird sanctuaries in the Beaufort Sea area. The locations of these sanctuaries are shown on Figure 3.7-1, while the major species they protect are described in Table 3.7-1. The Kendall Island Bird Sanctuary, located on Richards Island in the Mackenzie Delta, has been the site of considerable exploratory drilling in the past and several important gas fields have been discovered there and in the vicinity.

3.7.1.3 International Biological Programme (IBP) Sites

As part of the International Biological Programme (IBP), committees were established to identify ecologically significant areas in participating countries. Sites were chosen for their value as unique ecological areas, and for their potential suitability for observation of recovery from natural and man-made perturbations (Nettleship and Smith, 1975). Within the Canadian Beaufort Sea region eleven coastal, or partially coastal tundra areas have been established as IBP sites (Figure 3.7-1). Their salient features are described in Table 3.7-2. Other IBP sites exist in the map area but are not discussed as they are not within the Beaufort coastal region.

TABLE 3.7-1
MIGRATORY BIRD SANCTUARIES IN THE BEAUFORT SEA REGION

Sanctuary	Major Bird Species or Groups
Kendall Island	Breeding, staging and moulting waterfowl, especially lesser snow geese, brant and white-fronted geese.
Anderson River Delta	Nesting and moulting area for brant, white-fronted geese, Canada geese, whistling swans. Endangered eskimo curlew observed in 1961, 1962, 1964 and 1980. (Section 4.2)
Cape Parry	Only nesting colony of thick-billed murres in the western Canadian Arctic.
Banks Island No. 1 (South western Banks Island)	Nesting area for lesser snow geese, brant, king eiders, sandhill cranes. Peregrine falcons nest on cliffs.

3.7.1.4 Land Settlement Areas

The Committee for Original Peoples Entitlement (COPE) and the Government of Canada signed an Agreement-in-Principle on October 31, 1978. If ratified in its present state, this agreement would give the Inuit of the western Arctic title to 37,000 mi^2 (95,830 km^2) of land. Included in the proposed settlements are the mineral rights to six blocks of 700 mi^2 (1,813 km^2) and an 800 mi^2 (2,072 km^2) block south of Cape Bathurst (Figure 3.7-2). Title to the remaining areas will not include subsurface mineral rights, and these areas are to be selected from traditional lands of the Inuit before the signing of the final agreement. Some areas were selected and approved on May 22, 1979 (Figure 3.7-2). However, the final agreement is still under negotiation, and certain other areas that have been selected by COPE have not been approved by

TABLE 3.7-2
IBP ECOLOGICAL SITES ALONG THE BEAUFORT SEA COAST[1]

Site and Number	Area (km²)	Features	Protective Status
Herschel Island (4-7)	176	Exceptionally rich vegetation. Diverse terrestrial and marine fauna. One of the few known nesting sites of black guillemots in the western Arctic.	Withdrawn from further development by Order-in-Council
Firth River (4-10)	4820	Primarily terrestrial. Diverse vegetation. Unglaciated. River supports Arctic char and graylings.	Withdrawn from further development by Order-in-Council
Garry and Pelly Islands (4-3)	210	Waterfowl nesting area. Form part of the remnants of the ancestor of the present Mackenzie Delta.	None
Caribou Hills, Mackenzie River Delta (4-9)	660	Diverse flora and fauna including both boreal and tundra associations. Waterfowl nesting and staging area.	None
Kugaluk River and Estuary (44)[2]	3072	Waterfowl nesting and staging area. Good area for studies of the effect of fire on the treeline.	Within Reindeer Grazing Reserve
Toker Point (4-4)	325	Many pingos. Typical vegetation of coastal lowlands. Grizzly bear denning area.	None
Anderson River (4-2)	1280	Major nesting area for swans, geese, ducks, shorebirds. Partly unglaciated resulting in unique plant associations. Grizzly bears present.	Anderson River Migratory Bird Sanctuary
Cape Parry and Associated Islands (4-11)	570	Sole breeding site of thick-billed murres in the western Arctic.	Cape Parry itself is a Federal Migratory Bird Sanctuary
Masik River, Banks Island (3-2)	1300	Primarily terrestrial; rich botanical area representing a refugium for low Arctic species during Wisconsin glaciation.	None
Egg River-Big River, Banks Island (3-5)	755	The largest lesser snow goose colony in the western Canadian Arctic occurs at the confluence of the Egg and Big Rivers.	Part of Banks Island Migratory Bird Sanctuary No. 1
Minto Inlet, Victoria Island (3-3)	6000	Highly diverse vegetation. Peregrine falcon nesting area. Possible polar bear migration route. Stable ice for ringed seal pupping.	None

[1]Based on Nettleship and Smith (1975).
[2]Based on Beckel (1975).

the Government of Canada at the present time.

3.7.1.5 Other Ecologically Significant Areas

The Reindeer Grazing Reserve adjacent to the Beaufort Sea (Figure 3.7-1) was established in 1935 for a herd of reindeer transported from Alaska to provide the basis for a local industry (Abrahamson, 1968). Hunting of reindeer in this area is prohibited. Caribou may be hunted by General Hunting License holders throughout the year within the Reindeer Reserve east of the Kugaluk River and for six weeks of the year between Eskimo Lakes and the Kugaluk River. Existing industrial developments at Tuktoyaktuk and McKinley Bay are located close to or within the grazing range of the herd.

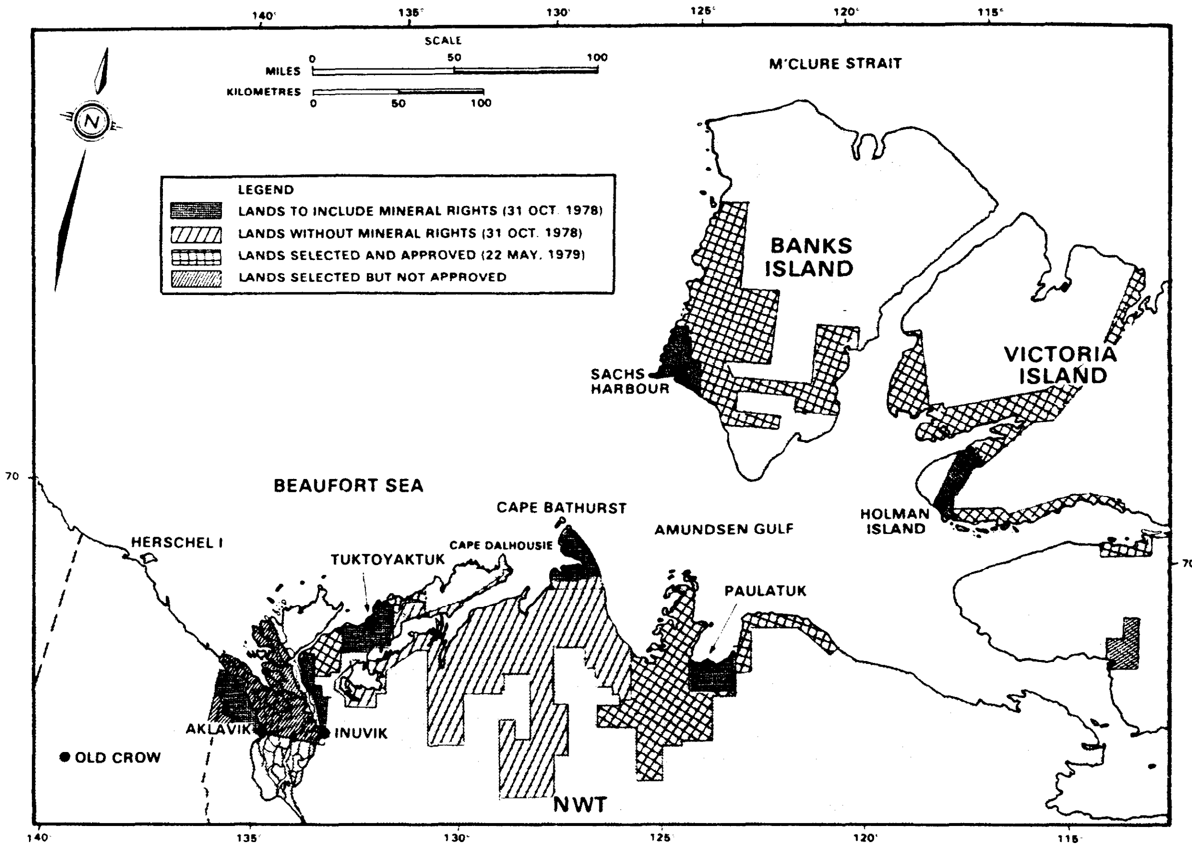


FIGURE 3.7-2 *Lands included in the COPE Agreement-in Principle*

Polynyas are areas of open water bounded by fast ice or by fast ice and land. Some are present all winter, while others appear in the spring before the onset of the general thaw. In the Beaufort-Chukchi region, polynyas may be used during winter by marine mammals (such as bearded seals) which do not normally maintain breathing holes in heavy ice, and during spring by migrant beluga whales, bowhead whales and birds. Polynyas are particularly important for marine birds in years when snowmelt and ice break-up are delayed and open leads are limited or unavailable (Section 3.3).

Generally, three recurrent leads form in the eastern Beaufort Sea. These are considered to be important staging habitats for migrant birds during spring, particularly for oldsquaws, eiders, glaucous gulls and loons (Section 3.3). One lead usually forms near Herschel Island, another forms off Cape Dalhousie and later extends northeast and north to Banks Island, and the third forms along the west coast of Banks Island (Barry, 1976). As the season progresses, these leads typically expand and become continuous, forming the 'Amundsen Gulf polynya.' Barry (1968) reported extensive mortality of migrating waterfowl when these leads did not form in 1964. The Canadian Wildlife Service (1972) indicated that in some years, open water along the Cape Dalhousie-Banks Island lead may persist all winter, and that polar bears concentrate in this area during these years. In the spring these leads are generally used as migration corridors by bowhead and beluga whales (Section 3.2).

3.7.2 ALASKA

3.7.2.1 Land Use/Native Claims

Land adjacent to the Beaufort and Chukchi seas in Alaska is owned by Federal and State governments, native corporations formed after the passing of the Alaska Native Claims Settlement Act (ANCSA), and some private individuals. Ownership of much of the land along the coast is either in dispute or in a state of changing ownership, and only those areas owned or selected by native corporations under ANCSA and certain federally-owned lands are discussed in this section.

In addition to providing for ownership of land by native corporations, ANCSA permitted the selection by the Federal government of lands for inclusion in a system of national parks, forests, and refuges [titled d(2) areas]. Figure 3.7-3 identifies lands owned by native corporations [d (2) areas] and 'dual withdrawal' lands (Selkregg, 1975). The last are lands chosen for ownership by the state under the Statehood Act and also by native corporations under ANCSA.

Land use planning along the Arctic coast of Alaska is the responsibility of the North Slope Borough Regional Government. To date they have proposed several conservation districts and buffer areas where surface industrial activities will be prohibited or discouraged, respectively, as well as a plan for the Prudhoe Bay area (North Slope Borough Planning Commission, 1979). However, all plans proposed by this group must be approved by the State government prior to implementation. One proposed conservation district is the "boulder patch" near Karluk and the Narwhal Islands. This area of discontinuous boulder and cobble is an unusual habitat in an area of predominantly soft-bottom substrates, and provides suitable habitat for organisms that cannot colonize soft bottoms.

3.7.2.2 Historic Places/Natural Landmarks

The National Register of Historic Places recognizes historic and archaeological sites of local, state or national importance. Two historic places of national importance occur in the region, and three other sites of local importance are under consideration (W. Hannibal, pers. comm., cited in LGL and ESL, 1982). The locations of these sites are indicated in Figure 3.7-3. Historic places do not have a legal protected status except that federally funded or licenced development projects in historic places of national significance must be reviewed by the National Parks Service before they are approved.

Natural landmarks are areas which are exceptional illustrations of the natural heritage of the United States and/or areas that contain outstanding examples of habitats in specified regions. Natural landmarks also have no legal status at present, but legislation prepared under the Carter Administration would have made them equivalent to historic places; that is, a national register would have been created, and federally funded or licenced development projects in natural landmarks of national significance would also be subject to review by the National Parks Service (J. Mosby, pers. comm., cited in LGL and ESL, 1982). This legislation has not yet been considered by Congress and appears unlikely to come into force under the Reagan Administration.

Table 3.7-3 summarizes the important characteristics of the eleven proposed natural landmarks in Alaska, while their locations are indicated on Figure 3.7-4. Of the eleven proposed natural landmarks, highest priority has been placed on attaining legal status for the Barrow-Nuwuk-Walapka (Site No. 4) and the Teshekpuk Lake-Pic Dunes (Site No. 5) areas. The

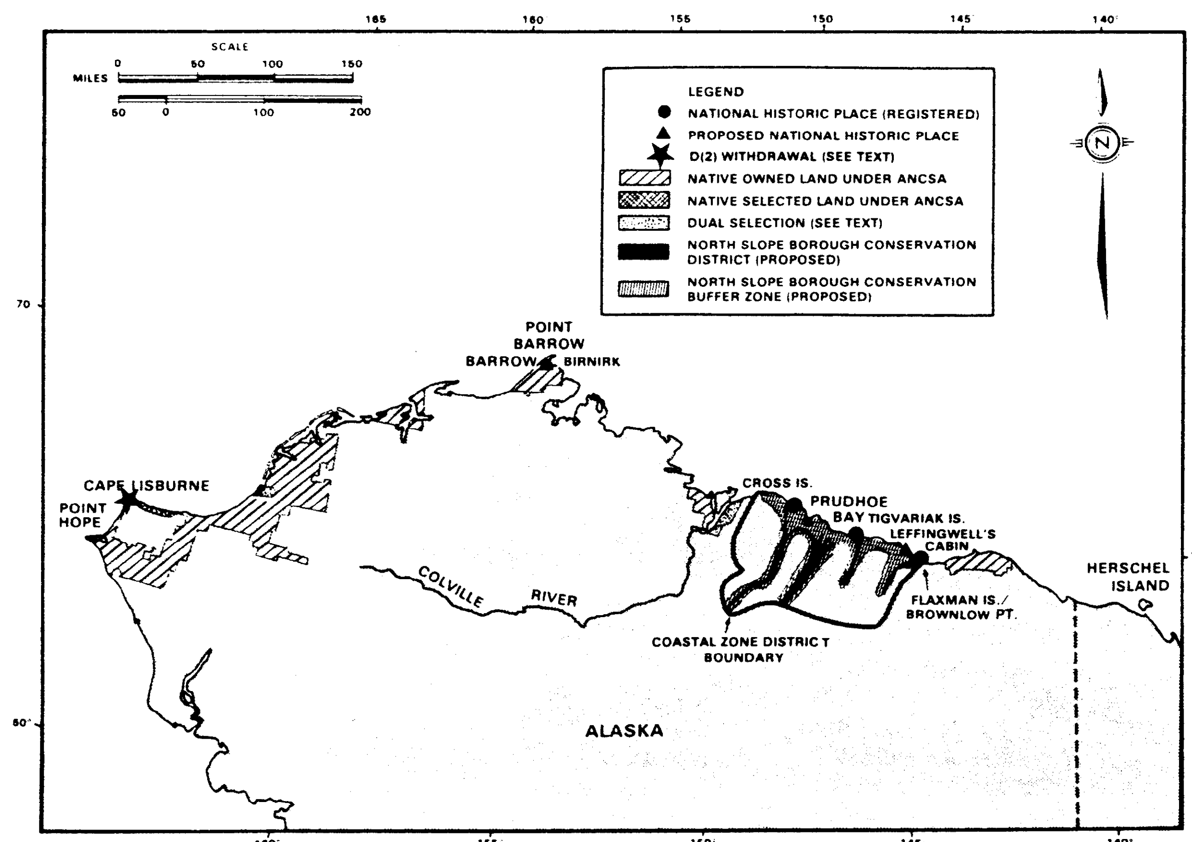


FIGURE 3.7-3 *National historic places and native claims settlement act lands in Alaska.*

TABLE 3.7-3
CHARACTERISTICS OF ALASKAN NATURAL LANDMARKS[1]

Name and Number[2]	Size (km^2)	Characteristics	Priority[3]
1 Cape Sabine-Pitmega R.	Undecided	Western Arctic coast. Ridge and valley topography. Bering Sea flora. Bears, wolverines.	Unassigned
2 Kasegaluk Lagoon-Icy Cape	2444	Large offshore bar system on Arctic coast. Marine mammals, fishes. Coastal topography.	1C
3 Kuk-Utukok R. Corridor	7473	Estuary and river system. Caribou calving grounds. Upland tundra topography. Coal and amber deposits.	1C
4 Barrow-Nuwuk-Walapka	1094	Naval Arctic Research Lab. Intensive ecological study site. Archaeological site.	1B
5 Teshekpuk Lake-Pic Dunes	2085	Marine fossils. Waterfowl nesting area. Large coalesced lake, polygons, oriented lakes, Arctic playa or drained lake.	2C
6 Colville R. Delta	3032	Large Arctic delta with unique fish populations, waterfowl, dunes and tidal flats.	2C
7 Beechey Mound Area	610	Coastal topography. Pingos, polygons, oriented lakes. Waterfowl nesting area.	3C
8 Bullen Point	Undecided	Arctic char schooling area.	Unassigned
9 Cross Island	12	Offshore island on Arctic coast. Marine strands. Polar bear denning. Waterfowl nesting.	3C
10 Flaxman Island	13	Site of explorer's cabin and camp. Location of erratic boulders. Waterfowl.	1C
11 Kongakut R.-Beaufort Lagoon	563	Offshore island and freshwater lagoon system. Waterfowl habitat. Fish populations. Braided river course.	1A

[1]Based on Koranda and Evans (1975)
[2]See Figure 3.7-4
[3]Definition of priorities:

1 - high degree of national significance
2 - national significance
3 - information lacking

A - site in serious danger of degradation
B - some danger
C - no apparent danger

applications for the Colville River delta (Site No. 6) and Kongakut River-Beaufort Lagoon (Site No. 11) areas have been recently deferred, pending requirements for further information. It is also noteworthy that the National Marine Fisheries Service (NMFA) have publically announced that they will not consider applications for natural landmarks which have a marine component until further notice.

3.7.2.3 Ecological Reserves System

The Ecological Reserves System is designed to identify and secure field sites uniquely suited to natural science research and education (Underwood and Juday, 1978), although at present the system is not fully implemented. Those coastal areas under consideration are shown on Figure 3.7-4 and described in Table 3.7-4. The system is an extension of several programs, including the International Biological Programme, and Ecological Reserves are the equivalent of IBP sites in Canada. The sites are not necessarily intended strictly for conservation purposes, but include areas suitable for observation of natural processes, as well as for experimental manipulation of natural processes.

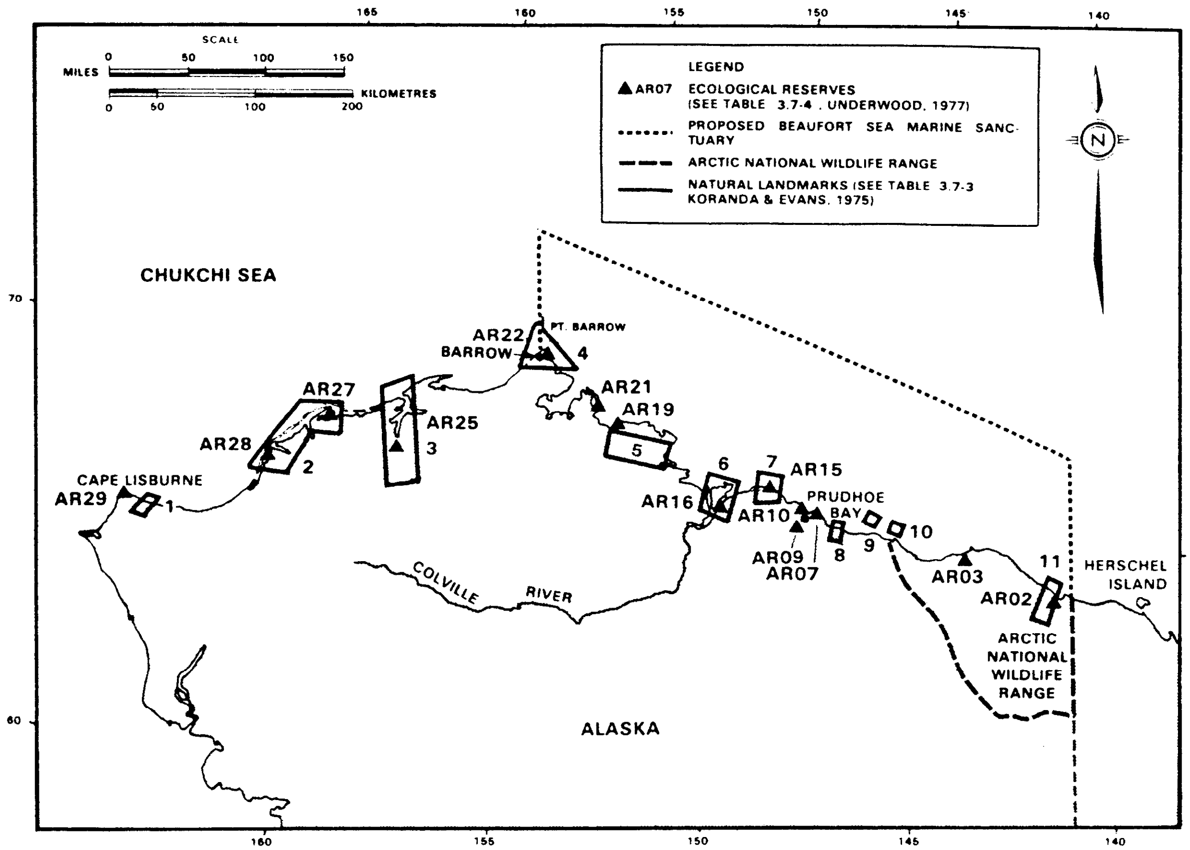


FIGURE 3.7-4 *Location of ecological reserves and natural landmarks in the Alaskan Beaufort and northeast Chukchi Sea area. Ecological reserves are the equivalent of IBP sites in Canada.*

3.7.2.4 Other Areas

The Arctic National Wildlife Range was created to preserve "unique wildlife, wilderness and recreation values" (U.S. Bureau of Land Management, 1979) in the areas east of the Canning River to the U.S.-Canadian border (Figure 3.7-4). It is an area of habitat protection rather than a game sanctuary, and as such, hunting, fishing and trapping in accordance with state laws are allowed (A. Thayer, pers., comm., cited in LGL and ESL, 1982).

Friends of the Earth Inc., a conservation-oriented private organization, has nominated an area from Point Barrow to the Canadian border and 160 km seaward from the coast as a marine sanctuary under the National Oceanographic and Atmospheric Administration's (NOAA) program for preservation and restoration of marine areas (U.S. Bureau of Land Management, 1979). However, as in the case of natural landmarks involving marine environments, applications for this or other marine sanctuaries are not being considered by the National Marine Fisheries Service until further notice.

TABLE 3.7-4

CHARACTERISTICS OF PROPOSED ECOLOGICAL RESERVES IN ALASKA[1]

Name and Number[2]	Size (km^2)	Main Characteristics
Cape Lisburne (AR29)	Undecided	Exposed coast and continental shelf environments. Dry mesic and alpine tundra. Numerous polar bears and ringed seals. Northernmost seabird colony in Alaska.
Point Lay (AR28)	Undecided	Natural and modified samples of protected coast, lagoons and barrier islands. Numerous seals, whales, walruses. Polar bear denning.
Icy Cape (AR27)	Undecided	Examples of barrier islands in the Chukchi Sea. Much research on coastal erosional processes has been conducted here. Wet tundra. Numerous waterfowl.
Kuk R. (AR25)	520	Examples of typical and modified exposed and protected coast, a delta, an estuarine system, the continental shelf and ice.
Point Barrow (AR22)	18	Well known ecologically.
Smith Bay (AR21)	Undecided	Numerous nesting birds. Large seal population. Protected coast threatened with modification.
Teshekpuk Lake (AR19)	610 (land surface)	Very large numbers of nesting and moulting birds. Many ringed seals.
Colville Lake (AR16)	Undecided	One of few examples of extensive river delta and sand dune environments on north coast. Protected coast, barrier islands, an estuary, continental shelf. Important area for polar bear, marine mammals, overwintering fish.
Barrier Island (AR15)	Undecided	Excellent example of barrier islands and lagoons. Protected coast expected to be modified in near future.
Point McIntyre (AR10)	Undecided	Important and well-researched waterfowl nesting area.
Prudhoe Bay (AR09)	0.4-2	Site should contain a control area of undisturbed coastal wet tundra and an area where modification has occurred. Purpose of site is to evaluate effects of oil exploration.
Howe Island (AR07)	Undecided	Natural and modified protected coast and delta. Barrier island, continental shelf and ice features.
Jago R. (AR03)	1620	Primary importance terrestrial but coastal lagoons important staging and migration habitats for waterfowl.
Beaufort Lagoon (AR02)		Large invertebrate population and abundant char, whitefish and grayling. Seals and Arctic fox numerous. Polar bear denning.

[1]Data from Underwood (1977)
[2]Assigned numbers are from Underwood 1977. See Figure 3.7-4

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CHAPTER 4
TERRESTRIAL PLANTS AND ANIMALS

This part of Volume 3A summarizes existing information on the plants and animals of the onshore or coastal zone of the Beaufort Sea-Mackenzie Delta region. The region includes the coastal area extending from the Yukon-Alaska border in the west, through to Cape Parry in the east and approximately Arctic Red River to the south (Figure 4-1). For certain key species which migrate into and out of the region (eg. Porcupine caribou) the area covered is extended. Separate sections provide the most relevant information on the terrestrial mammals, birds, fish, and lower trophic levels, while Section 4.6 reviews the terrestrially based resource harvesting activities of people living in the region.

Information presented here and in Chapter 2 of this volume (Terrestrial Physical Environment) forms part of the background for assessing the potential impacts of shorebased facilities and activities associated with hydrocarbon production and transportation in the region (Volume 4). Since the pipeline corridor extends into the onshore or coastal zone, there is a necessary duplication of some of the information presented in the following sections and Volume 3C, which describes the environment of the Mackenzie Valley.

4.1 TERRESTRIAL MAMMALS

There are at least 33 species of terrestrial mammals known to occur within the Mackenzie Delta and coastal areas adjacent to the Canadian Beaufort Sea east to the Parry Peninsula (Table 4.1-1). The local and regional abundance and distribution of these species varies considerably depending upon habitat availability and access to terrain suitable for various life history phases, such as calving and denning. The following discussion emphasizes those species which are considered important to the subsistence hunting and trapping economy of the Mackenzie Delta and

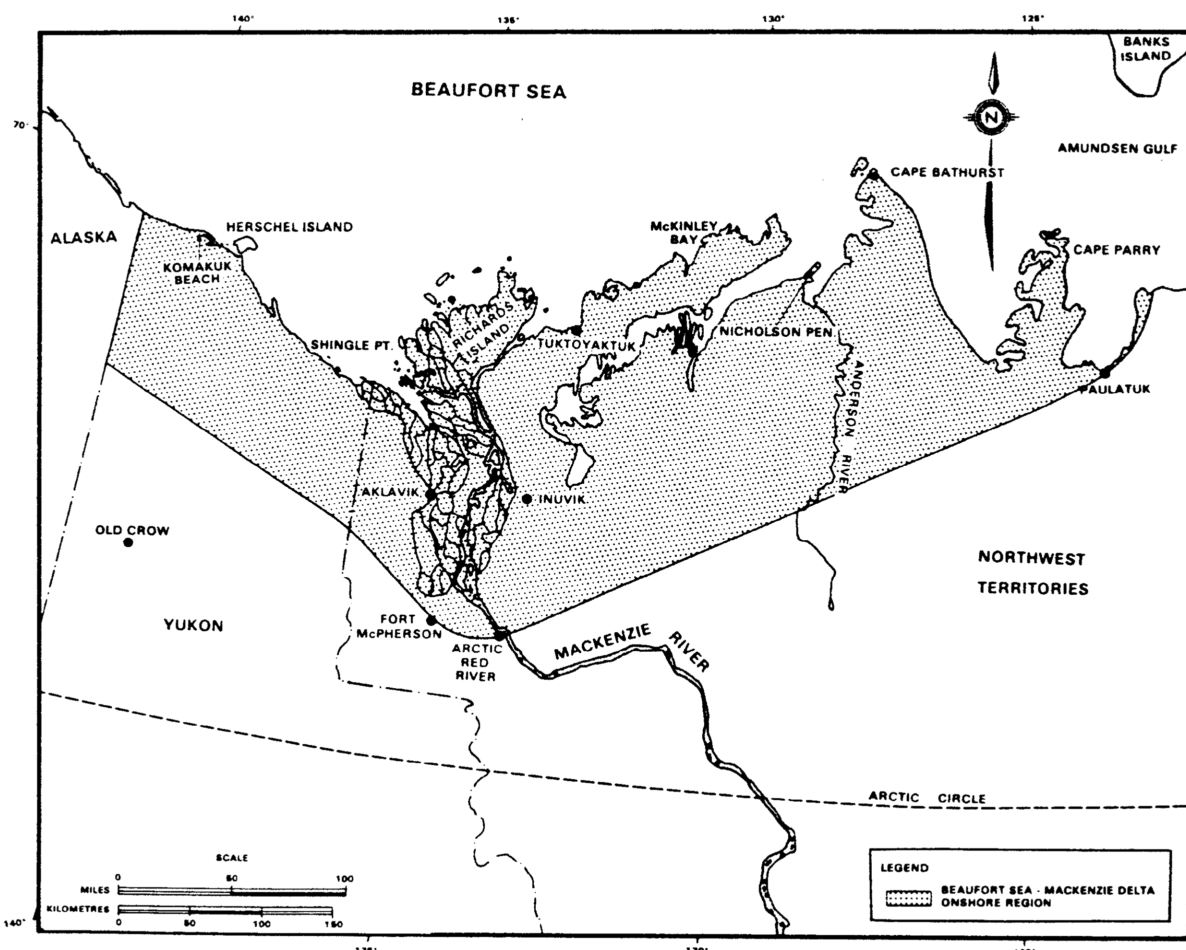

FIGURE 4-1 *Approximate boundary of the onshore coastal zone of the Beaufort Sea-Mackenzie Delta region.*

coastal Beaufort Sea.

TABLE 4.1-1

TERRESTRIAL MAMMALS IN THE MACKENZIE DELTA AND COASTAL BEAUFORT SEA

Common Name	Scientific Name
Masked Shrew	Sorex cinereus
Dusky shrew	Sorex monticolus
Arctic shrew	Sorex arcticus
Collared Pika	Ochotona collaris
Snowshoe hare	Lepus americanus
Arctic hare	Lepus arcticus
Arctic ground squirrel	Spermophilus parryii
American red squirrel	Tamiasciurus hudsonicus
American beaver	Castor canadensis
Northern red-backed vole	Clethrionomys rutilus
Brown lemming	Lemmus sibiricus
Collared lemming	Dicrostonyx torquatus
Muskrat	Ondatra zibethicus
Singing vole	Microtus miurus
Meadow vole	Microtus pennsylvanicus
Tundra vole	Microtus oeconomus
Coyote	Canis latrans
Wolf	Canis lupus
Arctic fox	Alopex lagopus
Red fox	Vulpes vulpes
American black bear	Ursus americanus
Grizzly bear	Ursus arctos
American marten	Martes americana
Ermine	Mustela erminea
Least weasel	Mustela nivalis
American mink	Mustela vison
Wolverine	Gulo gulo
River otter	Lutra canadensis
Lynx	Lynx canadensis
Moose	Alces alces
Caribou	Rangifer tarandus
Dall's sheep	Ovis dalli
Muskoxen	Ovibos moschatus

Sources: Banfield, 1974; Youngman, 1975; Jones, et al 1979

There are at least 33 species of terrestrial mammals known to occur in the Mackenzie Delta and coastal areas of the Beaufort Sea region.

There are at least 33 species of terrestial mammals known to occur in the Mackenzie Delta and coastal areas of the Beaufort Sea region.

A description of the general biology, distribution and abundance of each species in the region is provided. Geographic names referenced in these descriptions are shown in Figure 4.1-1. Biological information was obtained from a review of the existing literature on mammals in the area. The primary sources of information on distribution and abundance included reports prepared by various government agencies and consultants as a result of several pipeline projects proposed for the Mackenzie Valley and Yukon North Slope, and proposals for petroleum exploration and development in the Mackenzie Delta and the coastal Beaufort Sea. However, harvest statistics provide the only source of information on the distribution and abundance of some species, and are, therefore, presented in the absence of other documented information. Resource utilization of all species harvested in the region is addressed in Section 4.6.

4.1.1 UNGULATES

4.1.1.1 Caribou

Three of the five subspecies of caribou currently recognized in Canada frequent the Mackenzie Delta and/or coastal areas adjacent to the Beaufort Sea. The Grant caribou (*Rangifer tarandus granti*) occurs in the northern Yukon and eastern Alaska, while the barren-ground caribou (*R. t. groenlandicus*) inhabits the continental tundra zone of the Northwest Territories and Baffin and Bylot islands. Finally, there is a herd of domesticated European reindeer (*R. t. tarandus*) in the Mackenzie Delta and Tuktoyaktuk Peninsula area (Banfield, 1974). A fourth subspecies, the wood-land caribou (*R. t. caribou*), occurs in the Mackenzie River Valley (Volume 3C).

(a) Reindeer

As caribou had disappeared from the Mackenzie Delta area by the early part of this century (Porsild, 1945), the Canadian government purchased 3,000 reindeer (*R. t. tarandus*) from Alaska to supply the residents of the Delta with a reliable food supplement (Nowasad, 1972). A herd of semi-domesticated reindeer was established east of Inuvik in 1935 (Scotter, 1969) and was managed by various federal agencies until 1974, when it was sold to private interests. Currently owned by Canadian Reindeer (1978) Ltd., the herd has increased in size during recent years, numbering approximately 5,100 in 1973 (Slaney, 1974a), and up to 9,000 to 10,000 by fall round-up in 1978 (Hawley, pers. comm.; Hawkins, pers. comm.). In June 1980 the herd numbered 13,000 animals (Nasogaluak and Billingsley, 1981).

During winter reindeer feed primarily on lichens, but in the spring they forage on cottongrass, sedges and the young leaves of willows and birch. As the vegetation matures over the summer, reindeer are less discriminate in their choice of food (Slaney, 1974a). The major natural predators of reindeer on the summer and winter ranges are the wolf and grizzly bear.

The reindeer herd occurs on the Mackenzie Delta and Tuktoyaktuk Peninsula (Plate 4.1-1). The area designated for its use includes approximately 46,620 km^2 known as the Mackenzie Reindeer Grazing Reserve (Figure 4.1-2). In recent years the herd has been wintered in a broad area west of Eskimo Lakes and Sitidgi Lake, and has calved in the vicinity of Parsons Lake during April and early May (W. Nasogaluak, pers. comm.). By early June the reindeer have been herded by helicopter and/or snowmobile

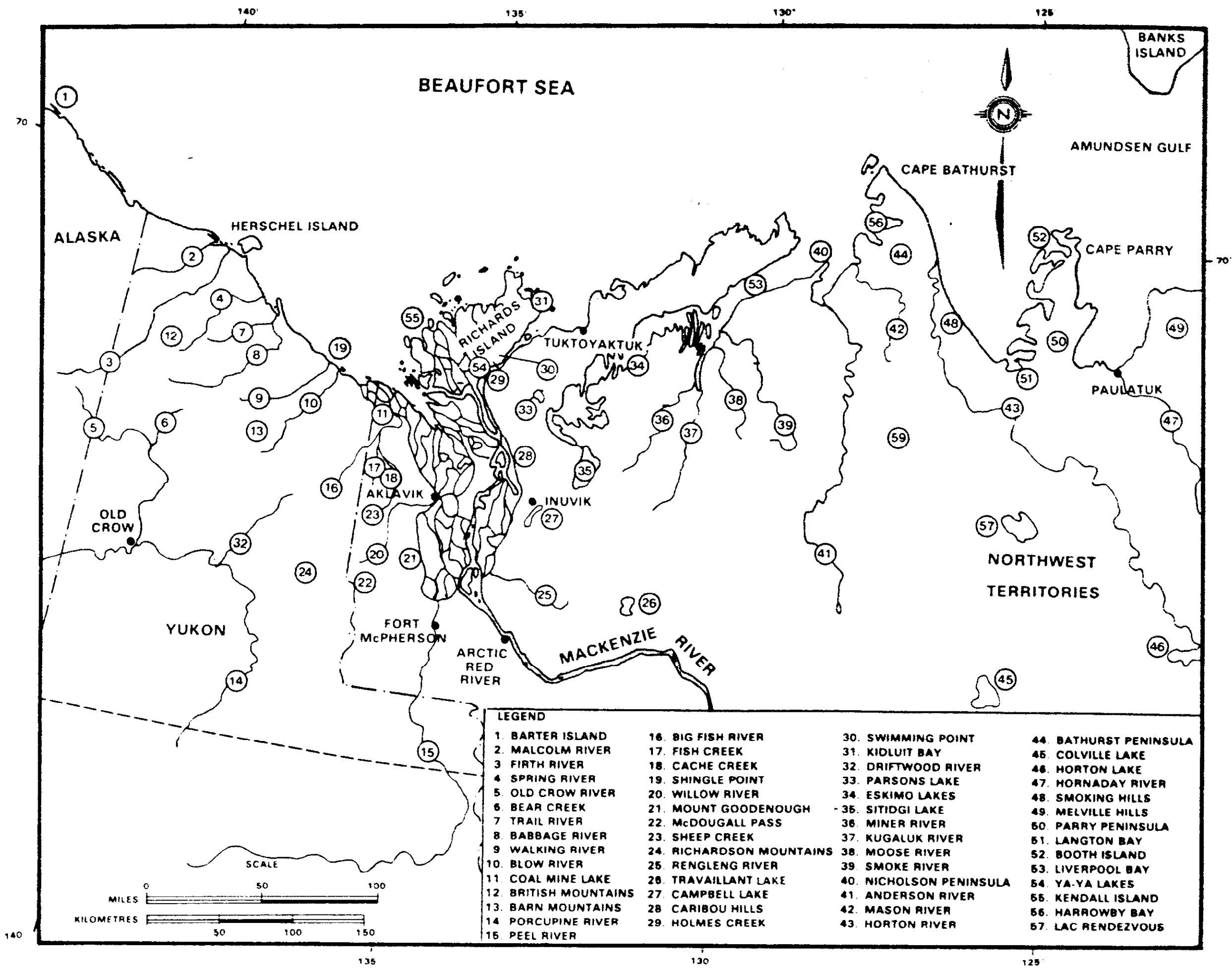

FIGURE 4.1-1 *Geographic names referenced in the descriptions of mammals.*

PLATE 4.1-1 *Reindeer taking shelter from the insects along the water edge. Every spring these domesticated animals are herded by helicopter and/or snowmobile to the summer range on the eastern half of the Tuktoyaktuk Peninsula.*

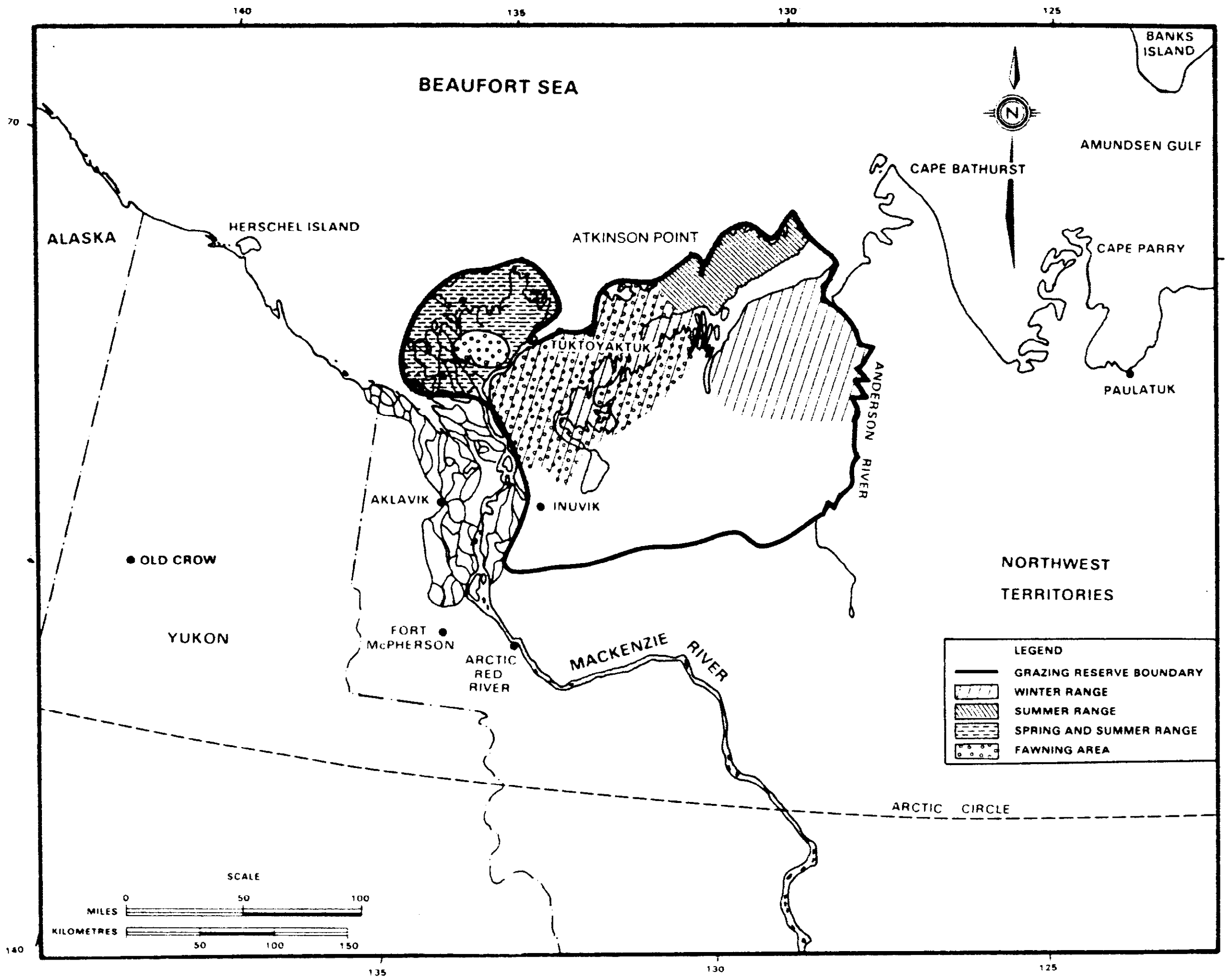

FIGURE 4.1-2 *Mackenzie Reindeer Grazing Reserve; present and future range use (W. Nasogaluak, pers. comm.) During late June the reindeer are corralled at the abandoned DEW site near Atkinson Point in order to count animals, harvest antlers, check their health and carry out other activities.*

to the summer range on the eastern half of the Tuktoyaktuk Peninsula, although a few individuals may remain near Parsons Lake (Hawkins, pers. comm.; Slaney, 1974a). During late June the reindeer are rounded-up and corralled at the abandoned DEW site near Atkinson Point in order to ear-tag the year's crop of animals, to carry out castrations so that steers will be available for subsequent slaughter, to harvest antlers, to count animals, and to check on the general health of the herd (Nasogaluak and Billingsley, 1981). Richards Island was used as the primary summer range for the herd until the early 1960's, but overuse of northern areas of the range eventually forced the herders to abandon it (Cody, 1963). However, Richards Island could be used again as either summer (Slaney, 1974a) or winter range in the future (Hawkins, pers. comm.). In October, the herd is moved westward back to the winter range. A second round-up occurs in February at which time the major slaughter of animals for market takes place (Nasogaluak and Billingsley, 1981).

A few feral animals may occur on Richards Island (Slaney, 1974a) and in the Caribou Hills (Prescott et al., 1973a) during summer, although their numbers are probably small. For example, fewer than 150 reindeer were estimated to occur on the northwest coast of the island in 1973 (Slaney, 1974a). Their winter distribution is less well known, although they have been observed on northern Richards Island during March 1972 and April 1973 (Slaney, 1974a). Some feral reindeer may also be part of a population of 1,000 to 2,000 caribou (undetermined subspecies) that summer in the vicinity of Eskimo Lakes and winter near Travaillant Lake (Prescott et al., 1973a; Watson et al., 1973).

(b) Barren-ground and Grant Caribou

Barren-ground caribou (*R. t. groenlandicus*) of the Bluenose herd occur to the east of the Mackenzie Delta, while Grant caribou (*R. t. granti*) of the Porcupine herd occupy areas to the west (Figure 4.1-3).

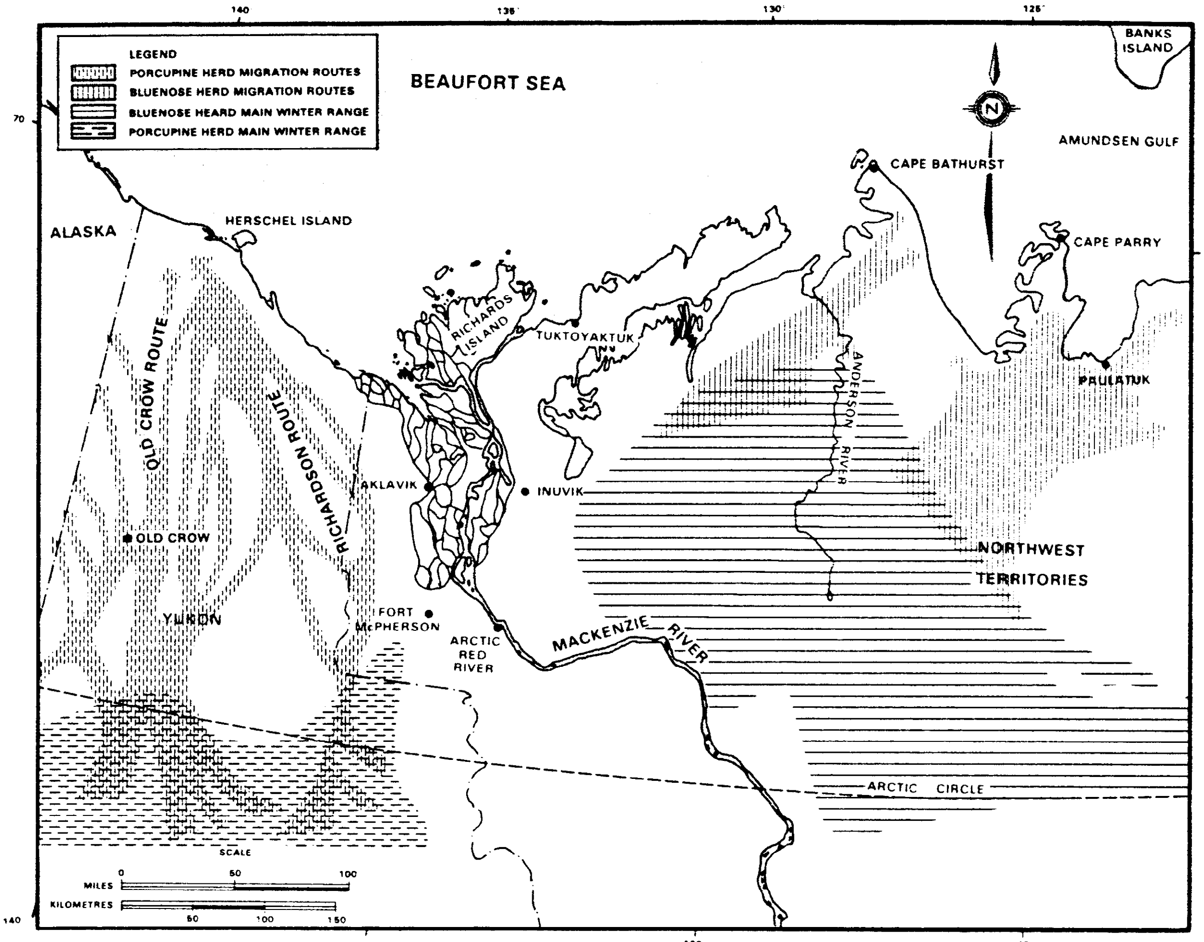

FIGURE 4.1-3 *Caribou winter range and spring migration routes (Hawley et al., 1976; Foothills Pipe Lines (Yukon) Ltd., 1978a, b). Both the Porcupine herd and the Bluenose herd are noted for their long distance migrations from wintering ranges in the northern boreal forests to summer ranges in coastal tundra areas.*

These caribou are noted for their long distance migrations from wintering ranges within the northern boreal forests to summer ranges in coastal tundra areas. They typically concentrate in large numbers during late winter (immediately prior to spring migration), mid summer (including shortly after the calving period), and fall (prior to migration and the rutting period) (Banfield, 1974).

The habitat requirements of caribou change seasonally and are associated with, and reflected in, changes in diet. During the winter the caribou usually occur within the mature boreal forest (Banfield, 1974) where they forage on lichen and moss undergrowth (Thompson and McCourt, 1981). The edges of frozen lakes are commonly used for sunning during winter (Banfield, 1974). In spring the proportion of mosses and lichens in their diet declines and by mid summer such vegetation contributes only a small part to the diet. Sedges and shrubs (primarily willow species) become more important during the period from spring migration to late summer. For example, Thompson and McCourt (1981) found that cotton grass (*Eriophorum* spp.) comprised the bulk of the diet of caribou of the Porcupine herd during spring migration and calving, while the leaves of deciduous shrubs constituted nearly the entire diet during the post-calving and mid summer periods, and about 20% of the late summer diet.

Caribou in this region calve from late May through early June, and rut from mid September through October. Females do not usually breed until at least 28 months of age, and frequently not until 40 months (Skoog, 1968). Approximately 80% of the adult females in the caribou population typically produce one calf each year, with the result that calves typically represent 26 to 35% of the population in a herd with a sex ratio of 1 male:2 females. Recruitment represented by calves which survive until one year of age may be in the order of 15% of the caribou population, although it is often lower (Thompson et al., 1980).

(c) Bluenose Caribou

The range of the Bluenose herd encompasses mainland areas of the Northwest Territories between the Coppermine and Mackenzie rivers north of Great Bear Lake (Figure 4.1-3) (Hawley et al., 1976). Several studies during the past 25 years have estimated the size of this herd. Estimates include 35,000 to 40,000 in the 1950's (Kelsall, 1968); 39,900 in the mid 1960's (Hawley and Pearson, 1966); 19,000 in 1967 (Thomas, 1969); 92,000 in 1974 (Hawley et al., 1976); 42,000 in March 1977 (Wooley and Mair, 1977); 33,000 in June 1978 and 37,000 in June 1979 (Brackett et al., 1978, 1979); 58,000 in March 1980 and 38,000 in February 1981 (Carruthers and Jakimchuk, 1981). This herd is considered to be stable presently at about 40,000 animals (D. Heard, pers. comm.).

The most frequently used winter range of the Bluenose herd is located between the Kugaluk River and Horton Lake and along the northeast shore of Great Bear Lake (Figure 4.1-3). In the early winter of 1974-75, Hawley et al. (1976) reported sighting more than the usual number of caribou of the Bluenose herd at the western-most margin of their winter range adjacent to the Mackenzie River near Travaillant Lake. The reports included an estimated 15,000 to 20,000 caribou in the Miner and Kugaluk river area east of Inuvik. In 1980 and 1981 the western limit of the winter distribution of the Bluenose herd extended to the Kugaluk and Mackenzie rivers, although caribou density in these areas was very low in comparison to the density further east (Carruthers and Jakimchuk, 1981). Surveys conducted in the winter of 1976-77 by Wooley and Mair (1977), however, revealed highest densities of wintering caribou north of Colville Lake and very few animals west of the Miner River. In general, the winter range surveys conducted between 1966 and 1981 indicate that the forested area north of the Hare Indian River and west of the Horton River is the largest and most consistently used winter range of the Bluenose caribou herd (Carruthers and Jakimchuk, 1981).

Coastal areas are also used regularly by wintering caribou. Hawley et al. (1976) stated that residents of Paulatuk reported a "goodly number" of caribou wintering on the coast in 1973-74 (particularly on the Parry Peninsula), and they had observed similar numbers there every year.

In addition, some barren-ground caribou may be included within a group of caribou that winter near Travaillant Lake and summer near Eskimo Lakes. This group has been estimated to number 1,000 to 2,000 animals, and may also include woodland caribou and feral reindeer (Prescott et al., 1973a).

Although the spring migration may begin as early as mid to late February, it usually begins in March or April (Hawley et al., 1976). Migration corridors extend from the winter range to calving grounds on the Bathurst Peninsula, in the Melville Hills, and in the vicinity of Bluenose Lake (Figures 4.1-3, 4.1-4). Calving occurs from late May to mid June. In 1975 most of the caribou which calved on Bathurst Peninsula did so north of Harrowby Bay and the Old Horton River channel, while only a few calved in the Smoking Hills. In addition, some caribou probably calve on the Parry Peninsula and in the vicinity of Paulatuk as indicated by numbers observed in these areas during late April (Hawley et al., 1976; Decker, 1976).

Post-calving aggregations probably occur in the vicinity of calving areas, such as on the Bathurst Peninsula and possibly near Paulatuk in the coastal Beaufort region. In 1975 post-calving caribou travelled west of the Horton River toward the Eskimo Lakes in July and August (Hawley et al., 1976). Hawley et al. (1976) also reported that there were usually large numbers of caribou along the coast east of the Horton River during August. However, during August 1975 there were large numbers scattered between the Anderson and Horton rivers north of Lac Rendezvous and south of the Old Horton River Channel, but few in coastal areas.

Very little information is available regarding the fall migration of the Bluenose herd but migration probably occurs along the routes indicated in Figure 4.1-5. Migration within the coastal Beaufort region would involve caribou that winter in the Kugaluk and Miner river drainages. In 1974 the fall migration to this area included approximately 15,000 to 20,000 caribou (Hawley et al., 1976).

(d) Porcupine Caribou

The size of the Porcupine caribou herd has fluctuated during the recent past. For example, a period of relatively low numbers during the early 1950's was followed by an increase to an estimated 110,000 animals (excluding calves) in June 1961 (Skoog, 1968). In 1964 Lentfer (1965) estimated the population size of the herd to be 140,000, while estimates from photographs taken in 1972 (Le Resche, 1975), 1977 (Bente and Roseneau, 1978) and in 1979 (Whitten and Cameron, 1980) ranged from approximately 98,000 to 110,000 caribou. At the present time this population is considered to be relatively stable (A. Martell, pers. comm.). A photo census of the Porcupine herd is planned for 1982 by the State of Alaska.

Historical and recent winter distribution patterns of the Porcupine herd have remained similar (Foothills Pipe Lines (Yukon) Limited, 1978a). The major wintering area is located in the central Yukon within the upper Peel River and upper Porcupine River drainages. Another smaller, but also important, wintering area lies within the Chandalar and Sheenjek river drainages in Alaska. Although the majority of the

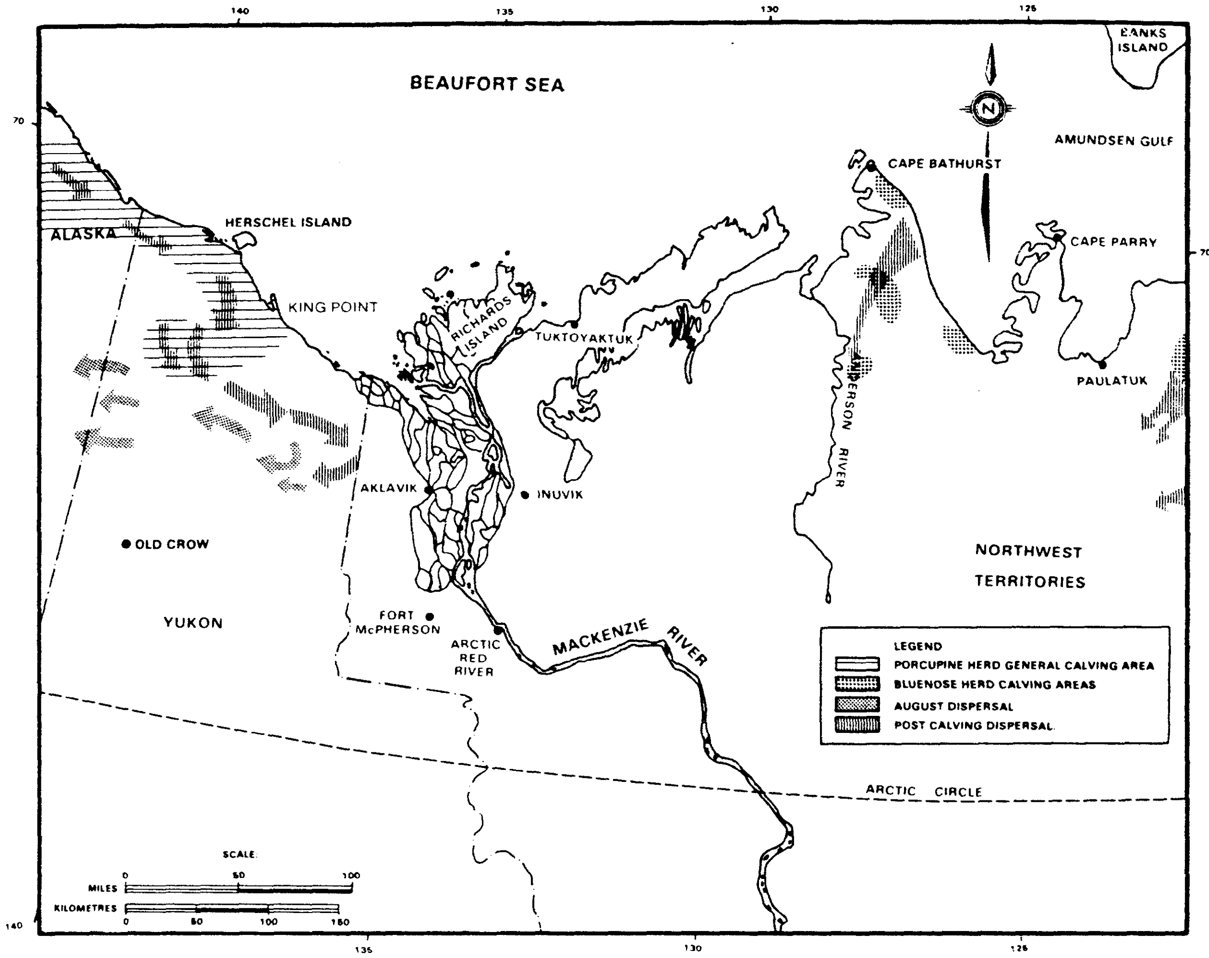

FIGURE 4.1-4 *Caribou calving areas, post calving and August dispersals (Roseneau et al., 1975, Hawley et al., 1976). The calving areas of both major herds of Caribou are located mainly on upland areas near the coast, along the Alaska-Yukon coast for Porcupine caribou, and on the Bathurst Peninsula for Bluenose caribou.*

herd winters south of coastal areas adjacent to the Beaufort Sea, a variable number of caribou may winter on the North Slope of the Yukon and eastern Alaska. The largest number of caribou that have been reported to winter on the slope was 5,000 (or about 5% of the herd) in 1973-74 (Foothills Pipe Lines (Yukon) Limited, 1978a). However, the average number wintering on the North Slope between 1971 and 1978 was less than 1% of the herd (Foothills Pipe Lines (Yukon) Limited, 1978a). The local winter distribution of caribou on the North Slope indicates that caribou prefer the foothills above the adjacent Coastal Plain (Thompson et al., 1978). The upland areas are more likely to be snow-free and to possess greater lichen cover, the major item in the winter diet of caribou.

Recent information on routes and timing of spring migration of the Porcupine herd has been reviewed and expanded by Foothills Pipe Lines (Yukon) Ltd. (1978b). That report was based on data reported by Calef and Lortie (1971, 1973), Pendergast (1973), Doll et al. (1974), Jakimchuk et al. (1974), McCourt et al. (1974), Hoffman (1975), Roseneau and Curatolo (1975, 1976), Roseneau et al. (1975), Curatolo and Roseneau (1977), Surrendi and DeBock (1976), and Bente (1977). Results of a survey of the 1978 spring migration were also presented and compared. Documented information on the spring migration of this herd suggests that there are two relatively consistent routes: the Richardson Route and the Old Crow Route (Figure 4.1-3) (Jakimchuk et al., 1974).

Spring migration along the North Slope can be expected to begin between mid April and early May, and routes across this area are generally within the Barn and British mountains or foothills. West of the Firth River, however, caribou move onto the Coastal Plain. During spring migration the number of caribou that move across the North Slope is highly variable, depending on the location of the wintering areas and the number of caribou using the Richard-

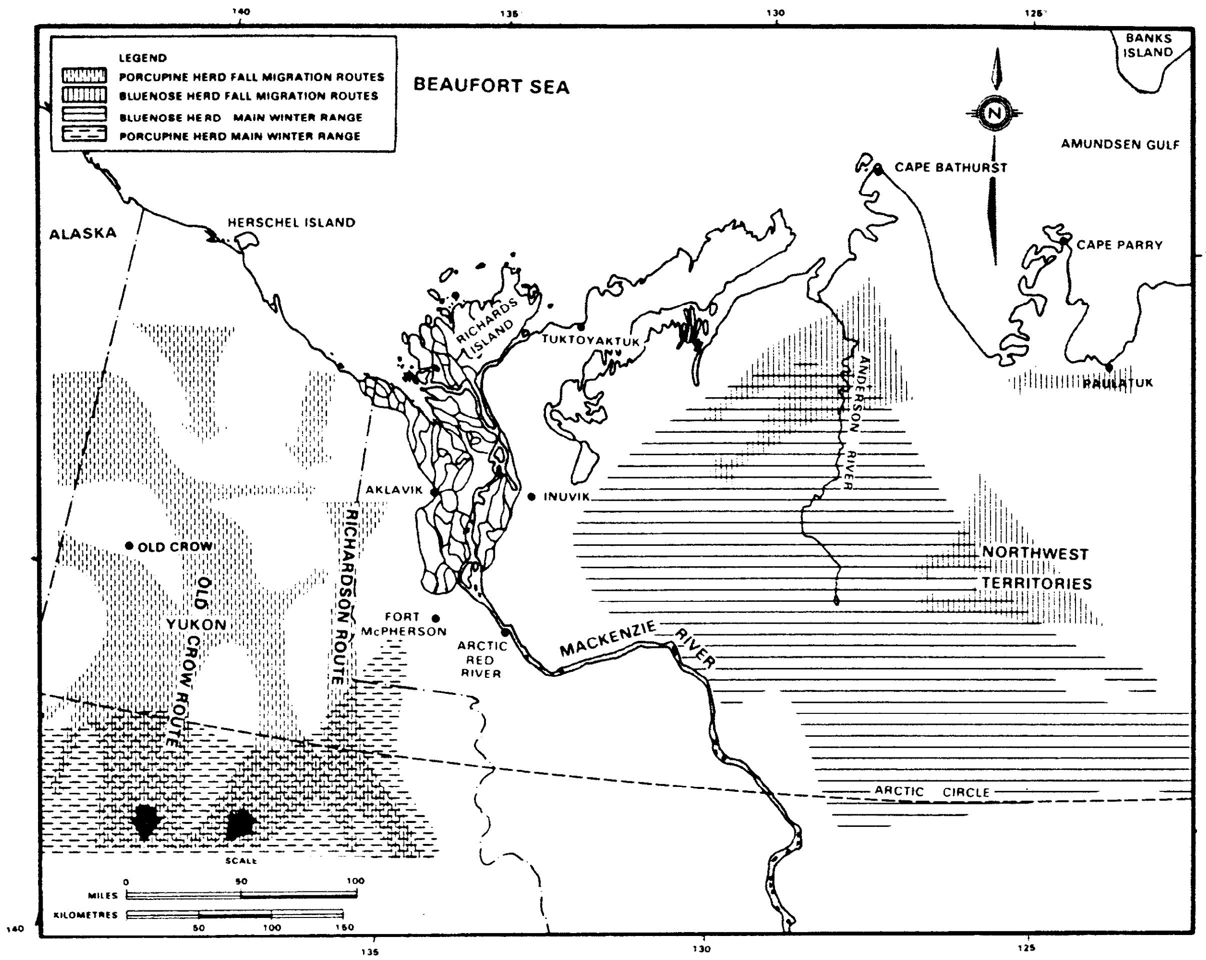

FIGURE 4.1-5 *Caribou fall migration routes and winter range (Hawley et al., 1976; Foothills Pipe Lines (Yukon) Ltd., 1978a, 1979b)*

son Route. Most caribou that use the Old Crow Route move into Alaska before reaching the North Slope. Non-calving caribou, which include bulls, yearlings, and non-pregnant females, tend to remain segregated from the calving portion of the herd but follow the same general spring migration route. The number of caribou following the Richardson Route during the spring has varied from 4,200 to 60,000 during recent years (Foothills Pipe Lines (Yukon) Limited, 1978b).

Calving usually occurs during the period from late May through mid June with peak calving activity in early June (Thompson et al., 1978). Calving occurs in both the Yukon and Alaska, and is concentrated along the North Slope from the Babbage River in the Yukon to the Canning River in Alaska (Figure 4.1-4). In five of the years during the period 1971 through 1977, at least 50% of the pregnant cows calved in the Yukon (Curatolo and Roseneau, 1977; Bente, 1977). However, this proportion has ranged from virtually none in 1974 and 1975 (Roseneau and Curatolo, 1975, 1976) to almost 100% in 1977 (Bente, 1977).

Surrendi and DeBock (1976) suggested that the location of specific calving grounds used from year to year depends on the chronology of migration, and on the consistency of use and location of wintering areas. For example, during years when the amount of snow cover permits early spring migration, calving will probably occur further west along the Alaskan coast. In contrast, calving probably occurs primarily in the Yukon during years when conditions inhibit early migration.

Although the calving locations may vary from year to year, caribou appear to prefer well-drained and snow-free areas (Lent, 1964, cited in Curatolo and Roseneau, 1977). Studies conducted since 1971 have indicated that caribou tend to select calving grounds in the rolling foothills between the rugged mountains to the south and the snowbound lowlands of the

Coastal Plain to the north (Curatolo and Roseneau, 1977). Curatolo and Roseneau (1977) found that upland areas (180 m to 610 m ASL) were dominated by *Eriophorum* spp. tussock communities which provide an early source of green vegetation. These calving areas are also characterized by having early snow-melt and relatively low predator densities, which aid calf survival (Thompson et al., 1978).

Surveys conducted during 1972, 1973, 1974 and 1977 (McCourt et al., 1974; Doll et al., 1974; Roseneau et al., 1975; Bente, 1977) indicate that caribou also calve on the Coastal Plain, and that the distribution of cows may extend right to the beach. Nevertheless, the largest calving concentrations usually occur throughout the aforementioned foothills and at the junction of this area with the Coastal Plain. Surrendi and DeBock (1976) found that the calving area between the Malcolm and Spring rivers had mineral licks which were used extensively by subadults and lactating cows.

As calving progresses during June, the caribou tend to form nursery bands consisting of cows with calves and yearlings. They usually move slowly westward toward Alaska, and northward toward the coast as it gradually becomes free of snow (Doll et al., 1974; Bente, 1977). Bull caribou do not usually merge with the cow/calf segment of the herd until late June or early July (Martell, pers. comm.). The herd gradually moves west to the Canning River-Barter Island area of the Alaskan North Slope, with most caribou having left the Yukon by the end of June. Large post-calving aggregations (Plate 4.1-2) occur in the Alaska coastal region between the Canning River and Barter Island between June 30 and mid July each year (Roseneau and Curatolo, 1975; Curatolo and Roseneau, 1977; Bente, 1977).

Immediately following the formation of post-calving aggregations, the caribou begin an eastward migration and re-enter the Yukon in early July along a corridor between the southern edge of the Coastal Plain (200 m contour) and the divide of the British Mountains (Figure 4.1-4). They continue to move eastward across the North Slope toward the headwaters of the Driftwood River in the northern Richardson Mountains, generally arriving by late July. Routes are usually restricted to the upland areas of the British and Barn mountain ranges, as the caribou tend to avoid the flat wet low-lying Coastal Plain to the north and Old Crow Flats to the south (Thompson et al., 1978).

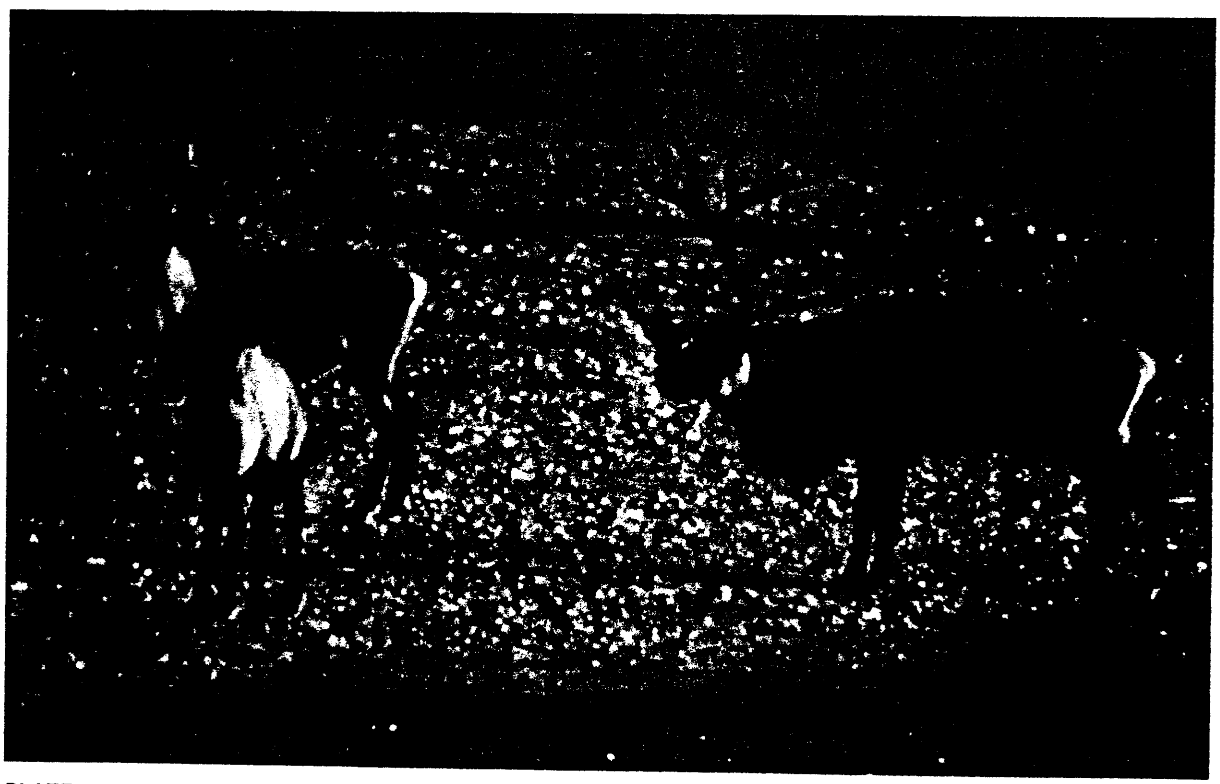

PLATE 4.1-2 *The Porcupine caribou herd, which spends most of its time in the North Yukon, is considered to have a relatively stable population at the present time, estimated at between 98,000 and 110,000 caribou. (Courtesy G. Calef, Northwest Territories Wildlife Service).*

By late July or early August the herd begins to disperse from the northern Richardson Mountain-Driftwood River region and moves westward to Alaska. The caribou move through a broad corridor bounded on the north by the southern slopes of the British Mountains and on the south by the Old Crow Range (Jakimchuk et al., 1974; McCourt et al., 1974; Doll et al., 1974; Roseneau and Curatolo, 1975; Roseneau et al., 1975) (Figure 4.1-4). Although this dispersal does not usually occur along the North Slope, a few groups move northward to the coast in most years. For example, about 2,000 caribou moved to the Coal Mine Lake area and the mouth of the Blow River in 1971 (Jakimchuk et al., 1974), while a herd of about 2,000 individuals was located near Shingle Point in 1972 (McCourt et al., 1974).

The southward fall migration may begin as early as the second week of September, and follows both the Old Crow and Richardson routes (Figure 4.1-5) (Jakimchuk et al., 1974; McCourt et al., 1974). However, the timing of initiation of the southward migration may vary considerably between years and is probably related to the occurrence of the first major snow storm (Roseneau and Curatolo, 1975). Since very few caribou are typically located on the North Slope during late summer, little activity occurs there during fall migration. However, occasionally caribou have been reported to remain at or return to the North Slope. For example, approximately 4,000 caribou were located in the uplands bordering the Mackenzie Delta between Big Fish River and Shingle Point in November 1973 (Doll et al., 1974).

4.1.1.2 Moose

Moose are represented by a single subspecies (*Alces alces andersoni*) in the Northwest Territories (Banfield, 1974). They are generally solitary, commonly ranging throughout the boreal forest and occasionally the forest-tundra transition zone or even tundra areas (Kelsall, 1972). Moose are widely distributed in climax and sub-climax boreal forest habitats which provide adequate forage and shelter (Le Resche et al., 1974). The twigs of shrubs, especially willow, form the bulk of their diet, except during summer when a substantial portion of the forage consists of rooted aquatic vegetation. Early successional-stage vegetation, such as that found in riparian areas or in recently burned areas, provides good quality winter range. Riparian habitat is important to moose owing to its relative spatial and temporal stability. Animals associated with such habitat often develop local migration traditions and come to river-edge habitat from adjacent uplands to overwinter (Plate 4.1-3).

PLATE 4.1-3 *A bull moose moving through lowland country. (Courtesy, McCourt Management Ltd.). These are generally solitary, commonly ranging throughout the boreal forest and occassionally to tundra areas.*

Winter habitat is extremely important for moose because during this period they exist on a negative energy balance (Gasaway and Coady, 1974) and alternative habitat in a given region may be unavailable. If suitable winter range is limited, modest concentrations of moose may occur.

Moose breed annually from about the age of 30 months, although some yearlings have been known to breed. Twinning is relatively common, particularly in expanding populations. The average annual recruitment of yearling moose usually falls between 12 and 25%, probably averaging 15 to 17% (Peterson, 1955).

Although moose were historically plentiful in the Mackenzie Delta (Clarke, 1944), heavy hunting pressure in recent years has drastically reduced this population (Prescott et al., 1973b). The Delta has been classified as poor moose winter range (Class 3) because of the harsh environment characterized by frequent flooding, deep snow and a lack of shelter from the prevailing winds (Prescott et al., 1973b). However, there is one area (Class 3) of local importance in the vicinity of the Delta along Holmes Creek and the lowlands adjacent to the East Channel of the Mackenzie River (Prescott et al., 1973b).

In general the uplands along the east and south sides of the Mackenzie Delta provide insignificant (Class 4) moose wintering habitat. Some streams along the northeast and southeast portions of Campbell Lake, and the lower portions of the Rengleng River were rated as poor moose wintering range (Class 3) (Prescott et al., 1973b). A moose survey along the proposed route of the Dempster lateral gas pipeline in this area indicated an observed moose density of 1.92/100 km^2 (Foothills Pipe Lines (Yukon) Limited, 1979a).

Moose habitat is more limited west of the Mackenzie Delta along the Yukon North Slope. During spring moose follow river valleys to the Arctic Coastal Plain and remain there until late September (Ruttan, 1974a). Poor winter range (Class 3) occurs along several river valleys including Cache Creek, Blow River, Walking River, Babbage River, Trail River, Crow River, and upper portions of the Firth River (Prescott et al., 1973b), but small areas of Class 2 (fair) winter range occur along the Willow River and Aspen Creek. Prescott et al. (1973b) suggest that even low quality habitat (including Class 3 areas) may become extremely important to moose if higher quality alternative areas are unavailable.

The quality of moose winter range is also generally poor east of the Mackenzie Delta. Class 3 range occurs along the Miner, Kugaluk, Moose, Smoke, and Anderson rivers (Prescott et al., 1973b). Moose are also reported to use the willow growth along the lower Mason and Horton rivers during the summer, although they move upstream to forested regions in winter (RRCS, 1972). Moose are not common on the Anderson River delta, but have been observed as far north as Nicholson Peninsula, Cape Bathurst and Langton Bay (Zoltai et al., 1979).

4.1.1.3 Muskoxen

Muskoxen (*Ovibos moschatus*) are known to occur in Canada, Alaska, and Greenland. The majority of the Canadian population inhabits the Arctic Archipelago, but substantial numbers occur on the Canadian mainland, particularly in the Thelon River Game Sanctuary and Bathurst Inlet region (Tener, 1965). Their distribution in the mainland areas of the Beaufort Sea region is shown in Figure 4.1-6.

In summer, muskoxen occur in lowland areas where streams, ponds, and lakes permit maximum growth of vegetation. Wintering areas are usually located in higher terrain where winds tend to keep areas snow-free (Lent, 1971). The diet of this species consists primarily of sedges, willow and mosses (Fischer and Duncan, 1976).

Breeding may begin in late June or early July, and lasts until October, although activities usually peak in August (Tener, 1965; Gray, 1973; Hubert, 1974). The calves are born in April and May. Twinning seldom occurs. In general, females calve once every two years (Tener, 1965). Wolves are the major predator of muskoxen, while starvation during adverse climatic conditions is also a common cause of natural mortality (Gray, 1973; Miller and Russell, 1974).

The small number of muskoxen observed in the northern Yukon are probably stray animals from the population on the North Slope of Alaska. The Alaskan muskoxen were transplanted to Barter Island and Kavik camp in 1969 and 1970 (Roseneau and Warbelow, 1974). Surveys conducted in 1972 indicated that from one to possibly three lone adult muskoxen were present on the Yukon North Slope (Roseneau and Stern, 1974). A group of six were reported near the Spring River in 1973 (Roseneau and Warbelow, 1974).

Muskoxen also occur within the watersheds of the Horton and Hornaday rivers (Plate 4.1-4). Major muskoxen areas were found on the tundra southwest, south and southeast of Paulatuk (Jacobson, 1979). Kelsall et al. (1970) estimated that between 425 and 625 muskoxen were present in the area south of Paulatuk and Darnley Bay, while the Land Use Information Series (Fisheries and Environment

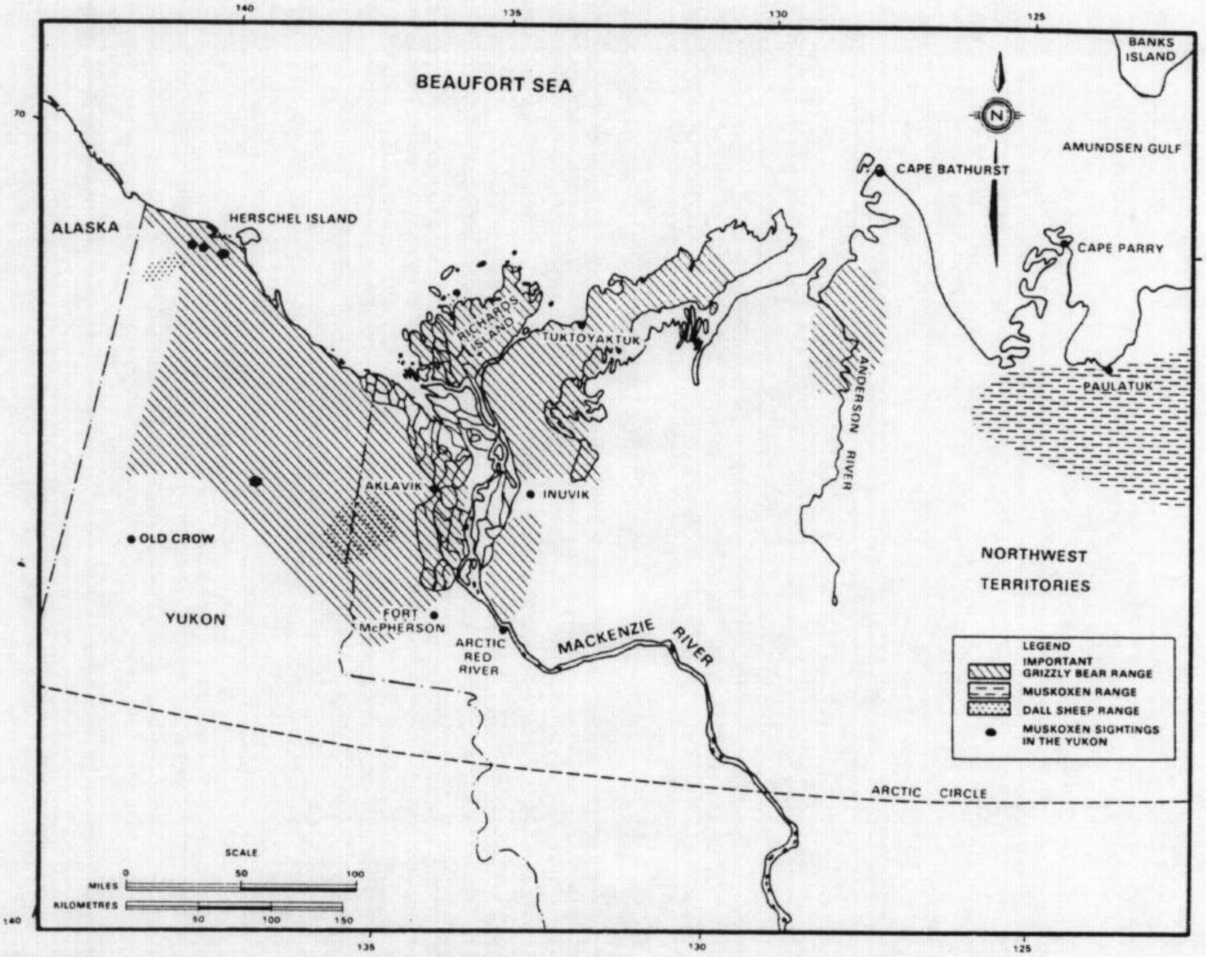

FIGURE 4.1-6 *Grizzly bear, muskoxen and dall sheep ranges (based on sources in text)*

PLATE 4.1-4 *Large numbers of muskoxen are found in the tundra southwest, south and southeast of Paulatuk. (Courtesy, D. Karasiuk).*

Canada, 1977) states that over 1,000 muskoxen occupy the watersheds of the Horton and Hornady rivers. In a study area between the Coppermine and Anderson rivers north of Great Bear Lake, Carruthers and Jakimchuk (1981) estimated the muskoxen population at approximately 6,700 in March 1980. Muskoxen within this area are generally distributed in the area south of Paulatuk from the Horton River to the foothills of the Melville Hills, in the area around Horton Lake, Brock River and the headwaters of the Rae-Richardson rivers. Muskoxen are present on the Parry Peninsula in summer and may occur as far north as Letty Harbour (W. Spencer, pers. comm., cited in Canadian Marine Drilling Limited, 1979). Spencer (pers. comm.) reported seeing 75 animals north of Langton Bay in June 1978, and Spencer (1980) and Carruthers and Jakimchuk (1981) observed similar numbers on the Parry Peninsula in March 1980.

4.1.1.4 Dall's Sheep

Dall's sheep (*Ovis dalli*) occur in the mountains of northwestern British Columbia, the Yukon, Alaska, and western Northwest Territories. In coastal areas adjacent to the Beaufort Sea, sheep occur in the northern Richardson Mountains and in the British Mountains.

Sheep winter range is characterized by well vegetated plateaus or slopes that have minimal snow depth as a result of exposure to prevailing winds, and are associated with escape terrain such as canyons, steep slopes, or cliffs. Summer range varies from high talus ridges to low cliffs along streams, and is also associated with escape terrain. Mineral licks are important features of the summer range, and large concentrations of sheep may occur at these sites. However, winter range and lambing areas are considered to be the most important habitats for Dall's sheep. This species has a relatively low reproductive potential. Sheep of both sexes may be sexually mature by 18 months of age (Nichols, 1978). Females usually produce a single lamb at the age of 3, and twinning is rare. Lambing occurs during late May and early June after a gestation period of approximately 171 days (Nichols, 1978).

A relatively large population of Dall's sheep occurs in the Mount Goodenough area of the Richardson Mountains (Figure 4.1-6). Feist et al. (1974) estimated the population to total 400 to 600 sheep. During a survey conducted in November 1973, 141 sheep were observed in the immediate vicinity of Mount Goodenough, and another 60 were scattered throughout the Bear, Cache, Fish and Sheep creek drainages (Feist et al., 1974). Dall's sheep are also suspected to winter in the area between Fish Creek and the Bell River (Feist et al., 1974). This species was not observed in the timbered lowlands and lower slopes between Mount Goodenough and the Mackenzie Delta during surveys in November 1973 (Feist et al., 1974). Mineral licks used by sheep were reported at locations on Bear Creek and near the headwaters of Grizzly Creek. Watson et al. (1973) reported that the major wintering area for the Mount Goodenough sheep population is in the eastern portion of the mountains north of McDougall Pass where high winds keep exposed plateaus and slopes relatively snow-free. Feeding areas are in close proximity to escape terrain. In summer, there is a general movement of this population to areas at least as far west as the Bell River (Watson et al., 1973).

Another population of Dall's sheep occurs in the mountainous areas of the Firth River drainage (Figure 4.1-6). In 1971, 44 sheep were observed in this area (Jakimchuk et al., 1974), while Watson et al. (1973) reported approximately 50 to 75 sheep. The latter authors suggested that the sheep they observed were part of a herd which extends from the Brooks Range in Alaska. Watson et al. (1973) noted that good winter range for sheep was available on the western side of the Firth River.

4.1.2 BEARS

4.1.2.1. Grizzly Bear

Barren-ground grizzly bears (*Ursus arctos*) usually occupy zones of low relief and open tundra north of the boreal forest, although they may also occur occasionally in the forest-tundra transition (Watson et al., 1973). The barren-ground grizzly bear is considered rare by the IUCN (Goodwin and Holloway, 1972) and a "species at risk" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This committee is described in more detail in Section 4.2.

The behavior, distribution and movements of grizzly bears are closely associated with their diet and the availability of food. They are omnivorous, feeding on roots, berries, herbs, ground squirrels, fish and ungulates. In mountainous regions grizzlies make seasonal shifts in altitude primarily to take advantage of vegetation producton in different zones (Miller and Barichello, in prep.). Tundra-dwelling bears occupy low-lying coastal areas in June and ascend into the higher hilly areas a few kilometres inland during July, August and September (Pearson and Nagy, 1976). The seasonal distribution of grizzly bears on Richards Island was found to follow the above pattern (Slaney, 1974a). For example, occupation of the low-lying marshy areas coincided with the presence of nesting waterfowl and an abundance of sedges and herbs, while presence of bears in upland areas was concurrent with the presence of ground squirrels and berry-producing shrubs (Slaney, 1974a).

Den sites are particularly important to grizzly bears, and the availability of suitable sites can be a potential limiting factor in some areas (Pearson, 1975). Grizzly bears normally den from mid October or November to April or May. During this time, pregnant females produce one to three cubs. Pearson (1972) reported a minimum breeding age of approximately 6 years for females and an average litter of 1.58 for the northern interior grizzly bears in the Yukon.

Grizzly bears were common in the Mackenzie Delta between 1927 and 1935 (Porsild, 1945), but bears attracted to the reindeer herds since 1935 have been destroyed by the herders. Grizzly bear sightings declined to such a degree that a closed season was declared in 1943. Six years later the closure was declared year round. The frequency of grizzly bear sightings increased substantially during the 1950's, the bears either expanding their range or reoccupying areas where they had formerly been eliminated (Macpherson, 1965).

There is currently a relatively large population of grizzly bears in the Delta area (Figure 4.1-6). An estimated 23 animals in 1973, and 15 to 20 bears in 1974 used Richards Island and the adjacent lowlands (Slaney, 1974a). An additional nine grizzlies occurred in the vicinity of Holmes Creek and Parsons Lake in 1973 (Slaney, 1974a). Grizzly bear densities have been estimated at one animal per 106 km^2 on Richards Island (Harding, 1976) and one per 199 km^2 between Sitidgi Lake and Tuktoyaktuk (Pearson and Nagy, 1976).

Between Tuktoyaktuk and Inuvik, bears are known to prefer den sites along lake shores and stream banks having slopes greater than 30° (Pearson and Nagy, 1976). Clarke (1944) reported that the countless cutbanks of the Mackenzie Delta provided suitable sites for grizzly bear dens. Similarly, on Richards Island, this species usually (78%) selected dens in banks of water-bodies with moderate slopes (30% to 50% grade) (Harding, 1976). The soil texture was usually sandy or silty, but was generally consolidated enough to endure at least one season's use. Dens are occasionally reused in subsequent seasons. Den sites on Richards Island and the Tuktoyaktuk Peninsula have been mapped (Slaney, 1974b; Pearson and Nagy, 1976), with no concentrations of den sites being reported. The presence of sufficient alternate habitat for den construction suggests that den sites are not a limiting factor for grizzly bears along the tundra portion of Richards Island and the Tuktoyaktuk Peninsula (Pearson and Nagy, 1976).

Grizzly bear habitat has been rated as Class 2 (common use but less than optimum habitat) from Richards Island and the southern portion of the Tuktoyaktuk Peninsula to Inuvik (Nolan et al., 1973a).

West of the Mackenzie Delta, Class 1 (high use) habitat for grizzly bear occurs in the Richardson Mountains, the Barn Range, and the British Mountains. The Coastal Plain north of these mountain ranges is designated as Class 2 (common use) habitat because bear sightings are infrequent and dens have not been found (Nolan et al., 1973a). Pearson and Goski (1974) reported a density of one bear/65 km^2 on the Arctic coastal plateau of the northern Yukon Territory. Doll et al. (1974) and Ruttan and Wooley (1974) reported an apparent southward shift of this species from the coast during September.

East of the Mackenzie Delta region grizzly bears occur throughout most coastal areas adjacent to the Beaufort Sea. An extensive area in the vicinity of the Anderson River has been given the Class 2 rating (Nolan et al., 1973a) (Figure 4.1-6). These authors also reported that several grizzly bears have been recorded on the Anderson River delta, and that dens have been located along banks of small streams near the Anderson River. Similarly, the banks of the Horton River provide suitable habitat for grizzly bear denning (RRCS, 1972). Grizzly bears occur on the Parry Peninsula and are abundant in the Langton Bay area (W. Spencer, pers. comm., cited in Canadian Marine Drilling Limited, 1979). In addition, Ward (1979) reported one grizzly on Booth Island during a general environmental survey in the spring of 1979.

4.1.2.2. Black Bear

The black bear (*Ursus americanus*) is widely distributed throughout forested lands of North America (Banfield, 1974). Individuals occasionally range out to the open forest-tundra transition, but are rarely found on open tundra. In the Mackenzie Delta region this species is considered uncommon south of the tree line and rare north of tree line (Martell and Casselman, 1975). However, black bears may be extending their range into tundra regions (Jonkel and Miller, 1970). Black bears are more common in the forested areas south of the Mackenzie Delta (Volume 3C). This species does not typically occur along either the Yukon North Slope or coastal areas adjacent to the Beaufort Sea east of the Mackenzie Delta.

4.1.3 AQUATIC FURBEARERS

4.1.3.1 Muskrat

The muskrat (*Ondatra zibethicus*) is the widest ranging of all North American furbearers and is capable of inhabiting diverse environments ranging from drainage ditches along cornfields in temperate regions to glaciolacustrine lakes along the Arctic Ocean. Although muskrats are unable to control habitat water levels like beavers, this species is well adapted to utilize a variety of habitats for lodge construction and to exist on a variety of food items.

Muskrats eat a wide variety of aquatic plants and occasionally carrion. In the Mackenzie Delta and coastal Beaufort region, water horsetail and sedges are the major emergent food species, while submerged aquatic food items consist primarily of pond weed and duckweed. Submerged plants are often used for the construction of pushups (winter feeding huts). Submerged aquatic plants are the most important foods during the winter in standing water bodies but emergent plants are preferred by muskrats during summer and along moving stream channels in winter. The accessibility of aquatic plant species is the most important factor governing their use by muskrats for both food and lodge construction. Owing to its general availability and excellent nutritional value, water horsetail is highly preferred in northern latitudes.

Muskrat houses typically found in marshes in southern regions are almost totally absent in the Mackenzie Delta and coastal Beaufort region. Rather, muskrats dig bank burrows along lakeshores or stream channel margins and often extend their winter range by constructing pushups in small lakes. Pushups are small domes of vegetation built over holes in the ice which enable animals to haul up submerged aquatics and feed without returning to the main house.

In the Mackenzie River Delta severe climatic conditions place restrictions on the suitability of water bodies to support muskrat populations. For example, Stevens (1955) found that optimum winter habitat for muskrats in the Northwest Territories occurred in lakes 2 m deep, while Hawley and Hawley (1974) found that lakes from 1.2 to 3 m deep were optimal in supporting high densities of muskrats. One further requirement for lakes in northern latitudes is steeply sloping banks so that muskrats have ready access from the shore to food supplies in unfrozen portions of the lake.

Muskrats have a high reproductive potential. Females on Old Crow Flats produce an average of more than seven embryos and sometimes produce two litters annually (Ruttan, 1974b). However, the high productivity of this species is offset by high natural mortality (Stevens, 1953).

Muskrats occur at the northern-most limit of their range in the Mackenzie Delta region (Banfield, 1974), with greatest population densities being located in standing-water habitats. The Mackenzie Delta region is well known for its high production of muskrats (see Sec. 4.6.1). Habitat within the Delta proper is considered the best habitat (Class 1) available in the region (Figure 4.1-7) (Dennington et al., 1973). However, within the Delta, habitat varies from optimum in the southwest quarter to least suitable in the northwest quarter (Hawley, 1968). Habitat is much less suitable (Class 3 or 4) in the uplands east of the Delta. Slaney (1974a) found that floodplain lakes near Swimming Point had the highest densities of muskrat pushups, while upland lakes near the Parsons Lake area and on Richards Island had an intermediate number of pushups. In contrast, muskrat habitat in areas east or west of the Mackenzie Delta region is considered either poor or insignificant (Class 3 or 4) (Dennington et al., 1973).

4.1.3.2 Beaver

Beaver (*Castor canadensis*) are widely distributed over North America, and in Canada are found from coast to coast south of the tree line.

Both the physical characteristics and dominant vegetation communities of an area determine its suitability as beaver habitat (Slough and Sadlier, 1977). Although beavers occur in a wide variety of geographical areas ranging from mountains to prairies to boreal forest, there are certain physical environmental constraints to their successful colonization of new habitat. Only slow flowing streams and rivers can be colonized, since fast flowing water may wash away dams and food caches (Standfield and Smith, 1971; Banfield, 1974). Beaver usually live in streams with gradients of less than 6% and are most successful in wide valleys with meandering streams and rivers (Retzer et al., 1956). Marshes and ponds with appropriate food supplies are prime habitats, while creeks and small rivers are often dammed to create ponds (Retzer et al., 1956; Banfield, 1974). Beaver prefer shallow lakes with gently-rising shores that support aquatic and terrestrial vegetation over deep lakes with steep, rocky shorelines (Hall, 1971; Standfield and Smith, 1971). Rivers that have widely fluctuating water levels and those carrying ice which results in significant scouring of shorelines during spring, are considered poor beaver habitat (Nash, 1951). Beaver require relatively deep water so that the pond will not freeze solid during winter thereby blocking access to food caches, and they require stable water levels in order to prevent their lodges from flooding (Plate 4.1-5). Attempts are made to avoid flooding or freeze-out by constructing dams (Retzer et al., 1956). Along the Mackenzie River system beaver are more abundant in bog drainages than in the Mackenzie Delta, since the former are more stable (Novakowski, 1965).

Although beaver will cut and consume virtually every available plant species within their range, they prefer aspen (*Populus* spp.), willow (*Salix* spp.), birch

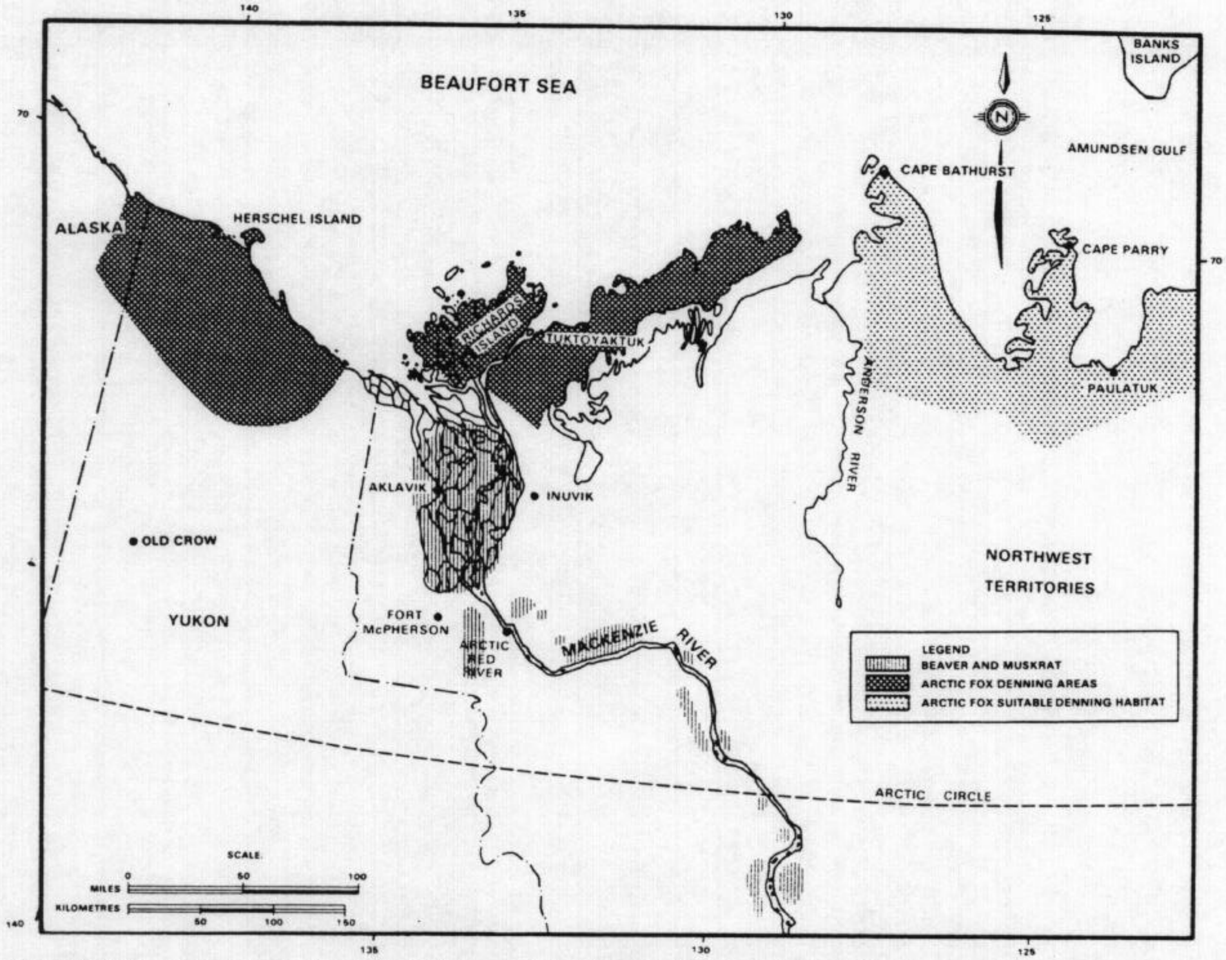

FIGURE 4.1-7 *Beaver, muskrat and Arctic fox range (class 1 and 2) (Nolan et al, 1973b; Dennington et al., 1973; Fisheries and Environment Canada, 1977)*

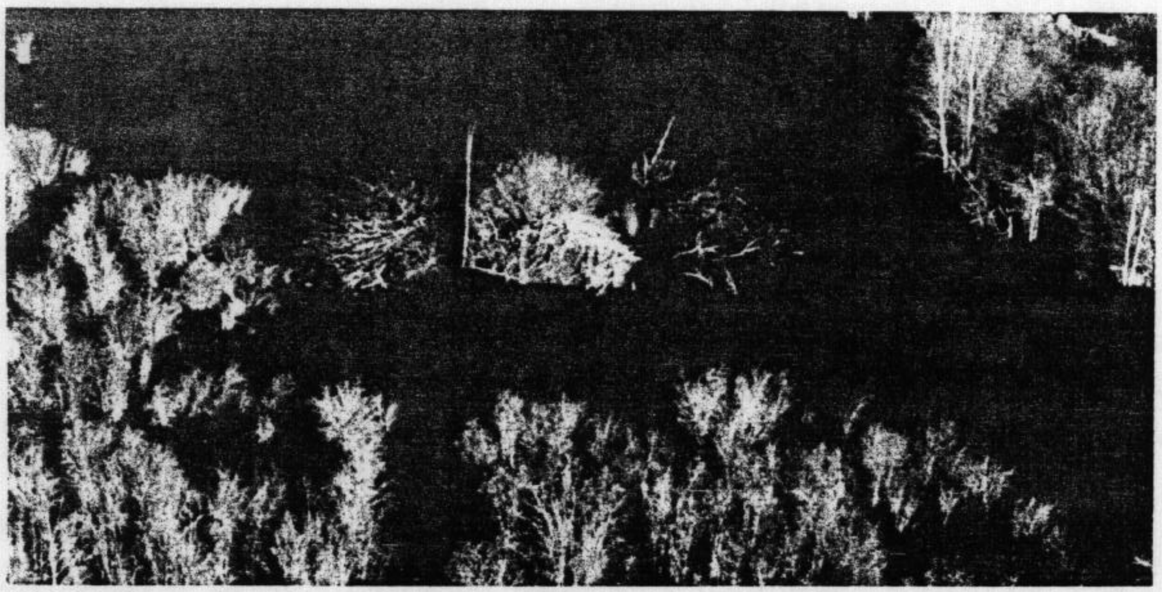

PLATE 4.1-5 *Beaver lodge and food cache. (Courtesy, McCourt Management Ltd.). Beavers usually live in streams with gradients of less than 6% and are most successful in wide valleys with meandering streams and rivers.*

(*Betula* spp.) and various aquatic plants such as water lily (*Nuphar* spp.). However, pine (*Pinus* spp.) and spruce (*Picea* spp.) are considered starvation diets (Novakowski, 1965; Aleksiuk, 1970). Beaver can survive in areas of poor food supply, but colonies and individuals are typically smaller, and reproductive rates are lower (Gibson, 1957; Hay, 1958; Gunson, 1970). Slough and Sadleir (1977) found that the presence of alder, willow and aspen were the most important factors in predicting beaver use of an area.

In the Mackenzie Delta region beavers are at the northern-most limit of their range (Hawley and Aleksiuk, 1974)(Figure 4.1-7). In general, habitat on Richards Island and in the Parsons Lake area is considered poor (Class 3) or insignificant (Class 4) (Dennington et al., 1973). Beaver activity has been observed at Ya-Ya Lakes (Slaney, 1974a), Kidluit Bay (Cowan, 1948), Holmes Creek (Wooley, 1974) and between the East Channel and Eskimo Lakes (Slaney, 1974a). However, the Mackenzie Delta lowlands are considered Class 2 (intermediate quality) habitat for beaver (Dennington et al., 1973) (Figure 4.1-7). An estimated 1,600 beaver colonies (6,400 to 9,600 beavers) were present in the Mackenzie Delta in 1965 (Hawley, 1968), while approximately 400 colonies (1,600 to 2,400 beavers) occurred within the Mackenzie Delta in 1970 (RRCS, 1972). Colony densities in the most suitable beaver habitat of the Mackenzie Valley were 0.3 to 0.4/km^2 during 1962-1965, and 0.1/km^2 in 1968 and 1969 (Hawley and Aleksiuk, 1973). Wooley (1974) reported a density of 0.04 active beaver lodges per km of transect near Inuvik and 0.14 per km of transect in the Travaillant Lake area.

Beaver habitat in coastal areas adjacent to the Beaufort Sea west and east of the Mackenzie Delta region is restricted to a few river valleys and is considered poor to insignificant (Class 3) (Dennington et al., 1973).

4.1.4 TERRESTRIAL FURBEARERS

4.1.4.1 Arctic Fox

The Arctic fox (*Alopex lagopus*) is a small terrestrial mammal that ranges throughout the Arctic tundra, forest-tundra transition and landfast ice areas of North America and Eurasia. Adults attain an average weight of 2.5 to 3.5 kg (Macpherson, 1969). This species has two fur colour phases, "white" and "blue." While the former fur is white in winter and brown during the summer, foxes of the blue fur phase vary from gray to black during both summer and winter. The white pelt of the Arctic fox is sought by trappers from coastal communities throughout the Beaufort Region and provides a major source of cash income for both Canadian and Alaskan Inuit (Section 4.6.1). Arctic foxes use component habitats in relation to availability of prey species and in association with their own den sites. The movements and fluctuations observed in natural populations are believed to be related to the availability and abundance of prey (Macpherson, 1969; Banfield, 1974; Dickinson and Herman, 1979).

Although this species is terrestrial throughout most of its range, Arctic foxes in coastal areas move onto the nearshore landfast ice during winter (see Section 3.2.4). During spring and summer Arctic foxes occupy areas near the terrestrial breeding dens and remain there during the relatively snow-free period from May until August. In terrestrial areas the range of Arctic foxes overlaps with that of red (or "coloured") foxes (*Vulpes vulpes*). Both species prefer den sites in well drained consolidated soil where snow-melt occurs early, although the Arctic fox is known to avoid sites in dense shrub vegetation (Nolan et al., 1973b). All Arctic fox den sites reported by Nolan et al. (1973b) were in open areas with low relief. Den sites have been located in pingos on the Mackenzie Delta islands, in sand dunes, in frost heaves, and at the tops of banks of lakes, rivers and streams. Traditional den sites are usually located in sandy vegetated areas with a gentle slope (Macpherson, 1969).

Arctic foxes are efficient scavengers and prey upon a variety of species. Primary food items include lemmings and other small rodents, ringed seal pups, seal and caribou carrion, and birds (especially their eggs and nestlings). The diet of Arctic foxes changes with the seasonal availability of prey and the habitat occupied. For example, lemmings are the primary food source during summer (Chesemore, 1968; Macpherson, 1969; Banfield, 1974). In the winter, inland populations depend primarily on lemmings, while coastal populations prey on seal pups and seal carrion on the landfast ice. In some terrestrial areas nesting birds and their eggs or young also form a major part of the summer diet (Burgess, 1979). Although the winter diet of inland Arctic fox populations is primarily lemmings, caribou carrion may be eaten when available. Arctic foxes may follow caribou herds to take advantage of carrion left after wolf kills (Manning, 1943; Macpherson, 1969) or follow polar bears on the winter sea ice to scavenge on the remains of seals killed by them (Blood, 1977). Arctic foxes are also known to scavenge at community garbage dumps.

Although the productivity of Arctic fox populations in the south-eastern Beaufort Sea region has not been documented, studies of Arctic foxes in the Districts of Keewatin and Franklin, Northwest Territories (Macpherson, 1969) may be representative. Arctic foxes are sexually mature at 9 months but most do not breed until their second or more commonly, third year. Mating takes place between late February and late April, with den sites being excavated as early as late March. Arctic foxes are probably territorial during the denning period. The litter is born about late May and is weaned by the third week in July. Although mean litter size at birth (10.6) does not vary between years or age of the female, the mean size of weaned litters varies greatly between years depending on prey availability. For example, in years of lemming abundance an average of 9.6 whelps were weaned (range 4-14), while in years when lemmings were scarce few or no whelps were weaned (Macpherson, 1969). Both adults guard and feed the litter until they leave the dens in late summer. The whelps disperse from the den sites after mid August.

Arctic fox populations fluctuate dramatically in response to the cyclic abundance of lemmings (Macpherson, 1969; Banfield, 1974). These natural fluctuations are reflected in annual harvest data (Section 4.6.1). However, annual harvest data from communities on Banks and Victoria islands suggest that fox populations in these areas are more productive and less subject to typical oscillations than populations elsewhere. This effect may be the result, at least in part, of the abundance of ringed seal pups, a common and relatively stable alternative food source (Smith, 1976).

In summary, the most important habitats for Arctic foxes include suitable den sites and winter range. Habitat for den sites is restricted to areas without permafrost but does not include areas where flooding frequently occurs in the spring such as the low-lying areas of the Mackenzie Delta. Fall and winter movements are probably initiated by food scarcity and regions of high prey abundance during winter are consequently important to survival. Areas with high densities of seals (in marine areas) or high densities of caribou and small mammals (on the tundra) would be of significant local importance to wintering Arctic fox populations.

The size and density of the Arctic fox population in coastal areas of the Beaufort Sea has not been documented, although historically (1927-28) this species was common along the coast and rare inland (Porsild, 1945). Arctic foxes were considered the most abundant denning species on deltaic islands south of and including Kendall Island (McEwen, 1955 cited in Gulf Oil, 1975). Nolan et al. (1973a) classified the area from Parsons Lake to the seaward coast of Richards Island as important habitat (Class 2) for Arctic fox, while areas south to Inuvik and along the east side of the Mackenzie River were considered Class 3 (little importance) habitat. Slaney (1974a) recorded only two possible Arctic fox dens during extensive surveys of Richards Island in 1973.

The general distribution and movements of Arctic foxes in the southeastern Beaufort region are probably typical of most coastal populations (C.f. Macpherson, 1969). Foxes in coastal areas generally move onto the sea-ice during winter and return to land-based dens in the spring, although Porsild (1945) noted that Arctic foxes on the Tuktoyaktuk Peninsula tend to follow the reindeer herd (Sec. 4.1.1.1(a)), presumably to feed on reindeer carrion and weak fawns.

Arctic foxes are relatively common residents of the Yukon North Slope (Figure 4.1-7). Ruttan (1974c) identified four distinct areas of denning habitat. The most suitable area (Class 1) occurs along the coastal plain between the Malcolm and Babbage/Crow rivers, and had a density of one den per 44 km^2 (Nolan et al., 1973b). Twenty-six of the 27 dens found in this area were Arctic fox dens, with the highest density of the dens occurring between the Firth and Spring rivers.

The coastal plain between the Alaska/Yukon border and the Malcolm River is considered Class 2 fox habitat (Nolan et al., 1973b), and is less productive than the aforementioned area because of the presence of low wet terrain. However, the density of dens recorded in this area was one per 41 km^2 (7 out of the 8 dens recorded in this area were Arctic fox) (Ruttan, 1974c). Similarily, the area between the Babbage/-Crow River and the Blow River is also considered important habitat (Class 2) for Arctic fox (Nolan et al., 1973b). Again, the low wet terrain limits its suitability for denning. Ruttan (1974c) recorded three Arctic fox dens in this area and a density of one den per 495 km^2. The highest density of fox dens (one den/10.4 km^2) recorded during Ruttan's (1974c) survey was on Herschel Island which provides Class 2 habitat for Arctic fox (Nolan et al., 1973b). A total of nine Arctic fox dens and three coloured fox dens were observed.

The Tuktoyaktuk Peninsula is considered important habitat (Class 2) for Arctic foxes, while the coastal areas, at least as far east as Liverpool Bay and the mouth of the Mason River, are of lesser importance (Class 3) (Nolan et al., 1973b). Cape Bathurst is considered a major denning area for Arctic fox (Macpherson, 1969). Fisheries and Environment Canada (1977) indicate that the Parry Peninsula and areas to the south are potential Arctic fox denning regions. The Cape Parry area is also an important trapping area for Arctic fox (Sec. 4.6.1).

4.1.4.2 Red Fox

The red fox (*Vulpes vulpes*) is widely distributed throughout northern latitudes. In the Northwest Territories this species occurs throughout the mainland and on Baffin Island, but is rare on Banks Island (Banfield, 1974). Population densities are usually greater in the forest and forest-tundra transition zone than on tundra.

The three fur colour phases of red fox are red, cross and silver. This species is important to the trapping economy of the Mackenzie District, particularly the Mackenzie Valley (Section 4.6.1). During the 1930's Porsild (1945) noted that the red fox was second only to the muskrat in importance as a furbearer on the Mackenzie Delta. Since 1970-71, fur harvest records indicate a substantial increase in the reported harvest of red foxes throughout the Northwest Territories (Section 4.6.1) (Dickinson and Herman, 1979).

Although only limited information is available on the general biology of the red fox in the Northwest Territories, this species has been studied in forested areas of northern Alberta. Soper (1964) observed that red fox litters had from 4 to 9 whelps and that populations appear to follow a ten year cycle. Natural population fluctuations are extreme, with rabies epidemics effectively reducing populations. A high reproductive capacity enables the fox to restore its numbers quickly.

Like the Arctic fox, red fox activities during summer are centred around the breeding den. Den sites are frequently traditional and are located in well-drained areas such as the steep slopes of river banks, ridges, eskers and moraines. Consolidated soil, consisting primarily of sands, gravels or sandy loams, is also an important requirement for den sites. Red fox dens usually face south and have entrances obscured by shrub vegetation (Slaney, 1974a).

The red fox is an omnivore and consumes small mammals, birds, insects, and berries (Banfield, 1974). Slaney (1974a) found that prey remains at Richards Island fox dens consisted of (in decreasing frequency) ptarmigan, ducks, unidentified birds, small mammals, ground squirrels, foxes, fish, swans, muskrats, reindeer, insects and berries.

The population size and local distribution of this species in the Mackenzie Delta and coastal Beaufort has not been well documented. Twenty-two of 24 active fox dens on Richards Island (counted during 1973 and 1974) were red fox dens (Slaney, 1974a). Some areas of Richards Island are considered to provide fox den habitat of medium to high suitability (Slaney, 1974a), while habitat near Parsons Lake has been primarily classified as being of low suitability. Slaney (1974a) also reported that red foxes were observed in open upland habitat throughout most of the year, but they were associated with the shrub areas where ptarmigan are found during winter.

Coloured foxes occupied 14% of 50 fox dens along the Yukon North Slope and Herschel Island during surveys conducted in 1972 (Ruttan, 1974c). The author suggested that the red fox may be displacing the Arctic fox in this area.

Red foxes are also relatively common in coastal areas east of the Mackenzie Delta. Freeman (1976) indicated that red foxes are trapped in the upper Eskimo Lakes region, in an area immediately south of the Parry Peninsula, and probably also along the Smoke and Anderson rivers.

4.1.4.3 Wolf

The tundra wolf (*Canis lupus*) was formerly widely distributed throughout North America but, with the exception of northern wild areas, has been virtually eliminated from much of its range (Plate 4.1-6). In the Northwest Territories wolves occur in forested and tundra habitats and are associated primarily with various species of ungulates, including bison, caribou, moose, muskoxen and sheep (Banfield, 1974). Sub-groups of the northern wolf population have developed different behavioural and habitat selection strategies in response to the movements, distribution and abundance of the predominant prey species (Dickinson and Herman, 1979).

The wolf is of moderate economic importance to the annual Northwest Territories fur harvest even though the numbers taken are small (Dickinson and Herman, 1979) (Section 4.6.1). Recent harvest statistics indicate a substantial increase in both the numbers harvested and the average pelt value. In addition, harvest data provide the available information on wolf populations in the Mackenzie Delta and coastal Beaufort region.

Most wolves occur in packs that are associated with the predominant prey species. Wolf packs are known to follow migratory prey (such as barren-ground caribou), although their mobility is usually limited during the period when activities are centred at the breeding dens. In areas where the predominant prey species is essentially non-migratory (as in the case of moose), the associated wolf packs establish well defined territories and generally confine their activities within these boundaries. Seasonal habitat selection is also strongly associated with activities of the prey species. During the winter packs often hunt over long distances along ridges, trails, seismic lines, lake shores and frozen lakes and rivers (Mech, 1970; Peters and Mech, 1975). In the summer wolves typically restrict their movements since they frequently return to the pup-rearing areas. Although most wolf packs prey primarily on ungulates, studies in northern areas have indicated that other prey items may include beaver, small mammals, snowshoe hares,

PLATE 4.1-6 *Wolves are commonly associated with caribou herds in Arctic regions. (Courtesy, McCourt Management Ltd.).*

birds and vegetation (Theberge and Cottrell, 1977; Stephenson, 1978). Wolves feed opportunistically and will frequent garbage dumps if they have access.

Both den and rendezvous sites have specific characteristics that provide security for pups. In Arctic Alaska, Stephenson (1974) found that the majority of dens were excavated in well-drained usually sandy soil, and were situated on a moderate to steep south-facing slope near a water supply. Den sites are commonly traditional (Mech, 1970; Stephenson and Johnson, 1972). Rendezvous sites are larger than denning areas (ranging to 0.64 km^2) (Kolenosky and Johnston, 1967) and are usually located near open water and an open understory of grass and sedges.

In summary, important habitats for wolves include traditional pup-rearing areas, and the range of their primary ungulate prey species. Wolves are primarily associated with caribou in the tundra and Delta regions (Wooley, 1976), while in the forested areas they are associated with moose. Few wolves are known to occur in the vicinity of the reindeer herd. There may be several important den sites in a single wolf pack territory since the adults may move young from one site to another during the same season (Mech, 1970).

The population size or location of den sites of wolves along the Yukon North Slope have not been documented. Doll et al. (1974) observed several wolves throughout this area during the summers of 1972 and 1973. There are no documented estimates of wolf population size or evidence of denning areas in coastal areas adjacent to the Beaufort Sea east of the Mackenzie Delta. On the basis of habitat requirements for wolf denning, the Parry Peninsula probably does not provide suitable areas, while the Smoking Hills-Melville Hills immediately south of the peninsula is considered suitable (Kelsall, 1968).

4.1.4.4 Marten

The American marten (*Martes americana*) occurs throughout the boreal forests of North America (Banfield, 1974), although atypical range extensions have been noted as far north as Tuktoyaktuk (Clarke, 1944). In general the range of this species is confined to continuously forested zones south of the timber line, with upland and foothills areas having the highest concentrations (Thurlow, 1973; Wooley, 1974).

Marten are effective predators of small mammals, hares and birds, supplementing their diet with insects, carrion and fruit (Banfield, 1974). In years of abundant prey, marten are usually more sedentary and consequently are more difficult to trap (Lensink et al., 1955). Dens or rearing areas may be located in a wide variety of sites including hollow trees, rock piles, and overturned trees (Banfield, 1974). Marten are solitary except when females are rearing young.

Marten are thought to be rare in coastal tundra areas adjacent to the Beaufort Sea, although the population size and density of marten in this region have not been documented.

4.1.4.5 Lynx

Lynx (*Lynx canadensis*) occur primarily in the boreal and Rocky Mountain forests of North America. In the Northwest Territories this species is usually confined to the mixed-wood forest, especially dense mature stands (Banfield, 1974). Porsild (1945) stated that lynx had never been abundant in the Mackenzie Delta region, and Slaney (1974a) reported only two lynx during studies in the Richards Island/Parsons Lake area between 1972 and 1974. Estimates of the population size or density of lynx in coastal areas adjacent to the Beaufort Sea have not been documented, but 'fur export tax' returns provide some information on the potential distribution of this species. For example, the average (1971 to 1979) annual harvest of lynx by the residents of Tuktoyaktuk and Paulatuk were low, within the range of 0 to 4 (Section 4.6.1), while yearly harvests from Inuvik were higher, averaging 167.5 lynx.

4.1.4.6 Other Terrestrial Furbearers

Other terrestrial furbearers trapped by residents of coastal communities in the Canadian Beaufort Sea region include mink, weasel, squirrel, wolverine, and otter (Section 4.6.1). Of these, mink is the most abundant and economically important species. Mink are more common in the fur harvests of communities near the Mackenzie Delta, such as Inuvik, Aklavik and Fort McPherson, than in the fur harvests of communities further removed from the Delta (Section 4.6.1). The Mackenzie Delta provides the most suitable mink habitat of all coastal areas adjacent to the Beaufort Sea.

Ermine and least weasel are known to occur throughout coastal areas of the Beaufort region, but do not constitute a large portion of the annual fur harvest (Section 4.6.1). Red squirrels are found in forested areas but contribute little to the trapping economy. Wolverine and otter are even less common, and coyote have been recorded occasionally (Slaney, 1974a).

4.1.5 OTHER TERRESTRIAL MAMMALS

Other terrestrial mammals known to occur in the Mackenzie Delta and coastal areas adjacent to the Beaufort Sea include three species of shrews, collared pika, snowshoe hare, Arctic hare, Arctic ground squirrel, two species of lemmings and four species of voles (Table 4.1-1) (Banfield, 1974). The collared pika occurs in the mountainous areas west of the Mackenzie Delta and the Arctic hare occurs on the tundra to the east. The snowshoe hare is found primarily in treed areas, while the Arctic ground squirrel is common throughout drier upland habitats. Collared and brown lemmings and the tundra vole are most common in the tundra, and the meadow vole and northern red-backed vole are more common in treed areas or shrub tundra. The singing vole is found only in mountainous areas (Banfield, 1974).

4.2 BIRDS

This section describes the distribution, abundance, seasonal timing, habitat use and activities of major species or species groups of birds that use the marine and adjacent terrestrial areas of the Canadian Beaufort Sea region including western Amundsen Gulf and, in lesser detail, the coastline and offshore areas of the Alaskan Beaufort and northeast Chukchi seas. A brief account of the biology and population status is also presented for each of the major species or species groups. More than 120 species of birds occur regularly in these areas and many other species have been recorded irregularly or accidentally. Many of the regularly occurring species breed only in the Arctic, and large portions of the North American populations of some species breed in coastal areas of the Canadian Beaufort Sea. Birds that occur in the Beaufort Sea region include true seabirds, which come ashore only to nest; waterfowl, which are the swans, geese and ducks; raptors which include hawks, eagles, falcons and owls; shorebirds; passerines; and others.

The most important spring migration routes to the coastal Beaufort Sea region are routes that go around the Alaskan coast and then east either along the Beaufort Sea coast or offshore across the Beaufort Sea, routes that cross interior Alaska to the western Beaufort Sea, and routes that go north along the Mackenzie Valley to the Beaufort Sea coast. Many species that migrate into the coastal region remain there to nest, but some move on to breeding areas elsewhere. Spring migration generally occurs from mid May until mid to late June. It is a rapid process for most species, but some species, especially the earlier-arriving ones, stop over at traditional staging areas before moving on to their nesting grounds.

The coastal Beaufort Sea region is an important area for many nesting species. The many wetland areas within the region together support large numbers of nesting waterfowl and shorebirds. Nesting terrestrial birds are generally widely dispersed within suitable habitat. The largest colony of nesting birds within the Canadian Beaufort Sea region contains nearly 200,000 nesting snow geese and is located inland on western Banks Island. Several smaller colonies within this region include a thick-billed murre colony at Cape Parry, snow goose colonies at the Anderson River delta and near Kendall Island in the Mackenzie Delta, and small colonies of glaucous gulls, Arctic terns, common eiders and brant at various locations along the coast. The peak of the nesting season is in June and early July, but some nesting begins in May or earlier in the case of the gyrfalcon, and the young of some raptors are still in the nests during August.

The period from mid July to mid August is when brood-rearing activities peak for most waterbirds. July and August are also the period when most waterfowl moult their flight feathers. Many of the lagoons and bays along the coast are important moulting areas for ducks.

Fall migration routes generally reverse those of spring migration. Fall migration generally occurs from early August to late September, but some shorebirds and waterfowl begin migration during July. For some species, fall migration is prolonged, with the different sexes and ages leaving at different times. Several areas within the region are important staging areas where the birds build up energy reserves for the migration flight. For example, the outer Mackenzie Delta and the North Slope of the Yukon are important staging areas for geese. Very few species overwinter in the coastal Beaufort Sea region.

Population declines that have occurred in some species of birds have recently caused much concern. In the U.S.A., this concern has led to the official designation of 'endangered' species of birds and to legislation for the protection of these birds and their habitats (U.S. Dep. Interior, 1973). In Canada, this concern has led to the formation of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which has officially designated some species (and subspecies) as 'rare', 'threatened' or 'endangered' in Canada. However, COSEWIC has not yet considered all the Canadian species for which some concern has been expressed. There is no national protective legislation *per se* in Canada for endangered species, although they are usually protected in most provinces and territories under some type legislation. Further, the journal *American Birds* has prepared and updates yearly an unofficial 'blue list' of North American species that are not yet endangered but that are considered to be of concern because of declining populations. Table 4.2-1 lists the definitions of these categories as used by COSEWIC and *American Birds*. Birds that have been recognized as falling within any of these categories are identified within the following descriptions.

The descriptions that follow are based on more detailed reviews and syntheses of the available literature as presented in LGL and ESL (1982) for marine areas of the Beaufort and Chukchi seas, and in Koski and Tull (1981) for the coastal and onshore areas of the Canadian Beaufort Sea region. Earlier reviews of the ornithological literature of the Beaufort and Chukchi Seas have been presented in Johnson et al. (1975) and Schamel (1978a). Figure 4.2-1 show the locations of geographic names mentioned in the following descriptions.

4.2.1 LOONS

Three species of loons, yellow-billed loon (*Gavia adamsii*), Arctic loon (*G. arctica*), and red-throated loon (*G. stellata*), commonly occur in the Beaufort-Chukchi region. The common loon (*G. immer*) is uncommon in the region both as a nester and as a migrant, and consequently is not considered in detail in the following section. It is on the 'blue list' of North American birds (Tate, 1981). Arctic and red-throated loons breed commonly throughout the Beaufort region, while the yellow-billed loon is a common migrant but a rare breeder (Höhn, 1959; Kevan, 1970; Johnson et al., 1975; Zoltai et al., 1979; Salter et al., 1980; Martell and Dickinson, 1982).

Loons are relatively large waterbirds that dive and catch their prey underwater. They are highly aquatic, awkward on land, and rarely go ashore except for nesting. Nests are located at the water's edge to allow the birds an easy escape by swimming or diving. Although loons are strong fliers, they have difficulty taking off from water and only the red-throated loon can take flight from land (Palmer, 1962). Loons feed primarily on small fish, but also take a variety of marine and freshwater invertebrates (e.g. mysids, copepods, euphausiids, amphipods) (Palmer, 1962; Divoky, 1978b).

All of the loon species in the Beaufort-Chukchi region usually occur singly or in small, widely-dispersed groups during nesting and migration (Richardson et al., 1975; Searing et al., 1975). They nest on freshwater lakes and ponds. The young are restricted to the nesting waterbody until they can fly, but adults forage at other freshwater lakes or in nearby coastal marine areas. Marine areas are particularly favoured summer foraging areas for red-throated loons (Davis, 1972). Subadult Arctic and red-throated loons also occur on lakes and in marine areas of the Beaufort-Chukchi region in summer (Palmer, 1962).

TABLE 4.2-1

DEFINITIONS OF STATUS FOR SPECIES WITH DECLINING POPULATIONS

Status as defined by Committee On the Status of Endangered Wildlife In Canada (COSEWIC)

Species:	any species, subspecies, or geographically separate population.
Rare Species:	any indigenous species of fauna or flora that, because of its biological characteristics, or because it occurs at the fringe of its range, or for some other reason, exists in low numbers or in very restricted areas in Canada but is not a threatened species.
Threatened Species:	any indigenous species of fauna or flora that is likely to become endangered in Canada if the factors affecting its vulnerability do not become reversed.
Endangered Species:	any indigenous species of fauna or flora whose existence in Canada is threatened with immediate extinction through all or a significant portion of its range, owing to the action of man.

Status for inclusion on the Blue List of American Birds*

1. those species that may or may not be declining now, but may be in jeopardy in the foreseeable future;
2. those species that occur in such small numbers that their status should be monitored;
3. those species for which there are no scientific data to determine whether or not they are declining, but for which there is definite concern; or
4. those species that give definite evidence of non-cyclical declines in all or part of their ranges.

*The journal American Birds has prepared and updates yearly an unofficial 'blue list' of North American bird species that are not endangered, but that are considered to be of concern, for the reasons listed in this table.

Loons have a low reproductive potential. They are comparatively long-lived, and do not breed until they are at least two years old (Palmer, 1962). Clutches typically consist of only 2 eggs (Palmer, 1962).

Loons are migratory and winter in nearshore marine waters along the Atlantic and Pacific coasts. Migration of arctic-nesting species occurs mainly in coastal and offshore areas, but there is also some movement of loons along inland routes (Palmer, 1962). During migration, loons tend to travel singly or in small flocks (Palmer, 1962). Loons moult at their wintering areas, and are flightless during this period (Godfrey, 1966).

4.2.1.1 Yellow-billed Loon

No reliable estimates are available for the population of yellow-billed loons in the Canadian Arctic, but this species is primarily Eurasian and the North American population is not believed to be large (Palmer, 1962). The main North American nesting areas of the yellow-billed loon appear to border or lie immediately east of the southeastern Beaufort Sea (see LGL and ESL, 1982). Spring migrants first arrive in the Beaufort and northeast Chukchi Seas during late May and early June (Manning et al., 1956; Palmer, 1962; Williamson et al., 1966; Smith, 1973; Johnson et al., 1975; Searing et al., 1975; Richardson and Johnson, 1981) and are occasionally observed in open leads during spring (Barry et al., 1981). Subadult yellow-billed loons remain in wintering areas during the breeding season (Palmer, 1962).

In the Beaufort-Chukchi region, yellow-billed loons nest sparsely along most of the mainland coast except in the Mackenzie Delta-Liverpool Bay area and along the Yukon coast. They nest more commonly on Banks and Victoria Islands (Manning et al., 1956; Gabrielson and Lincoln, 1959; Parmelee et al., 1967;

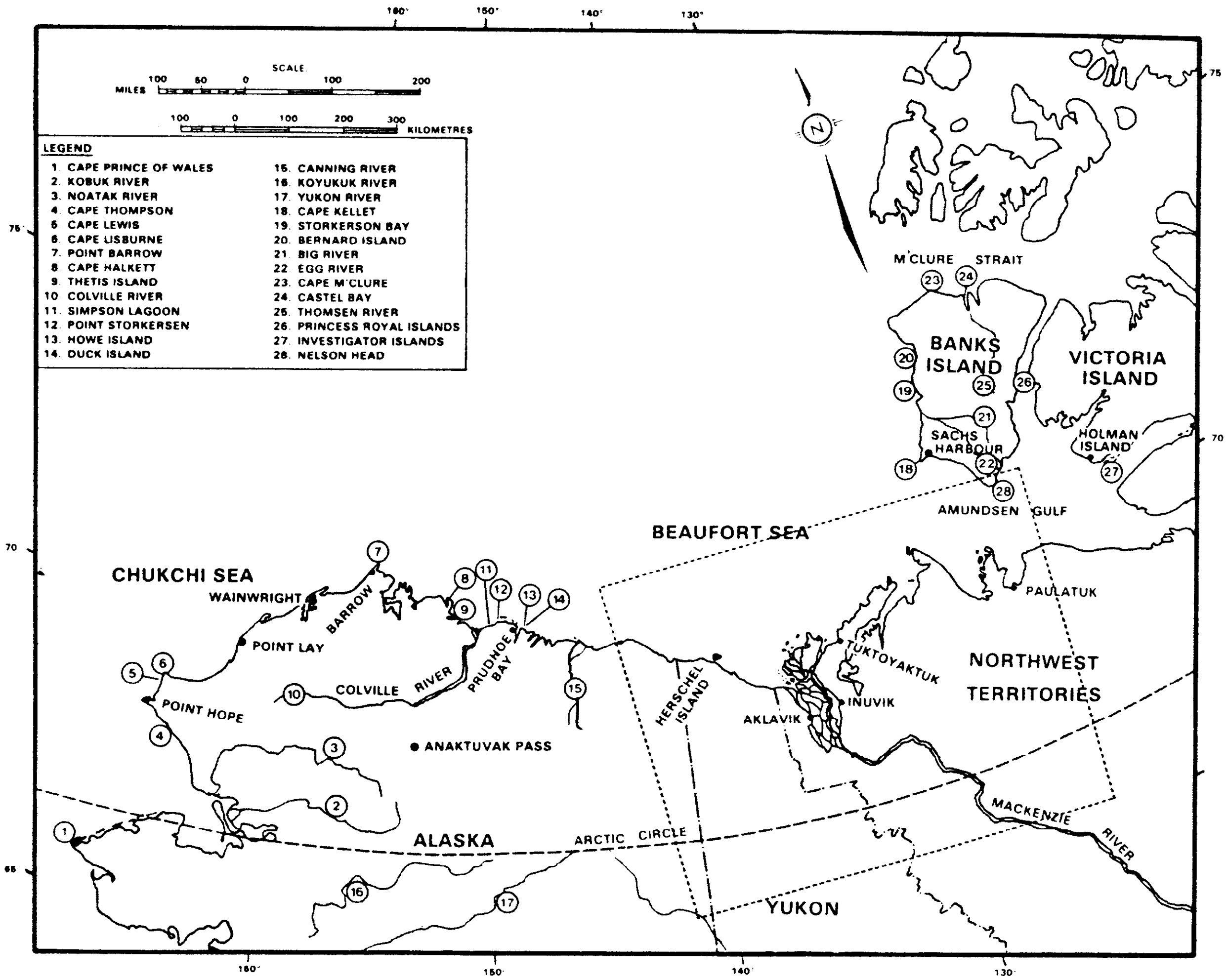

FIGURE 4.2-1 *Geographic names in the descriptions of birds (continued on next page).*

Barry, 1967; Sage, 1971; Campbell, 1973b; Slaney, 1974a; Salter et al., 1980). In the early 1950's, an estimated 3,000 adults were reported to nest on Banks Island (Manning et al., 1956). This species is also locally abundant at some lakes on southeastern Victoria Island (Parmelee et al., 1967). The fall migration is relatively 'leisurely', and probably occurs along an offshore route from mid August to mid September (Smith, 1973; Searing et al., 1975).

4.2.1.2 Arctic Loon

The spring migration of Arctic loons to the Beaufort and Chukchi Seas occurs both overland (Barry et al., 1981) and along the Alaskan coast (Palmer, 1962). The migration is rapid and occurs during late May and early June. Arctic loons are not known to concentrate in significant numbers in leads or coastal areas during spring migration (Richardson et al., 1975; Searing et al., 1975).

The Arctic loon is the most common breeding loon on the Yukon coastal plain and in the Mackenzie Delta (Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977; Salter et al., 1980). Arctic loons breed at lakes or ponds throughout the region. Nesting usually starts during mid June, although incubating Arctic loons have been observed as early as June 8 (Parmelee et al., 1967; Campbell, 1973b; Bergman et al., 1977). On the Yukon Coastal Plain, this species occurred at 15 of 22 lakes surveyed in 1972, and at 50 of 60 lakes surveyed in 1973 (Gollop and Davis, 1974b; Sharp et al., 1974). In the Mackenzie Delta, the densities of breeding Arctic loons recorded during aerial surveys have been 0.10 to 0.26 birds/km^2 (Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977). Arctic loons are also common nesters on the Tuktoyaktuk Peninsula (Kevan, 1970) and in the Horton and Anderson River areas (Barry, 1967; Zoltai et al., 1979).

Arctic loons are not known to concentrate in the coastal areas of the southeastern Beaufort prior to or during fall migration (Searing et al., 1975). Most birds depart during mid August to mid September and many probably migrate offshore (Searing et al., 1975; Timson, 1976; Divoky, 1978c; Barry et al.,

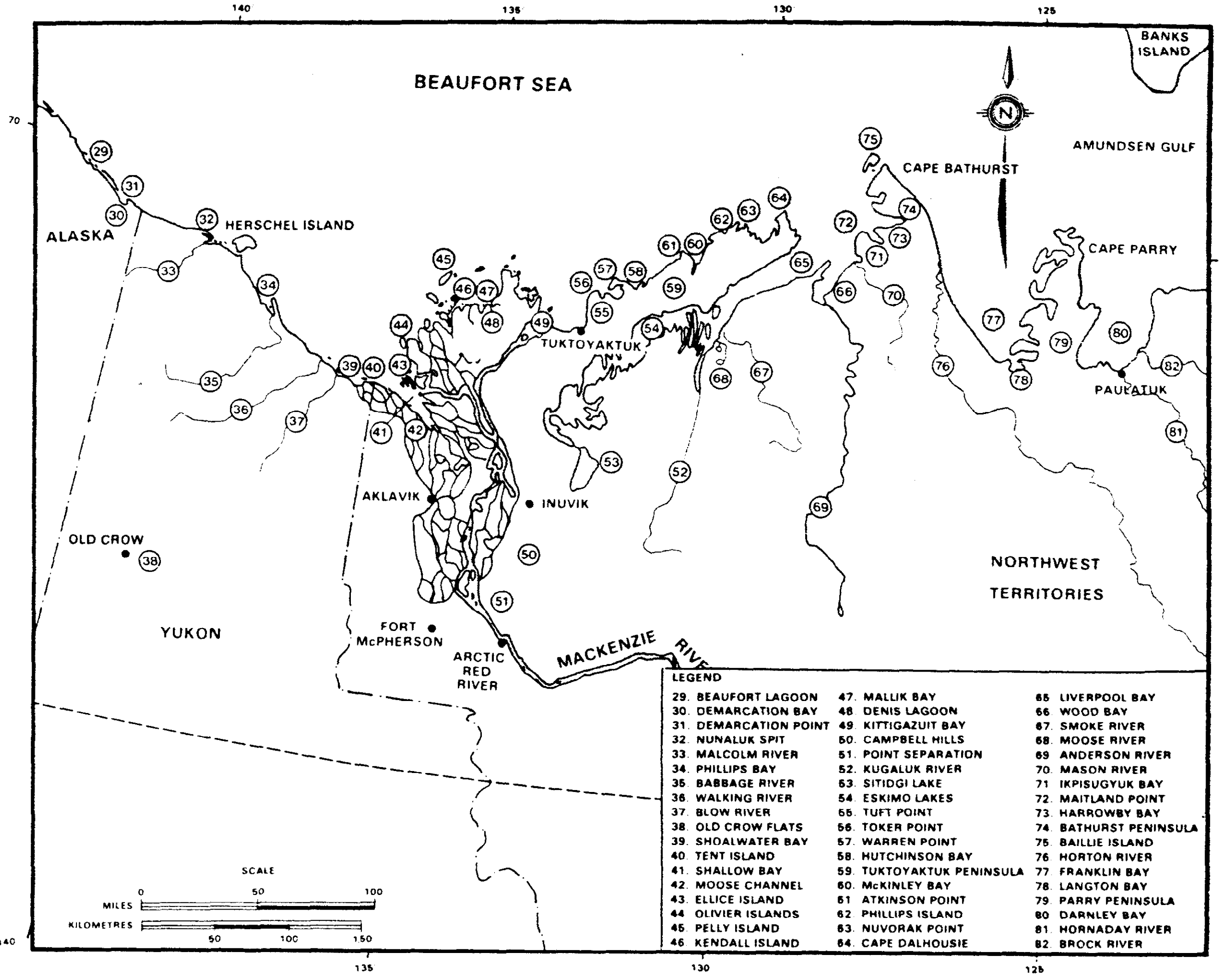

FIGURE 4.2-1 *(continued) Geographic names in the descriptions of birds.*

1982; LGL and ESL, 1982). Timson (1976) estimated that 50,800 loons moved westward past Point Barrow, Alaska, during August 27 to September 16, 1976. Most of the loons that she identified were Arctic loons (629 of 663).

4.2.1.3 Red-throated Loon

Red-throated loons arrive in the Beaufort and northeast Chukchi Seas during late May and early June (Manning et al., 1956; Williamson et al., 1966; Slaney 1974a; Johnson et al., 1975; Bergman et al., 1977; Richardson and Johnson, 1981) following coastal or offshore migration routes (Palmer, 1962). During spring surveys of the ice edge in the Beaufort Sea-Amundsen Gulf region in 1980, red-throated loons were observed in most open leads but the numbers were small (Barry et al., 1981).

Red-throated loons usually nest on small, shallow tundra ponds near the sea or some other large body of water (Plate 4.2-1), and make frequent trips to the sea, rivers, or large lakes to feed during the nesting period (Davis, 1972). Nesting red-throated loons are locally abundant in Alaskan coastal marshes from Cape Prince of Wales to Demarcation Point (Gabrielson and Lincoln, 1959), along the Yukon North Slope (Salter et al., 1980), in the Mackenzie Delta (Campbell and Weber, 1973; Slaney, 1974a), on the Tuktoyaktuk Peninsula, on Banks Island and along the west coast of Victoria Island (Manning et al., 1956). On the Yukon Coastal Plain, red-throated loons were found at 3 of 22 lakes surveyed in 1972, and at 9 of 60 lakes surveyed in 1973 (Gollop and Davis, 1974b; Sharp et al., 1974). In the Mackenzie Delta area during the breeding season, the density of red-throated loons recorded during aerial surveys has ranged from less than 0.01 to 0.02 birds/km^2 (Campbell and Weber, 1973; Wiseley et al., 1977). Ground surveys conducted near Point Storkersen, Alaska, indicated densities of 1.2 to 1.6 red-throated loons/km^2 (Bergman and Derksen, 1977).

Although in the fall some red-throated loons may migrate offshore through the western Beaufort Sea (Divoky, 1978c), most are believed to migrate overland (Searing et al., 1975; Timson, 1976; Johnson, 1979). Most red-throated loons have left the Beaufort Sea by mid September (Searing et al., 1975).

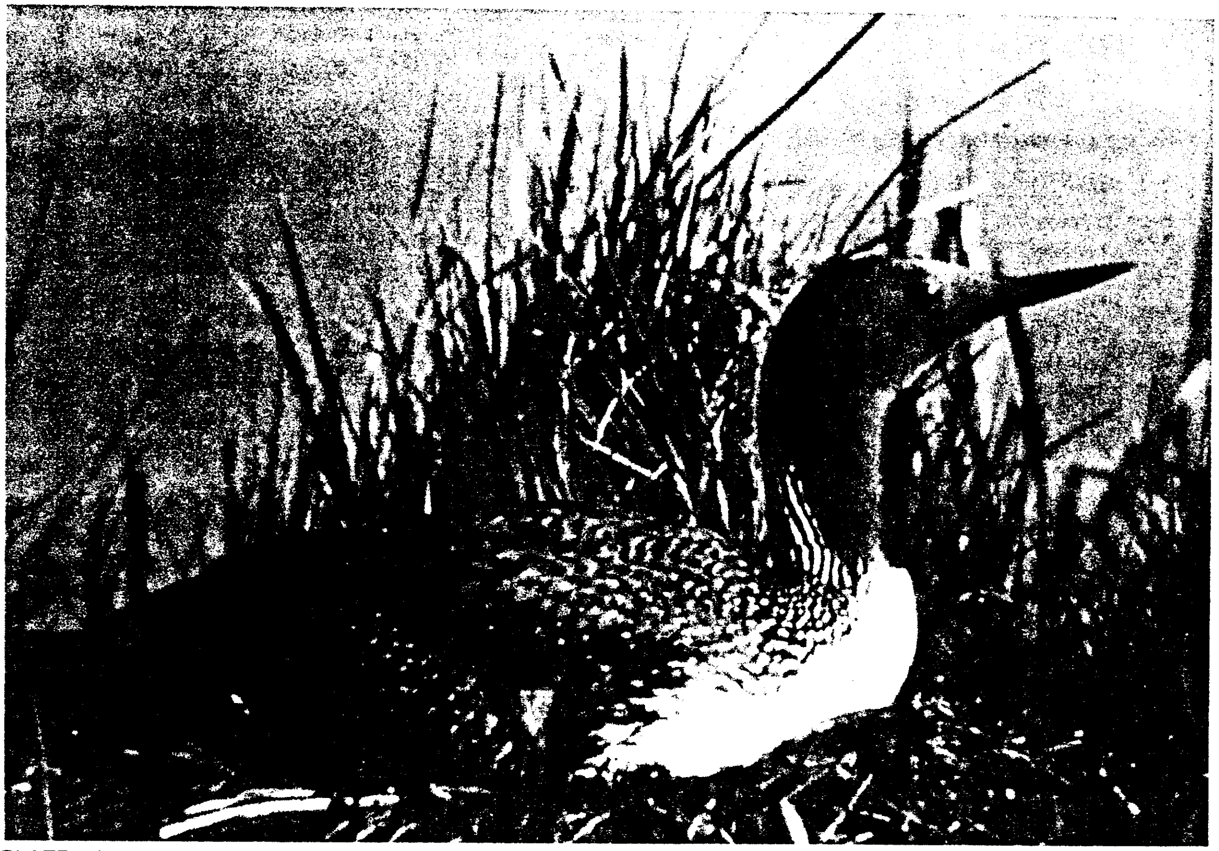

PLATE 4.2-1 *Loons build their nests at the water's edge as exemplified by this nesting red-throated loon. Loons usually occur singly or in small groups during nesting and migration.*

4.2.2 GREBES

Two species of grebes, red-necked grebe (*Podiceps grisegena*) and horned grebe (*P. auritus*), occur as far north as the Canadian Arctic. Like loons, grebes are highly aquatic birds and seldom come ashore. They construct floating nests on streams, lakes and ponds (Godfrey, 1966).

Both species occur regularly in very small numbers in the forested (southern) portion of the Mackenzie Delta and in some forested areas to the east (Zoltai et al., 1979; Salter et al., 1980; Martell and Dickinson, 1982). Campbell and Weber (1973) recorded only 0.005 red-necked grebes/km^2 and no horned grebes during aerial surveys of the southern Mackenzie Delta, and 0.002 unidentified grebes/km^2 in the boreal forest east of the Mackenzie Delta. Salter (1974b) and Wiseley et al. (1977) recorded no grebes during aerial surveys to the immediate east of the Mackenzie Delta. Both species are rare visitants and nesters in other areas of the Mackenzie Delta (Searing et al., 1975; Martell, 1974), on the Yukon North Slope (Salter et al., 1980), and on the Arctic coast of Alaska (Gabrielson and Lincoln, 1959).

4.2.3 WHISTLING SWAN

The whistling swan (*Olor columbianus*) is a North American waterfowl species that breeds in the subarctic and Arctic tundra from Bristol Bay, Alaska, east to Baffin Island. The species population in spring is approximately 90,000 birds, 60,000 of which summer in Alaska and the remaining 30,000 in Canada. Of the whistling swans that summer in Canada, approximately 21,000 are found in areas adjacent to the Beaufort Sea. The primary wintering grounds of the whistling swan are along the east and west coasts of the United States (Bellrose, 1976); those that summer in the Beaufort Sea area winter along the east coast (Sladen, 1973).

The reproductive potential of this species is moderate to low as a result of a moderate clutch size and delayed sexual maturity. Although the age of first breeding is unknown, Lensink (1973) speculates that whistling swans at the Yukon River delta in western Alaska do not breed before their third summer, and most are probably older. Delacour (1954) suggests that whistling swans do not breed until five or six years of age. The observed recruitment rates of young birds (see Lynch and Voelzer, 1974; Koski, 1977b) indicate that the age of first breeding is probably as suggested by Delacour (1954). Average clutch size in Alaska ranges between 3 and 5 eggs (Lensink, 1973). Mortality rates for adults and young are not well known; however, it is believed that mortality of immatures during their first year is high (Bellrose, 1976).

Nesting whistling swans are highly territorial and are widely distributed over their lowland tundra nesting habitat. Their nests are generally adjacent to, or on islands in, tundra ponds, lakes and sluggish rivers, and less often near sheltered tidal waters (Palmer, 1976a). Many non-nesters also maintain territories.

The interval from the laying of the first egg to the fledging of the young is approximately 100 days. The male remains with the incubating female and assists the female in defence of the brood. Brood-rearing usually occurs in areas relatively close to the nest site (Bellrose, 1976). Both adults moult during the brood-rearing period; the females moult before the males (Banko and MacKay, 1964).

Subadults also return to the nesting grounds and these birds remain in small flocks (3 to 15 birds) throughout the breeding season. Subadults moult before the adults and when they regain flight they begin to congregate in coastal lowlands or near large inland lakes. These flocks are later joined by family groups. Flocks averaging about 50 birds then begin migrating from nesting areas to wintering areas. Whistling swans are noted for their long-distance non-stop migratory flights (Bellrose, 1976).

Whistling swans feed mainly on the tubers and stems of aquatic plants, and usually in the shallow water of ponds, lakes and slow-moving streams (Bellrose, 1976; Palmer, 1976a).

Whistling swans migrate overland along the Mackenzie Valley and first arrive in the Mackenzie and Anderson River deltas in mid May (Barry, 1967; Slaney, 1974a, 1975) and on the Yukon North Slope in late May (Salter et al., 1980). Approximately 800 swans that nest on the Alaska North Slope migrate through the Mackenzie Delta region and along the Yukon North Slope (Sladen, 1973). Over 500 were estimated to have flown west along the Yukon coast into Alaska during late May and early June 1975 (Richardson and Johnson, 1981). Courtship and copulation occur at the northern spring staging areas along the Mackenzie River and the swans are ready to nest when they arrive in the Beaufort region. Soon after the swans arrive, they disperse to the nesting area and establish territories; nesting begins during late May or early June.

Pairs of territorial whistling swans are widely distributed over the tundra nesting habitat. Consequently, large numbers of nesting birds do not occur in a small area. About two-thirds of the Canadian population or about 20,000 whistling swans are known to summer between the west side of the Mackenzie Delta and the east side of the Anderson River delta (Bellrose, 1976). Smaller numbers summer on the Yukon North Slope (200+; Mossop, 1975), the Bathurst Peninsula (400+; CWS, 1972) and the Parry Peninsula (200; CWS, 1972). In addition to the birds in the Canadian Beaufort region, approximately 800 whistling swans summer on the Alaskan North Slope (Sladen, 1973).

The highest densities of whistling swans occur in the low tundra areas from the west side of the outer Mackenzie Delta to the east side of the Anderson River delta. Densities are highest in the coastal tundra areas and only slightly lower in the adjacent upland tundra. Surveys conducted during 1948-54 by the U.S. Fish and Wildlife Service revealed average densities of 0.5 swans/km^2 in the outer Mackenzie Delta, 0.6 swans/km^2 along the outermost coastal strip of the Tuktoyaktuk Peninsula, and 0.5 swans/km^2 in the upland tundra east of the Delta and along both sides of the Eskimo Lakes. Summering whistling swans were also found in the transition zone between tundra and boreal forest, to the south of the upland tundra; however, densities (0.2 swans/km^2) were much lower there than in adjacent upland and coastal tundra. The forested southern portion of the Mackenzie Delta had moderate densities (0.2 swans/km^2) of non-nesting swans (Martell and Dickinson, 1982).

Both non-nesting and nesting swans remain on their territories throughout the brood-rearing and moulting period, which extends from early July to mid August for non-nesters and unsuccessful nesters, and to early September for successful nesters. During the breeding season non-territorial birds are found in small groups scattered throughout available habitat, but some subadults move to moulting areas during about the first week of July. For example, Slaney (1974a, 1975) noted 1,100 non-breeding swans in an area west of Mallik Bay in 1972, 950 in 1973 and 1,175 in 1974. CWS (1972) lists several important moulting areas for whistling swans within the coastal Beaufort region (see Figure 4.2-2).

Although a large number of whistling swans are known to concentrate in a few moulting areas, even larger numbers are dispersed throughout adjacent areas. Of the total 20,000 adults that summer in the Mackenzie Delta-Anderson River area, CWS (1972) accounts for fewer than 5,000 swans in the moulting areas shown in Figure 4.2-2.

By mid September, both adults that have nested successfully and their young are capable of flight and join the subadult flocks. Prior to the fall migration, flocks stage in suitable habitats adjacent to the Beaufort Sea (Bellrose, 1976). The areas used appear to be traditional, and congregations of birds are recorded by mid August, particularly along the outer Mackenzie Delta. The areas most consistently used are Mallik Bay, the vicinity of Kendall Island, Olivier Islands and along Shoalwater Bay (Koski, 1975a, 1977a, b).

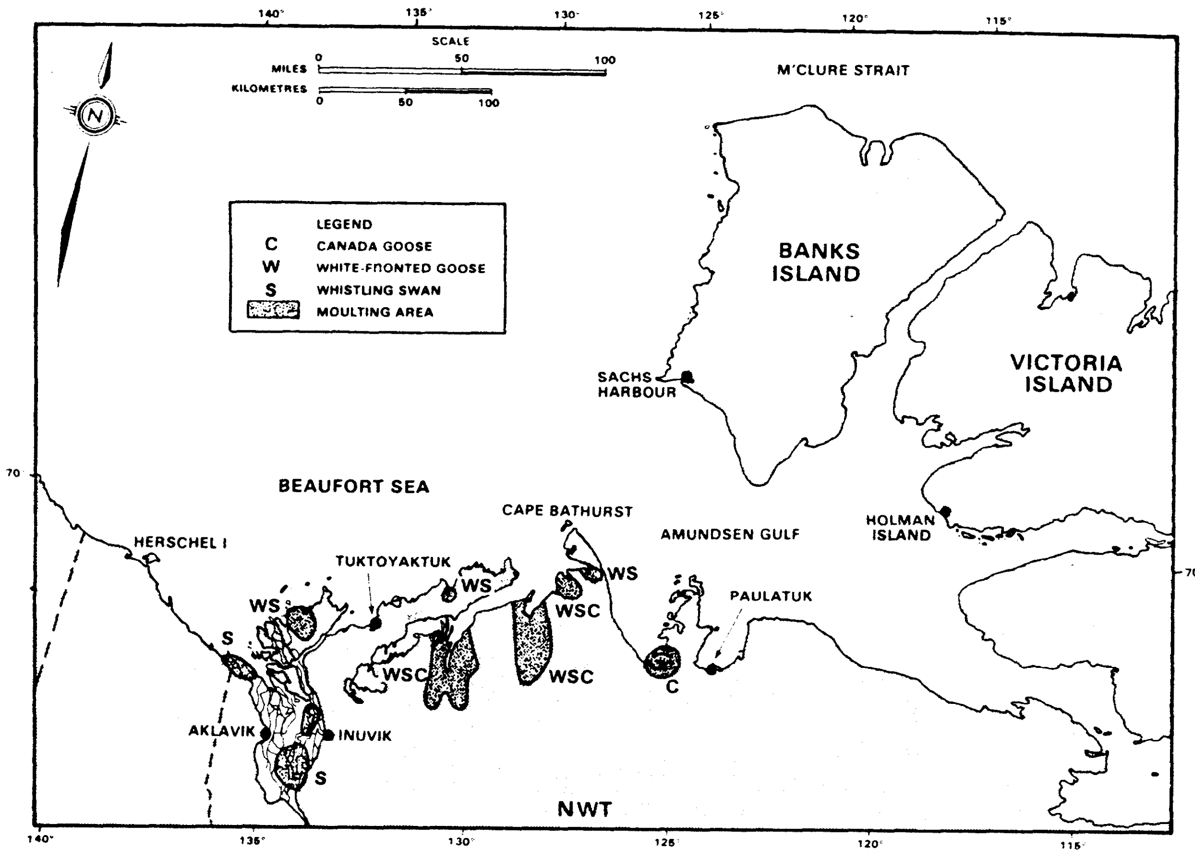

FIGURE 4.2-2 *Major moulting areas for whistling swans, Canada geese and white-fronted geese in the southeastern Beaufort Sea region (from CWS, 1972).*

As fall progresses, the swans move inland to the inner Mackenzie Delta. Large flocks have been recorded in some areas in the inner Delta. Such areas may be used fairly consistently from year to year, but repeated surveys have not been conducted to identify the locations and the degree of use. The last swans to leave the outer Delta include a high proportion of adults with young (Koski, 1977b). Whistling swans from the Alaskan North Slope migrate along the Yukon coast as freeze-up begins, and appear to join the Mackenzie Delta birds. Whistling swans leave the inner Delta from mid September to early October, although some have been recorded in the area as late as October 12 (Porsild, 1943).

4.2.4 GEESE

Four species of geese nest and moult regularly in coastal and adjacent terrestrial areas of the Canadian Beaufort Sea: Canada goose (*Branta canadensis*), brant (*B. bernicla*), white-fronted goose (*Anser albifrons*) and show goose (*Chen caerulescens*). A fifth species, the Ross' goose (*C. rossii*), nests primarily in the Queen Maud Gulf lowlands but a small number may occur in summer on southern Banks Island (Manning et al., 1956; Barry, 1961).

Geese have moderate reproductive potentials. Under favourable conditions some birds of these four species may first nest as two-year-olds; however, most first nest as three-year-olds. The average clutch size is generally 3 to 5 eggs, and replacement clutches are not laid by the Arctic-nesting populations. More than half of the high annual mortality (about 30% for adults and subadults and 50% for immatures) is due to hunting (for review see Bellrose, 1976).

During the breeding season geese are primarily associated with terrestrial habitats, although coastal areas, particularly areas of recent marine emergence, are important or exclusive breeding areas for some of these species. Depending on the species, the distribution of nesting geese varies from highly colonial (snow geese) to loose colonies or aggregations (some brant and white-fronted geese) to widely dispersed nesting pairs (Canada geese; some brant and white-fronted geese). Only the female incubates and, later, broods the young. The male stands guard at the nest and defends the young. Adults moult and are flightless for about three weeks during the brood-rearing period. Subadults also return to the Arctic to moult. These subadults may return to their natal areas to moult or they may use other moulting areas (generally coastal) within the Arctic, sometimes far to the north of the natal areas. Immatures are the first to moult, followed by two-year-olds and adults that failed to nest. Last to moult are brood-rearing adults (for reviews see Bellrose, 1976; Palmer, 1976a; Ogilvie, 1978).

Geese tend to concentrate in traditional staging areas prior to and during both spring and fall migrations in order to replenish or increase energy (fat) reserves required for long migratory flights and/or successful nesting (Patterson, 1974; Ankney and MacInnes, 1978; Raveling, 1979). Geese are largely grazing birds and feed on both aquatic and terrestrial vegetation, although most species forage almost exclusively in terrestrial habitats while in the Arctic.

4.2.4.1 Canada Goose

The Canada goose is indigenous to North America and is numerous and widespread throughout continental areas south to Mexico. In spring 1975 the North American population was estimated to be approximately 2.1 million birds (Bellrose, 1976).

The Canada goose is a regular summer resident of the Beaufort-Chukchi Seas area (Bellrose, 1976). Of the eleven recognized subspecies of Canada geese (Delacour, 1954; Bellrose, 1976), two subspecies of small Canada geese (*B.c. taverneri* and *B.c. parvipes*) nest in the Beaufort-Chukchi area (for reviews see Johnson et al., 1975; Bellrose, 1976; Palmer, 1976a).

Nests of Canada geese are widely dispersed over favourable nesting habitat. One of the preferred habitats of arctic-nesting birds are islets in ponds, lakes, streams, rivers or the ocean (see Bellrose, 1976; Palmer, 1976a; Ogilvie, 1978), but this species shows no affinity for coastal nesting areas.

About 90% of all clutches contain from 4 to 7 eggs (Bellrose, 1976). Incubation requires 24 to 28 days (MacInnes, 1962; Bellrose, 1976); time to fledging varies according to the subspecies. For example, *B.c. hutchinsii* fledges in 52 to 60 days (MacInnes, cited in Bellrose, 1976); *B.c. minima*, a small subspecies, fledges in 40 to 46 days (Mickleson, 1973); and *B.c. moffitti*, a large subspecies, fledges in 71 to 73 days (Sherwood, 1965).

After the young have hatched, family groups often form into brood flocks until the young have fledged and the adults have moulted (MacInnes, 1962). Non-breeding adults, immatures, and some failed-breeding birds, gather in large numbers at traditional moulting areas that are often far to the north of their natal/-breeding areas (Sterling and Dzubin, 1967; Zicus, 1981).

Canada geese that breed in the Beaufort Sea region winter in southeastern Colorado and the Texas Panhandle (Jacobson, 1974). The northward spring migration begins in late winter or early spring and generally proceeds at a leisurely pace. Canada geese nesting in the Beaufort region migrate to breeding areas via overland routes that include the Mackenzie River Valley and usually arrive during May (Jacobson, 1974; Salter et al., 1980). Few birds migrate along the coast (Richardson et al., 1975). Nesting begins by early June. Both breeding adults and their young are capable of flight by mid to late August. Few Canada geese nest in the coastal areas adjacent to the Beaufort Sea (Grieb, 1970; Salter et al., 1980). However, moulting non-breeding birds are known to concentrate in some coastal lowlands (Figure 4.2-2). Non-breeding Canada geese probably arrive at moulting areas during mid to late June and have completed their moult and are capable of flight by mid to late July (Sterling and Dzubin, 1967). The largest concentration of Canada geese recorded in this region was 25,000 moulting birds at the Kugaluk and Smoke River deltas in 1965 (Barry, in Sterling and Dzubin, 1967).

Fall migration occurs primarily overland and few Canada geese stage in coastal areas during migration (Searing et al., 1975; Koski, 1977a,b). Post-moulting birds leave moulting areas as soon as they are capable of flight and proceed to the more southerly staging areas. Most Canada geese have left the Beaufort Sea region by early September.

4.2.4.2 Brant

The brant is the most northerly-nesting goose species and has a circumpolar breeding distribution (Godfrey, 1966; Ogilvie, 1978). Two subspecies of the brant nest in North America: the Atlantic brant (*Branta bernicla hrota*), which nests in northwest Greenland and in the eastern Canadian Arctic; and the balck brant (*B.b. nigricans*), which nests on the westernmost islands of the Arctic Archipelago and along the mainland coasts of the western Northwest Territories, Yukon and Alaska. The black brant is the common subspecies in the Beaufort region; the Atlantic brant is found in this region only as an irregular migrant. The winter population levels of the black brant have remained relatively stable during the past 30 years at approximately 140,000 birds (Bellrose, 1976).

Brant generally nest in coastal meadows, often just above high tide line, and many nests may be lost when storm surges occur during the nesting season (Barry, 1967). Nests are also often placed on the edge of freshwater or tidal pools or on small islets (Bellrose, 1976). Brant may nest in loose colonies, or nests may be widely dispersed (Barry, 1964).

Mean clutch size is 3 to 5 eggs. Incubation averages 24 days and the young are probably capable of flight at 40 to 50 days of age (Barry, 1967; Bellrose, 1976). After the young hatch, the adults and young move to tidal flats where they join flocks consisting of other breeding birds with young and non-breeding moulting birds. Large numbers of non-breeding birds (probably mostly immatures) may move to moulting areas that are far from their natal/nesting areas.

Brant feed almost exclusively on vegetation. They graze on sedges and other tundra vegetation during summer (Barry, 1967), and feed very heavily on eelgrass in the winter (Bellrose, 1976; Palmer, 1976a).

Black brant winter along the coast of Baja California and the adjacent coast of Mexico (Bellrose, 1976). The northward spring migration occurs along the Pacific coast to the major spring staging area at Izembek Bay near the tip of the Alaska peninsula in southwest Alaska. From Izembek Bay black brant migrate into the Beaufort-Chukchi area along various routes, both overland and coastal (Figure 3.3-1, Section 3.3). Some brant fly from the Bering Sea to the Beaufort Sea along the Yukon-Koyukuk Basin and through Anaktuvuk Pass or possibly the Blow River Pass (Cade, 1955; Gabrielson and Lincoln, 1959; Irving, 1960; Einarson, 1965; Johnson et al., 1975). Others migrate from the Chukchi Sea to the Beaufort along the Kobuk, Noatak and Colville River drainages (Bailey, 1948; Gabrielson and Lincoln, 1959; Irving, 1960). The number of brant that use these overland routes is not known but is suspected to be substantial (cf. Richardson and Johnson, 1981).

Spring migrant black brant in the northeast Chukchi - Beaufort Seas consist of birds that summer in the Beaufort region as well as those en route to summering areas to the northeast and east of the Beaufort Sea. It has been speculated that some brant destined for the Arctic Islands may use a coastal route to Point Barrow and then fly a direct offshore route toward Banks Island (Einarson 1965; Barry, 1967). Other black brant may follow a coastal route through the northeast Chukchi and Beaufort Sea. However, most are likely to migrate overland across Alaska, then fly eastward along the coast after reaching the Beaufort Sea in northeast Alaska (cf. Richardson and Johnson, 1981; W.J. Richardson, pers. comm.). At least 20,000 black brant must pass through the Beaufort Sea on route to summering areas east of the Beaufort (Bellrose, 1976; Boyd and Maltby, 1979).

Spring migration of black brant into the northeast Chukchi and Beaufort Seas begins during late May and is rapid. By late May brant have begun to arrive at nesting areas throughout the southern Beaufort Sea and by early June the first brant have arrived at Victoria and Banks Islands (Barry, 1967; Johnson et al., 1975; Johnson, 1979; Richardson and Johnson, 1981). Peak migration occurs during the first two weeks of June (Johnson et al., 1975; Searing et al., 1975; Johnson, 1979).

Of the estimated 4,000 brant that breed along the Beaufort Sea coast from Demarcation Bay to Darnley Bay, about 2,000 breed in the vicinity of the Anderson River delta (CWS, 1972). Smaller colonies occur near Paulatuk (500 birds), at the mouth of the Kugaluk River (400 birds), from Warren Point to Atkinson Point (500 birds), and on islands in the outer Mackenzie Delta (500 birds). Slaney (1974a) reported a colony of approximately 200 nesting brant at an inland location (Denis Lagoon) in the outer Mackenzie Delta (Figure 4.2-3). Scattered individuals nest at other locations along the Canadian Beaufort Sea coast, but total numbers are low. Bellrose (1976) estimates that approximately 17,000 black brant nest along the Alaskan North Slope. An estimated 10,000 brant also nest on western Banks Island (CWS, 1972).

Brant begin nesting along the Beaufort Sea coast in early June. After hatching in early July, broods in coastal areas move to tidal flats where they feed on sedges and marine invertebrates. Adults moult during the brood-rearing period, but are capable of flight by mid August when the young have fledged (Barry, 1967; Johnson et al., 1975).

Non-breeding birds also moult in coastal areas starting in early July (Barry, 1967). Major moulting areas for brant in the Beaufort and northeast Chukchi Seas are shown in Figure 4.2-3. Major moulting areas for non-breeding birds occur outside the Canadian Beaufort region; about 5,000 moulting brant have been recorded on northern Banks Island (CWS, 1972), and between 14,000 and 33,000 moult near Cape Halkett, Alaska (Figure 4.2-3). The Cape Halkett area is an extremely important one and in recent years has been used by 11 to 20% of the entire black brant population (King, 1970; Derksen et al., 1979). In the Canadian Beaufort, the only area where substantial numbers of moulting brant (700 birds) have been reported is McKinley Bay (CWS, 1972), but studies in recent years have recorded few moulting brant there (Searing et al., 1975; Boothroyd and Karasiuk, 1981; Scott-Brown et al., 1981). Non-breeding birds have generally completed their moult by late July (Derksen et al., 1979).

The fall migration of black brant is almost entirely confined to coastal routes and retraces the coastal spring migration routes (Figure 3.3-4, Section 3.3). The migration begins during mid to late August. Brant make frequent stops at lagoons and deltas to feed and rest. The more important fall staging areas in the Beaufort region include Cape Dalhousie, Mallik Bay, Tent Island, the Blow River delta, Phillips Bay and Demarcation Bay (Searing et al., 1975; Koski, 1975a, 1977a, b; Barry et al., 1981). By early September, most brant have left the Beaufort Sea region (Searing et al., 1975; Timson, 1976).

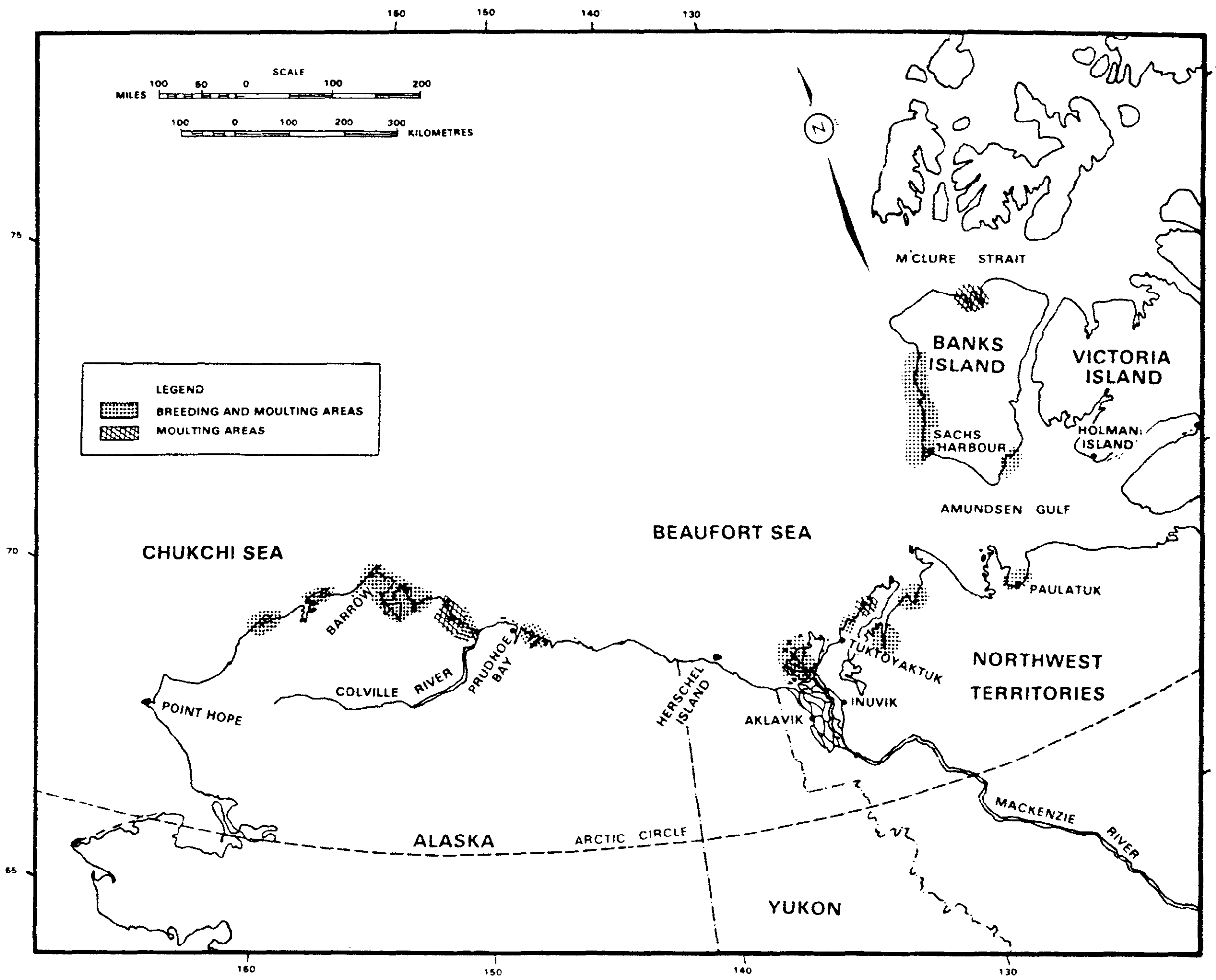

FIGURE 4.2-3 *Breeding and moulting areas of brant in the northeast Chukchi-Beaufort region (based on sources in text). The brant is the most northerly nesting goose species and has a circumpolar breeding distribution.*

4.2.4.3 White-fronted Goose

The white-fronted goose has a circumpolar breeding distribution; the only subspecies which is common in the North American Arctic is *Anser albifrons frontalis* (Bellrose, 1976; Palmer, 1976a). The North American wintering population has averaged about 200,000 birds in recent years and appears to be relatively stable (Bellrose, 1976). North American populations breed in Alaska, the Yukon and Northwest Territories, and winter along the coast of the Gulf of Mexico, in central Mexico and in central California (Bellrose, 1976).

White-fronted geese nest as dispersed pairs, and the yearlings remain close to their parents throughout the nesting period. White-fronts nest on tidal flats or on higher, drier terrain, usually near lakes or rivers (Bellrose, 1976). Clutch sizes average 5 to 7 eggs (Barry, 1967). Incubation requires 23 to 25 days and is done exclusively by the female. Young white-fronts require about 45 days to fledge.

Like other geese, non-breeding white-fronts gather at traditional moulting areas. When they can fly again after moulting, some move to premigratory staging areas. Departure of white-fronted geese from moulting and breeding areas is gradual, and they are known to travel non-stop for long distances between staging areas.

The white-fronted goose is the most abundant species of nesting goose along the mainland coast of the western Canadian Arctic from Demarcation Bay to Darnley Bay. Barry (cited in Bellrose, 1976) estimated a post-breeding population of 40,000 birds in the area, with 25,000 to 30,000 of these in the Kugaluk-Anderson River areas (Barry, 1967; CWS, 1972). In 1966, approximately 50,000 breeders, nonbreeders and young were present on the arctic slope of Alaska during late July and early August (King, 1970). Thus, approximately one third of the North American population of white-fronted geese summers in coastal areas adjacent to the Alaskan and Canadian Beaufort Sea.

The white-front is the first species of goose to arrive in the Beaufort Sea region each spring. The northward overland migration from the Gulf of Mexico and central Mexico is gradual and begins in early February. White-fronts first arrive in the Peace-Athabasca delta in northeastern Alberta during late April to mid May, and in the years from 1959 to 1964 they first arrived at the Anderson River from May 12 to 17 (Barry, 1967). Spring migration to breeding areas east of the Mackenzie Delta occurs overland from the staging areas on the Mackenzie River (between Fort Good Hope and Arctic Red River) to the Kugaluk and Anderson Rivers, which are followed to the coast. Similarly, any birds that summer on the Alaskan North Slope migrate from the Mackenzie River staging areas via overland routes; few white-fronts use the Yukon coast as a spring migration corridor (Johnson et al., 1975; Salter et al., 1980; Richardson and Johnson, 1981).

White-fronted geese begin nesting in late May or early June, and hatching occurs during the last week of June or the first week of July. About the time the young hatch, subadults that have been associated with nesting adults migrate to traditional moulting areas on large inland lakes, river channels and coastal flats along the eastern Beaufort Sea coast (Barry, 1967; Parmelee et al., 1967; Kuyt, 1974; Johnson et al., 1975). The largest moulting area in the Beaufort Sea is located on the Smoke-Moose River flats where in 1965, 20,000 moulting white-fronts were seen mixed with an equal number of Canada geese (Barry, 1967). Other important moulting areas are located on the upper Kugaluk River (4,000; CWS, 1972), Richards Island (4,000; Slaney, 1974a), Anderson River (5,000; CWS, 1972) and the Harrowby Bay area (3,200; CWS, 1972) (Figure 4.2-2). Non-breeding white-fronts have completed their moult by early August, while breeding adults with young are able to fly by about August 20 (Barry, 1967).

The migration of white-fronted geese from the Beaufort Sea region is gradual, beginning possibly as early as mid August and continuing until late September or early October (Barry, 1967). During the migration, large numbers stage in the Mackenzie Delta. In the outer Delta, the major concentration areas are Shallow Bay, Kittigazuit Bay, and the Ellice Island area. Other important staging areas include Phillips Bay, the Blow River delta and Tent Island (Koski, 1975a, 1977a,b). In three of four years when August-September surveys were conducted in the outer Mackenzie Delta (1973-76), estimated peak numbers of more than 19,000 were recorded there (Koski, 1977b). In the fourth year (1976), an estimated peak of only 12,500 was recorded; in that year large numbers (peak count of 18,000) staged on the Yukon North Slope. Since turnover rates are unknown, the total numbers of birds using these staging areas cannot be estimated, but they are likely to be considerably larger than the peak numbers mentioned above.

White-fronted geese that stage in the Mackenzie Delta include birds from the Anderson River delta area as well as birds from the Alaskan North Slope (Koski, 1977b). Anderson River birds that stage in the Mackenzie Delta area are probably present by the fourth week of August (Koski, 1977b). In late August and early September there is an influx of birds from Alaska. Migration watches indicate that most of the birds from Alaska travel along the North Slope inland from the coast (cf. Gollop and Davis, 1974a; Johnson, 1979; Salter et al., 1980). White-fronts are believed to travel non-stop from their Alaskan nesting and moulting grounds to Yukon-Mackenzie staging areas (Koski, 1975a).

By the fourth week of September, most white-fronted geese have departed from the Beaufort Sea region (Koski 1977a,b).

4.2.4.4 Snow Goose

Two distinct subspecies of the snow goose are found in North America. The lesser snow goose (*Chen caerulescens caerulescens*) is the more common, and nests from Baffin Island to Wrangel Island, Siberia. The greater snow goose (*C.c. atlantica*) is restricted to islands in the Arctic Archipelago and western Greenland (Bellrose, 1976). With total estimated populations of approximately 2.5 million lesser snow geese and 100,000 greater snow geese, this species is believed to be the most abundant goose in the world (Kerbes, 1975; Bellrose, 1976).

Snow geese, particularly the lesser snow goose, frequently nest in dense colonies. Colonies are generally located in low grassy tundra on coastal plains, along broad shallow rivers near the coast, and inland on islands in shallow lakes. The largest snow goose colony, which is located at the McConnell River, west Hudson Bay, has contained more than 325,000 nesting birds (Kerbes, 1975).

Clutch sizes for snow geese generally are in the range of 3 to 5 eggs (Bellrose, 1976). The incubation period varies between 19 and 24 days, and the young fledge within 45 days after hatching (Cooch, 1958; Lemieux, 1959; Barry, 1967; Ryder, 1970).

During the brood-rearing period, large aggregations of moulting adults with young and moulting non-breeding birds usually occur in areas adjacent to breeding colonies (Plate 4.2-2). The use of specific brood-rearing areas appears to be traditional (Healey et al., 1980).

After flight is regained, even larger concentrations

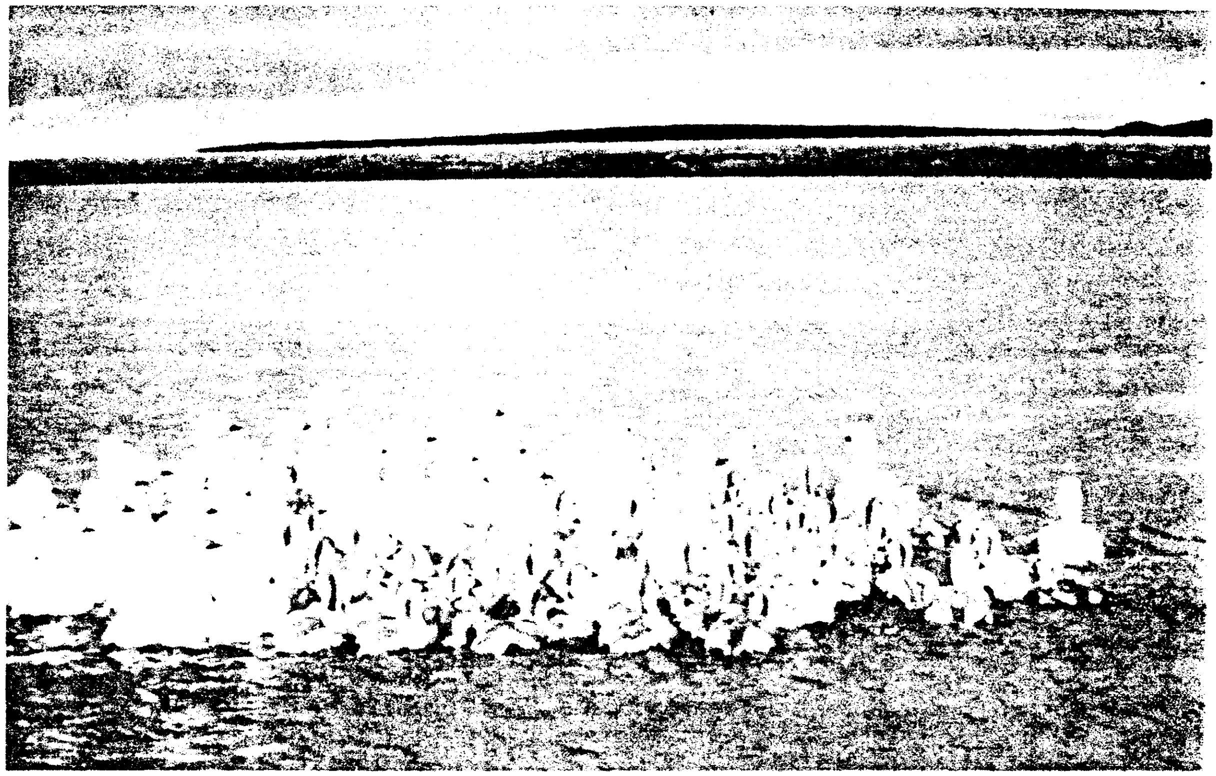

PLATE 4.2-2 *Snow geese with their young. The largest snow goose colony in the western Arctic is along the Egg River on southern Banks Island where approximately 99,000 pairs nested in 1981.*

may occur in premigratory staging areas (Koski, 1977b; Wypkema and Ankney, 1979). Geese greatly increase their fat reserves and juveniles complete growth while on the staging areas. The energy reserves are important for their southward migration (Patterson, 1974; Wypkema and Ankney, 1979).

Snow geese feed almost entirely on vegetation. They feed primarily by grazing in terrestrial areas on the seeds, stems and roots of grasses and sedges, although they may also feed on berries and aquatic plants (Palmer, 1976a; Prevett et al., 1979).

Only the lesser snow goose nests within the Beaufort -Chukchi area. The largest colony of lesser snow geese in the western Arctic is at Egg River on southern Banks Island (Figure 4.2-4). The colony was estimated to contain approximately 82,500 breeding pairs in 1976 and approximately 99,000 pairs in 1981 (R. Kerbes, pers. comm.). Two other colonies, one at the mouth of the Anderson River and another on Kendall Island in the Mackenzie Delta, formerly supported 3,750 and 2,750 pairs, respectively (Barry cited in Bellrose, 1976). The Anderson River colony was estimated to contain approximately 1,900 pairs in 1976 and approximately 4,200 pairs in 1981 (R. Kerbes, pers. comm.). The Kendall Island colony has declined in recent years. R. Kerbes (pers. comm.) estimated the Kendall Island population at approximately 400 pairs in 1976, and in 1979 T. Barry (pers. comm.) observed only about 10 birds at the colony. However, in 1981 there were approximately 500 pairs at this colony (R. Kerbes, pers. comm.). Relatively small numbers of snow geese nest in Alaska. Johnson et al. (1975) suggests that approximately 200 nesting pairs and 2,000 to 3,000 non-breeding snow geese may summer along the Alaskan portion of the Beaufort Sea coast. In recent years there have been small colonies (usually 50 to 60 pairs) on Howe and Duck Islands near Prudhoe Bay (Gavin, 1976, 1980). About 200 snow geese, including subadults, were estimated at these colonies (Welling et al., 1981).

Snow geese that nest in the northeast Chukchi and Beaufort Sea areas migrate from their wintering grounds in California by overland routes. The main migration route is along the Mackenzie Valley. Many birds proceeding to the Banks Island colony stage along the Anderson River (80-100 km inland) or in the Kittigazuit Bay area of the Mackenzie Delta (as many as 75,000 snow geese; Barry cited in CWS, 1972). The latter group fly along the Tuktoyaktuk Peninsula before crossing Amundsen Gulf to Banks Island (Barry, 1967). Some birds migrating to Banks Island may take a more easterly route over Great Slave Lake (Höhn, 1959) and reach the Arctic coast in the Parry Peninsula area. There are spring staging areas in Darnley Bay at the base of the Parry Penin-

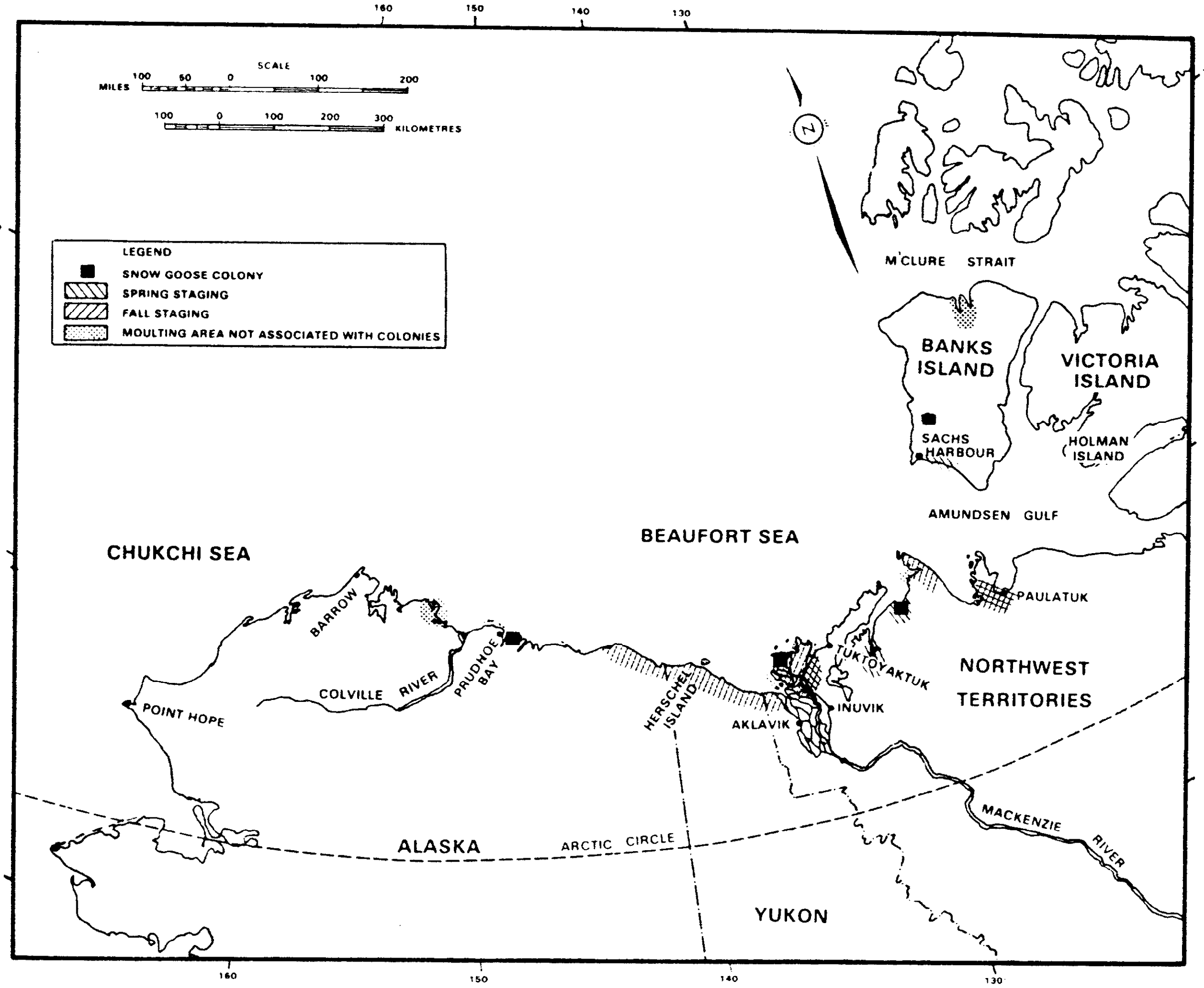

FIGURE 4.2-4 *Nesting, moulting and staging areas of snow geese in the Northeast Chukchi-Beaufort region*

sula and east of Sachs Harbour, Banks Island (Figure 4.2-4) (CWS, 1972). In addition to the geese summering in the eastern Beaufort Sea, some of the few birds that nest along the North Slope may migrate down the Mackenzie Valley and then westward along the coast of Alaska (Johnson et al., 1975; Richardson and Johnson, 1981).

In 1980 and particularly in 1981, relatively few snow geese staged in the Mackenzie Delta during spring migration. Apparently most moved to their colonies via the Anderson and Kugaluk rivers and the Parry Peninsula. Spring melt started early in both years and caused the geese to move to their colonies much more quickly than normal and probably by the most direct route, although in 1980 there was a weather reversal that forced geese from the Banks Island colony. The spring migration of snow geese in 1981 was particularly unusual in that the birds apparently made little or no use of traditional staging areas in Alberta and along the Mackenzie River (T. Barry, pers. comm.).

Snow geese first arrive in the Beaufort Sea-Amundsen Gulf area during mid May. Adult snow geese arrive at their nesting grounds at Anderson River, Kendall Island and Banks Island during the last few days of May or the first days of June (McEwen, 1958; Barry, 1967). In breeding years egg-laying begins very soon after arrival at the colonies and is generally completed by mid June. Hatching takes place in late June or early July (McEwen, 1954, 1958; Barry, 1967).

During the nesting period non-breeding birds congregate at the periphery of the colonies or in traditional moulting areas (Figure 4.2-4). The largest reported concentration of moulting snow geese at a distance from any colony is in the Thomsen River-Castel Bay Migratory Bird Sanctuary on northern Banks Island, where an many as 25,000 birds may moult (CWS, 1972). Recent evidence indicates that some non-breeding snow geese from the Anderson River and possibly from Kendell Island moult near Cape Halkett, Alaska (King and Hodges, 1979). However, numbers of moulting snow geese using this area are fewer than 1,000, and apparently are declining (Derksen et al., 1979).

After the young hatch, broods from the inland Egg

River colony disperse into coastal areas as far north as Storkerson Bay (McEwan, 1958). Brood-rearing and moulting at the coastal colonies on the Anderson and Mackenzie River Deltas takes place in low-lying coastal areas subject to storm surges (McEwan, 1954; Barry, 1967, 1976).

Snow geese may begin to leave the nesting and brood-rearing areas on Banks Island and the Anderson River as early as mid August. Some snow geese, presumably from both of these colonies, may stop and feed for several days at the Parry Peninsula and the mouth of the Horton River (Figure 4.2-4) before proceeding to their main staging areas on the Mackenzie Delta and North Slope (Koski, 1977a,b). The use of specific staging areas by snow geese is dependent upon weather conditions. In years when conditions are favourable on the North Slope, staging snow geese may spread as far west as the Canning River, Alaska, and the Mackenzie Delta area may be little used. However, when early freeze-up and snowfall prevent snow geese from staging on the North Slope, staging may be confined to the Mackenzie Delta (Koski, 1977a,b). Areas that have consistently received heaviest use are the east side of Shallow Bay, the vicinity of the Blow and Walking Rivers, and the Malcolm River delta (Koski and Gollop, 1974; Koski, 1975a, 1977a,b). These staging areas are used by the entire western Canadian population of lesser snow geese which in fall has ranged from 200,000 to 500,000 birds in size.

In 1981, fall migration differed from that described above in that probably half the Banks Island snow geese staged on the Parry Peninsula and flew south from there. As in spring, weather was probably again the major contributing factor (T. Barry, pers. comm.).

The movement from the colonies to the staging areas occurs about the third week of August and the peak of movement occurs during the first week of September. In normal years there is little eastward movement along the coast for two weeks after the birds arrive at the staging areas where they feed and accumulate fat reserves (Patterson, 1974). Movement eastward from the North Slope staging areas normally begins during the second or third week of September (Gollop and Davis, 1974a; Koski and Gollop, 1974) and by October most geese are retracing spring migration routes southward (see Johnson et al., 1975).

4.2.5 DABBLING DUCKS

Dabbling ducks include those duck species that feed on the water surface, in shallow water, or in terrestrial areas, but do not ordinarily dive for food. The diet varies considerably among species, although vegetation forms the major portion of the diet of most species. Food items include seeds, perennial storage organs, and occasionally other vegetative parts of aquatic and semi-aquatic plants. In addition, cereal grains, insects, molluscs, crustaceans and amphipods may also be eaten (Bellrose, 1976; Palmer, 1976a).

Dabbling ducks are highly gregarious at all times of year except during the nesting period. They occur in very large numbers in certain staging, moulting and wintering areas. All species of dabbling ducks are dispersed during the nesting period; they do not nest colonially. All species typically nest on the ground. During years of drought, major displacements of ducks to northern areas have occurred (Hansen and McKnight, 1964; Henny, 1973; Calverley and Boag, 1977; Derksen and Eldridge, 1980), although the reproductive success of ducks displaced to the north is generally lower than that of ducks remaining in the south (Pospahala et al., 1974; Calverley and Boag, 1977).

The reproductive potential of dabbling ducks is high. They are sexually mature at one year of age, have large clutches and, in southern areas, will renest if a clutch is destroyed. However, renesting is either absent or uncommon in Arctic areas (Calverley and Boag, 1977), and renesting in subarctic areas has not been documented. In general, average clutch sizes for dabbling ducks vary between 7 and 10 eggs (Bellrose, 1976), but clutch sizes of northern-nesting dabbling ducks are generally smaller than those of southern nesting birds (Calverley and Boag, 1977).

At the onset of incubation, male dabbling ducks abandon the females and move to moulting areas on large bodies of water. Moulting areas are generally close to breeding areas, but moult migrations of several hundred kilometres are suspected to occur in some species (e.g. pintails, see Bellrose, 1976). Incubation requires 21 to 30 days. The female generally attends her brood until fledging; the wigeon is the only species of dabbling duck that commonly forms creches. The young are capable of flight 34 to 60 days after hatching.

The Beaufort and northeast Chukchi Seas are at the northern extremity of the breeding range of at least seven species of dabbling ducks. These species include mallard (*Anas platyrhynchos*), gadwall (*A. strepera*), pintail (*A. actua*), green-winged teal (*A. crecca*), blue-winged teal (*A. discors*), American wigeon (*A. americana*), and northern shoveler (*A. clypeata*). In all areas east and north of the Bathurst Peninsula, these species are uncommon or occur irregularly (Manning et al., 1956; Parmelee et al., 1967; Smith, 1973; Johnson et al., 1975). The only species that is common throughout the Canadian Beaufort region is the pintail. Mallard, green-winged teal, and American wigeon are relatively common in the Mackenzie and Anderson River Deltas, but are present in low numbers in other areas of the Beaufort region. The northern shoveler is present in low numbers and blue-winged teal and gadwall have been sighted rarely in the Mackenzie Delta (LGL and ESL, 1982). The migration of dabbling ducks to and from nesting areas in the Beaufort region occurs primarily overland, and follows major geographical features such as the valleys of the Mackenzie and Yukon Rivers. However, some pintails, which are common along the Alaskan and Yukon North Slopes, are believed to migrate northwestward along the Yukon-Alaskan coast after following the Mackenzie River to its mouth (Johnson et al., 1975; Bellrose 1976; Richardson and Johnson, 1981). In 1975, pintails were observed migrating northwestward along the Yukon coast from late May through June; however, peak migration occurred in early and mid June (Richardson and Johnson, 1981). In contrast, few pintails have been reported during spring migration watches in areas east of the Mackenzie Delta, probably because few nest there (Slaney, 1974a; Searing et al., 1975; Wiseley et al., 1977).

Dabbling ducks first arrive at the Mackenzie and Anderson River Deltas during mid to late May, and small numbers disperse to areas of coastal tundra from late May to early June. In the Mackenzie Delta, early nesting species such as pintails had started nesting by the first week in June in 1973; however, some nests were still incomplete on June 20 (Slaney, 1974a). The start of nesting by other species of dabbling ducks probably occurs about one week later than that by pintails.

Aerial surveys of the Mackenzie Delta and adjacent coastal areas permit a comparison of relative distributions and densities of dabbling ducks. In general, aerial surveys underestimate the number of ducks present in an area (Martinson and Kazynski, 1967). In addition, there may be considerable variations in densities of dabbling ducks as a result of drought displacement (Hansen and McKnight, 1964). Nevertheless, aerial surveys provide the best available source of information on distribution and relative densities of waterfowl.

Breeding pair surveys conducted during June of each year in the inner Mackenzie Delta by the United States Fish and Wildlife Service demonstrate the variability in densities of waterfowl from year to year (Table 4.2-2). The data are not strictly comparable to those from other studies since the former have been adjusted to account for detectability of various species. During the 1974-1979 period, densities of dabbling ducks averaged $8.79/km^2$, and ranged from $4.64/km^2$ (1975) to $19.42/km^2$ (1977). The high density recorded in 1977 provides an example of northward displacement of ducks during drought conditions on the prairies (Derksen and Eldridge, 1980). The most common species of dabbling ducks in the inner Mackenzie Delta were American wigeon ($3.10/km^2$) and pintails ($2.92/km^2$), although mallards were also relatively common ($1.96/km^2$), particularly during 1977.

Densities of dabbling ducks are probably higher in the inner Delta where the aforementioned surveys were conducted than in the outer Mackenzie Delta or on adjacent tundra areas. For example, Campbell and Weber (1973) recorded 2.60, 2.03 and 0.23 dabbling ducks/km^2 (densities are corrected to include unidentified ducks) during surveys of the southern Mackenzie Delta, the lowlands of the northern Mackenzie Delta, and arctic tundra, respectively. However, since the surveys were flown at variable altitudes and at different times of the year, the densities and species reported by Campbell and Weber (1973) are not directly comparable to those from the breeding pair surveys summarized in Table 4.2-2.

Comparison of other studies show a similar trend. Wiseley et al. (1977) recorded 0.97 (91% pintails) and 0.71 (100% pintails) dabbling ducks/km^2 in the delta lowlands of the northern Mackenzie Delta on June 5 and 20, 1975, respectively. On the tundra to the east of the Mackenzie Delta, Slaney (1974a) recorded 0.39 dabbling ducks/km^2 (67% pintails, 12% wigeon), or $0.43/km^2$ when unidentified ducks were included, during the period June 18-21, 1973. Wiseley et al. (1977) surveyed the same general area in 1975, and recorded 0.23 dabbling ducks/km^2 (77% pintail, 15% green-winged teal) on June 5, and $0.31/km^2$ (80% pintail, 15% mallard) on June 20. On the coastal tundra to the west of the Mackenzie Delta, Wiseley et al. (1977) recorded 0.0 and 0.25 dabbling ducks/km^2 (75% pintail, 25% mallard) on June 5 and 20, 1975, respectively, and Calef and Lortie (1971) recorded $2.20/km^2$ (56% mallard, 44% wigeon) on June 17, 1971. Both of these surveys were of a very small area.

There are no known major moulting areas for pintails in the Mackenzie Delta - Tuktoyaktuk Peninsula area or in nearshore areas of the Beaufort Sea (Slaney, 1974a; Searing et al., 1975; Wiseley et al., 1977). Moulting pintails were recorded in approximately 17 of the 48 coastal areas surveyed by Searing et al. (1975); however, most areas had less than 50 birds, with the exceptions of Pelly Island and Cape Dalhousie where 100 pintails were observed.

Nesting American wigeon are relatively abundant in the inner deltas of the Anderson and Mackenzie Rivers (Barry, 1967; Voelzer and Jensen, 1974, 1975; Smith et al., 1976, 1977, 1978, 1979), but are not abundant in the outer Mackenzie Delta; largest numbers occur there during the latter half of August

TABLE 4.2-2

DENSITIES (ducks/km^2) OF WATERFOWL IN THE INNER MACKENZIE DELTA, 1974-79[1]

	1974	1975	1976	1977	1978	1979	1974-1979
Mallard	0.54	1.21	1.74	5.43	1.31	1.55	1.96
Gadwall	0.00	0.00	0.00	0.00	0.10	0.00	0.02
Pintail	2.42	1.74	3.33	6.98	1.90	1.16	2.92
American wigeon	2.33	1.39	3.96	5.76	3.69	1.49	3.10
Green-winged teal	0.61	0.20	0.20	0.40	0.40	1.42	0.54
Blue-winged teal	0.00	0.00	0.00	0.22	0.00	0.00	0.04
Northern shoveler	0.17	0.09	0.16	0.61	0.09	0.09	0.20
Total dabbling ducks	6.07	4.64	9.39	19.42	7.49	5.71	8.79
Redhead	0.00	0.00	0.00	0.00	0.00	0.12	0.02
Ring-necked duck[2]	0.30	0.17	0.09	0.26	1.02	0.13	0.33
Canvasback	0.16	0.10	0.16	0.37	0.21	0.88	0.31
Scaup sp.	4.11	5.25	7.51	4.41	4.67	6.28	5.37
Goldeneye sp.	0.00	0.12	0.00	0.35	0.00	1.89	0.39
Bufflehead	0.58	0.00	0.00	0.00	0.05	0.05	0.11
Oldsquaw	1.81	2.09	1.32	0.14	2.23	0.77	1.39
Scoter sp.	1.78	0.61	0.80	1.03	1.37	2.28	1.31
Merganser sp.	0.21	0.17	0.41	0.26	0.30	0.47	0.30
Total diving ducks	8.93	8.51	10.27	6.82	9.85	12.87	9.54
Total ducks	15.00	13.15	19.66	26.24	17.34	18.58	18.33

[1]Densities have been calculated from data presented in reports of waterfowl surveys conducted by the U.S. Fish and Wildlife Service (Voelzer and Jensen 1974, 1975; Smith et al. 1976, 1977, 1978, 1979). These indices, unlike those prior to 1974, have been adjusted to correct for visibility of species.
[2]This species has not been recorded by other researchers and may be scaup.

(Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977). Localized concentrations of wigeons were also observed during August 7 through 14, 1974, at two areas between Hutchinson Bay and Atkinson Point (400 to 600 birds), on Pelly Island (200 to 300 birds) and on the Blow River delta (500 birds) (Searing et al., 1975).

Fall migration of dabbling ducks from and through the Beaufort region begins in mid August and extends until mid September. Gollop and Davis (1974a) recorded a peak eastward migration of pintails past Nunaluk Spit, Yukon Territory, on August 20, 1972. Similarly Campbell (1973b) recorded peak southeastward movement of pintails and American wigeon past Point Separation on August 21 of the same year. Relatively large numbers of migrant pintails (low thousands) have been observed moving predominantly eastward at Moose Channel (Searing et al., 1975), while only a few have been observed near Prudhoe Bay, Alaska (Johnson, 1979) and east of the Mackenzie Delta (Searing et al., 1975). Slaney (1974a) estimated that the major departure of dabbling ducks from the outer Mackenzie Delta occurred between September 9 and 18 in 1973. However, some may remain in the Beaufort region as late as there is open water; Slaney (1974a) recorded 60 dabbling ducks south of Olivier Islands on October 4, 1973.

4.2.6 DIVING DUCKS

Diving ducks are highly aquatic birds that obtain food during dives below the water surface (Godfrey, 1966). Major food items include aquatic vegetation, various small fish and small invertebrates such as bivalves, mysids, amphipods, and copepods, and small quantities of aquatic vegetation (Bellrose, 1976; Divoky, 1978b). All species can dive to depths well over 10 m, and oldsquaws have been caught in fishing gear at depths of 60 m (Palmer, 1976b).

In general, diving ducks are highly social and occur in large flocks during migration, staging and moulting. Most species nest as dispersed pairs, and nest on the ground on islands, in emergent vegetation or on shores. After incubation begins, the males gather in large flocks and may undertake long migrations to moulting areas. The males moult during July and August, while females incubate the eggs and moult during the incubation or brood-rearing period. Both sexes are flightess during the moult (Boyd, 1962; Bellrose, 1976). Incubation requires from 22 to 34 days depending on species (Godfrey, 1966). Several species merge their broods into creches (Bellrose, 1976). The young of most species are able to fly from 45 to 70 days after hatching, but young of Arctic nesting eiders and oldsquaws may be capable of flight after 30-35 days (Bellrose, 1976).

At least 17 species of diving ducks have been recorded in the Mackenzie Delta and along coastal areas of the Beaufort Sea. The common species include oldsquaw, king eider, common eider, surf scoter, white-winged scoter and greater scaup. The first three species occur in offshore and coastal areas during spring and fall migration and/or in nearshore bays and lagoons during the annual moulting period, whereas the last three species are locally abundant in coastal areas during the moulting period and migrate via overland routes. The remaining eleven species of diving ducks also migrate overland and occur regularly or intermittently in low numbers throughout the Beaufort region.

4.2.6.1 Scaup

Two species of scaup, greater scaup (*Aythya marila*) and lesser scaup (*Aythya affinis*), occur in the Beaufort-Chukchi area, but the greater scaup is more abundant. Greater scaup breed in the tundra and boreal forest zones from Iceland eastward across northern Scandinavia, northern Russia, northern Siberia and the western Arctic in North America (Bellrose, 1976). Greater scaup winter on the Great Lakes, and on the Atlantic, Pacific and Gulf of Mexico coasts of North America; the largest numbers winter on the Atlantic coast (Bellrose, 1976). Most greater scaup that occur in the western Arctic apparently migrate along inland routes that cross the North American continent in a northwest-southeast line (Bull, 1974; Bellrose, 1976).

Although North American lesser scaup have an extensive breeding range, most of it lies to the south of the Beaufort-Chukchi area. Small numbers of lesser scaup may reach the Beaufort Sea in the region from the Yukon North Slope to Liverpool Bay (Porsild, 1943; Cowan, 1948; Johnson et al., 1975; Bellrose, 1976; Salter et al., 1980), but recent studies indicate that they are very uncommon (Barry, 1967; Campbell and Weber, 1973; Slaney, 1974a; Salter et al., 1980).

Because the two species of scaup are difficult to distinguish, except when birds are viewed at close range, they are discussed as a group. However, almost all scaup seen in the Beaufort-Chukchi area are greater scaup.

The combined North American population of lesser and greater scaup is greater than that for any other duck species except the mallard. Recently, North American summer populations have averaged approximately 7 million birds. There was no clear upward or downward trend in population levels of scaup in the years 1955 through 1975 (Bellrose, 1976).

Scaup arrive in the Mackenzie Delta in late May (Slaney, 1974a). They are apparently abundant as nesting birds only in the Mackenzie Delta-Liverpool Bay area and along the Yukon North Slope (Barry, 1967; Campbell and Weber, 1973: Slaney, 1974a; Wiseley et al., 1977; Salter et al., 1980). They are rare or absent in regions north or east of the Bathurst Peninsula (Manning et al., 1956; Parmelee et al., 1967; Smith, 1973). Gabrielson and Lincoln (1959) reported that, in Alaska, lesser scaup are interior-nesting birds and that greater scaup, which nest in and near coastal regions, are uncommon in northern Alaska.

Scaup are the most abundant species of nesting ducks in the inner Delta (Table 4.2-2). Surveys conducted in the Shallow Bay-Blow River area, Kittigazuit Bay and certain areas on the outer coast of Richards Island during June have indicated densities of scaup in the range from 0.5 to 3.1 birds/km^2 (Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977). During aerial surveys on June 20, 1975, Wiseley et al. (1977) recorded densities, in scaup/km^2, of 1.9 in the lowland portion of the outer Mackenzie Delta, 0.4 on the coastal tundra west of the Delta, and 0.9 on upland tundra to the east of the Mackenzie Delta. Slaney (1974a) recorded 0.6 scaup/km^2 on the east side of the Mackenzie Delta during aerial surveys on June 18 to 21, 1973. Calef and Lortie (1971) recorded 1.2 scaup/km^2 on the Yukon Coastal Plain west of the Delta on June 17, 1971. All studies have indicated a decrease in the number of birds during July, probably because of the movement of males to moulting areas elsewhere (Campbell and Weber, 1973; Slaney, 1974; Wiseley et al., 1977; Searing et al., 1975).

Scaup moult on large freshwater lakes in the Mackenzie Delta or in coastal marine waters (Searing et al., 1975; Barry, 1976; Barry et al., 1981). Scaup that moult in coastal areas of the southeastern Beaufort occur primarily along the outer Tuktoyaktuk Peninsula and in Liverpool Bay (Searing et al., 1975; Barry, 1976; Barry et al., 1981). During aerial surveys of coastal areas in mid July, late July and mid August

1980. Barry et al. (1981) reported concentrations of moulting scaup at Hutchinson Bay, Wood Bay, McKinley Bay, Ikpisugyuk Bay and Harrowby Bay. The maximum recorded densities (scaup/km^2) of moulting scaup were 227.1 and 219.2 at Hutchinson Bay and Wood Bay, respectively, during the mid August survey (approximately 5,000 and 7,000 birds respectively). In 1974, Searing et al. (1975) observed 3,500 moulting scaup between Toker Point and Tuft Point. Few moulting scaup are known to occur along the Yukon coast (Searing et al., 1975; Vermeer and Anweiler, 1975).

The fall migration of scaup from the eastern Beaufort Sea generally begins during late August (Searing et al., 1975) and most have left the region by mid September. The majority migrate southward along the Mackenzie River Valley (Salter, 1974a).

4.2.6.2 Oldsquaw

Oldsquaw (*Clangula hyemalis*) are circumpolar in their breeding distribution and are perhaps the most abundant ducks nesting in the Arctic. The North American spring population of this species is estimated at between three and four million birds (Bellrose, 1976). Estimates of the breeding oldsquaw population in the Beaufort-Chukchi region include 125,500 along the Alaskan North Slope, 208,000 in the Old Crow flats, Mackenzie Delta and Liverpool Bay area (Bellrose, 1976), 6,000 (Barry, 1960) and 60,000 (Manning et al., 1956) on Banks Island, and 20,000 on southeast and northwest Victoria Island (Barry, 1960).

The spring migration of oldsquaws from their wintering grounds in the north Pacific to the Beaufort and Chukchi seas is believed to follow a mainly coastal route around Alaska (Bellrose, 1976), although some overland migration does occur (Irving, 1960). The migration usually begins during the first half of May when the first leads develop in the ice near Point Barrow and offshore (Gabrielson and Lincoln, 1959). Early migrants probably travel along a direct route far offshore between Point Barrow and Banks Island (LGL and ESL, 1982). By late May and early June, migrating oldsquaw are commonly observed along the Beaufort Sea coast of Alaska and the Yukon, and at the Mackenzie Delta (Richardson and Johnson, 1981).

Aerial surveys have indicated that migrant oldsquaw (and many king and common eiders) stage in recurring leads and polynyas during late May and early June. Potentially important areas include the leads off the west coast of Banks Island, the Amundsen Gulf polynya, and the lead off Cape Dalhousie (Figure 4.2-5). On May 29, 1974, nearly 24,000 oldsquaws were reported in a lead offshore from Storkerson Bay, Banks Island; however, numbers in the lead decreased rapidly after this date and few were recorded in early June (Searing et al., 1975). Barry et al. (1981) conducted surveys of the lead from Herschel Island to Baillie Islands, the lead off the west coast of Banks Island, and the Amundsen Gulf polynya on June 5 and 9, 1980. Although oldsquaws were observed on 82% of transects, densities were generally low (average = 2 oldsquaw/km^2). The highest density (14.6 oldsquaws/km^2) was observed off the southwest coast of Banks Island. During a similar survey on June 9, 1981, Barry and Barry (1982) recorded the largest densities (54.4 and 34.6 oldsquaws/km^2) on two transects off Cape Dalhousie and the lowest (0.3 oldsquaws/km^2) off the coast of Banks Island. Overall, densities in 1981 averaged 7.1 oldsquaws/km^2. The total number of oldsquaws that migrate into and through the Beaufort Sea in spring is poorly known.

Oldsquaws begin to arrive at their breeding grounds in late May and early June (Manning et al., 1956; Parmelee et al., 1967; Slaney, 1974a; Bergman et al., 1977). Breeding pairs disperse to the nesting habitat when the snow has melted enough and this usually occurs during mid to late June (Manning et al., 1956; Parmelee et al., 1967; Bergman, 1974; Slaney, 1974a; Bergman et al., 1977). Nesting oldsquaws are widely distributed near lakes and ponds in both inland and coastal tundra areas adjacent to the Beaufort and northeast Chukchi seas (Godfrey, 1966; Alison, 1975; Bellrose, 1976). The densities of oldsquaws in the inner Mackenzie Delta in the years 1974 through 1979 are indicated in Table 4.2-2. The densities in most other areas of the region are in the order of 0.9 to 3.0/km^2 (see LGL and ESL, 1982).

Brood surveys conducted on the upland tundra to the east of the Mackenzie Delta in late July 1973 recorded 6.90 adult diving ducks and 1.28 broods/km^2 of waterbody surveyed (Poston, 1977). Similar surveys conducted on the Yukon North Slope in 1972 (Gollop and Davis, 1974b) indicated that there were 24.4 adult diving ducks/km^2 (65% oldsquaw, 34% scaup) and 1.16 broods/km^2 of waterbody. In these results, unidentified waterfowl are included in the same proportion as identified waterfowl, and unidentified broods are assumed to be diving ducks. Similarly, 36.1 adult diving ducks/km^2 (80% oldsquaw, 17% scaup) and 0.82 broods/km^2 were recorded in the same area in 1973 (Sharp et al., 1974).

Immature oldsquaws are believed to migrate to the Beaufort and Chukchi area in summer to moult, and gather on lakes and along the coast (Palmer, 1976b). In late June and early July, they are joined by adult males which leave the nesting areas after the females begin incubating their eggs. Greatest concentrations of moulting yearlings and adult males occur along

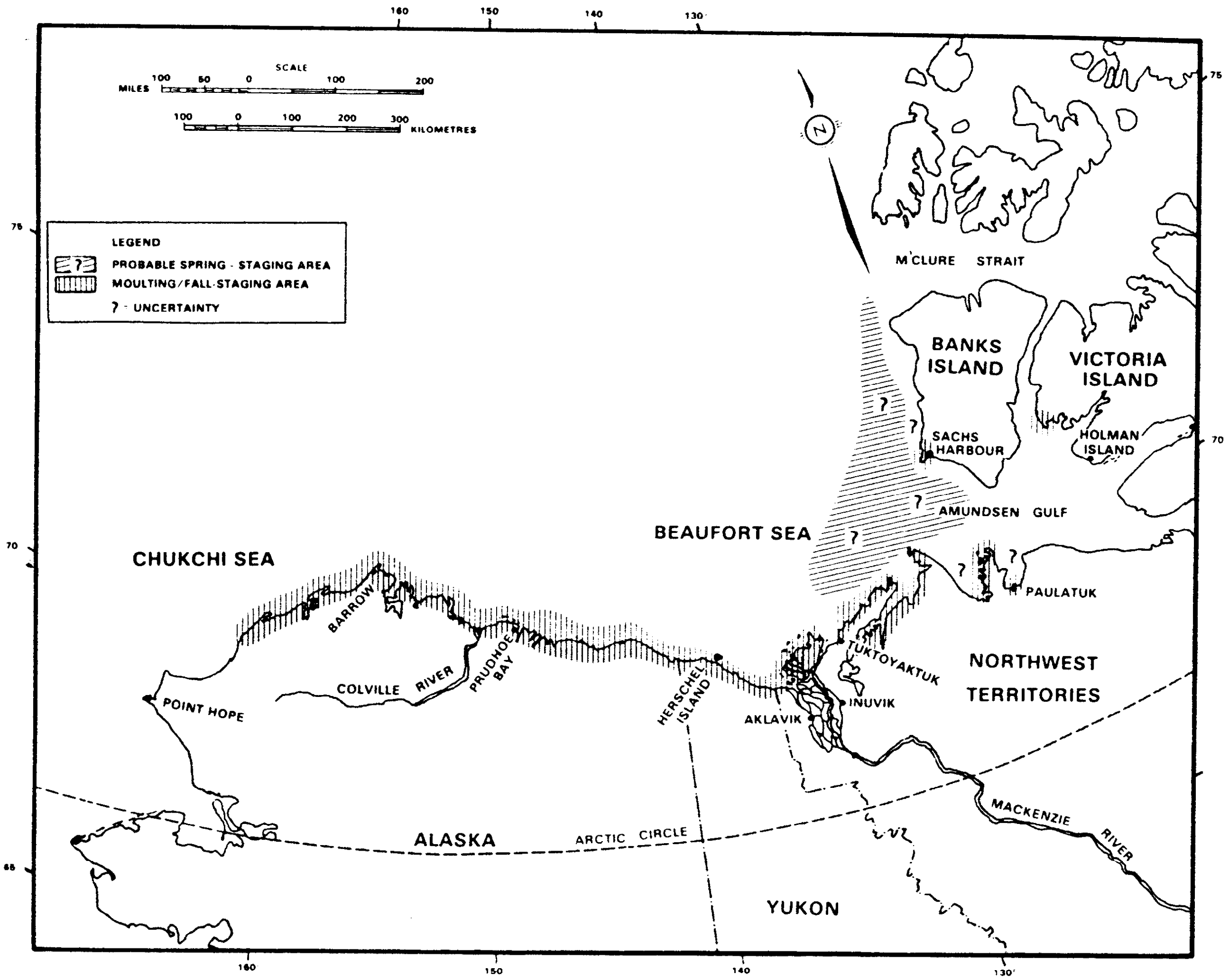

FIGURE 4.2-5 *Spring-staging, moulting and fall-staging areas of oldsquaws in the northeast Chukchi-Beaufort region (based on sources in text). Oldsquaws are circumpolar in their breeding distribution and are perhaps the most abundant ducks in the Arctic.*

the coast (Bergman, 1974; Searing et al., 1975; Palmer, 1976b). Adult females move to the coast with their young in late August and early September (Bellrose, 1976; Johnson and Richardson, 1981). Moulting and fall staging areas for oldsquaws in the Beaufort and Chukchi region are indicated on Figure 4.2-5. Most studies have found peak numbers of moulting oldsquaws during mid to late July (Barry et al., 1981; Johnson and Richardson, 1981), but the abundance and distribution of these birds in coastal areas apparently varies from year to year. In late July 1981, Barry and Barry (1982) recorded 11,992 oldsquaw along the coast between Nunaluk Spit and Cape Bathurst, including Liverpool Bay. Of this total, about 1,400 were recorded along the Yukon coast. In late July 1980, Barry et al. (1981) recorded 12,928 oldsquaw along the coast between Nunaluk Spit and Cape Bathurst. About 5,600 of these birds were along the Yukon coast. In early August 1974, approximately 8,000 were recorded between Nunaluk Spit and Cape Dalhousie, and of these, 1,000 were along the Yukon coast (Searing et al., 1975). In 1973, approximately 1,600 were recorded along the Yukon coast (Vermeer and Anweiler, 1975). In early August 1978, Johnson and Richardson (1981) recorded 40,000 oldsquaw in barrier island lagoons between Thetis Island, Alaska and the Canadian border. In late July 1979, they recorded about 61,400 oldsquaw in approximately the same area as during the 1978 survey.

Migration of oldsquaws from the Beaufort and Chukchi region follows coastal and probably offshore routes, and begins in late August (Bailey, 1948; Johnson, 1971; Gollop and Davis, 1974a; Searing et al., 1975; Timson 1976; Johnson, 1979). Initially most migrants are adult males and possibly yearlings. The proportion of females in coastal areas begins to increase in early September (Johnson, 1979). Most oldsquaws have left the region by late October (Gabrielson and Lincoln, 1959). Fall staging areas for oldsquaws occur along the entire coastline of the Beaufort and Chukchi region, although large concentrations have been observed only in barrier island lagoons in Alaska. For example, 100,000 staging oldsquaws were observed in Simpson Lagoon on

September 22, 1977, and 30,000 on September 23, 1978 (Johnson and Richardson, 1981).

4.2.6.3 Common and King Eiders

Common eiders (*Somateria mollissima*) and king eiders (*S. somateria*) are discussed together because their movements and distributions in the Beaufort-Chukchi region are very similar, and because the two species are often indistinguishable during surveys.

Both eider species are more-or-less circumpolar in their nesting distributions, and both nest through most of Arctic North America. However, the nesting range of the common eider, unlike the king eider, extends through boreal areas (Godfrey, 1966; Bellrose, 1976). North American population levels of these two species are not well known. Bellrose (1976) speculates that they are from 1.5 to 2 million for common eiders and from 1 to 1.5 million for king eiders.

The breeding range of the common eider includes coastal areas throughout the Beaufort-Chukchi region and Amundsen Gulf (Figure 4.2-6) (Bellrose, 1976; Palmer, 1976b). Common eiders may nest as single pairs, in loose colonies, or in dense colonies. Nests are usually close to the sea, generally on small islands or islets (Bellrose, 1976). The numbers and distribution of common eiders nesting in the Beaufort-Chukchi area is reasonably well known. In 1976, Divoky (1978a) surveyed all the barrier islands from Cape Lisburne to Demarcation Bay, Alaska, and recorded 586 nests in the Chukchi Sea and 420 in the Beaufort Sea. Surveys in the Canadian Beaufort Sea and Amundsen Gulf are less complete but cover most of the coast. Minor concentrations of nesting birds have been reported at Nunaluk Spit on the Yukon coast (approximately 30 nests; Gollop et al., 1974; Salter et al., 1980) and at Phillips Island on the outer coast of the Tuktoyaktuk Peninsula (100-200 nests; J. Ward, pers. comm.). Common eiders were not reported to nest on barrier islands off the Mack-

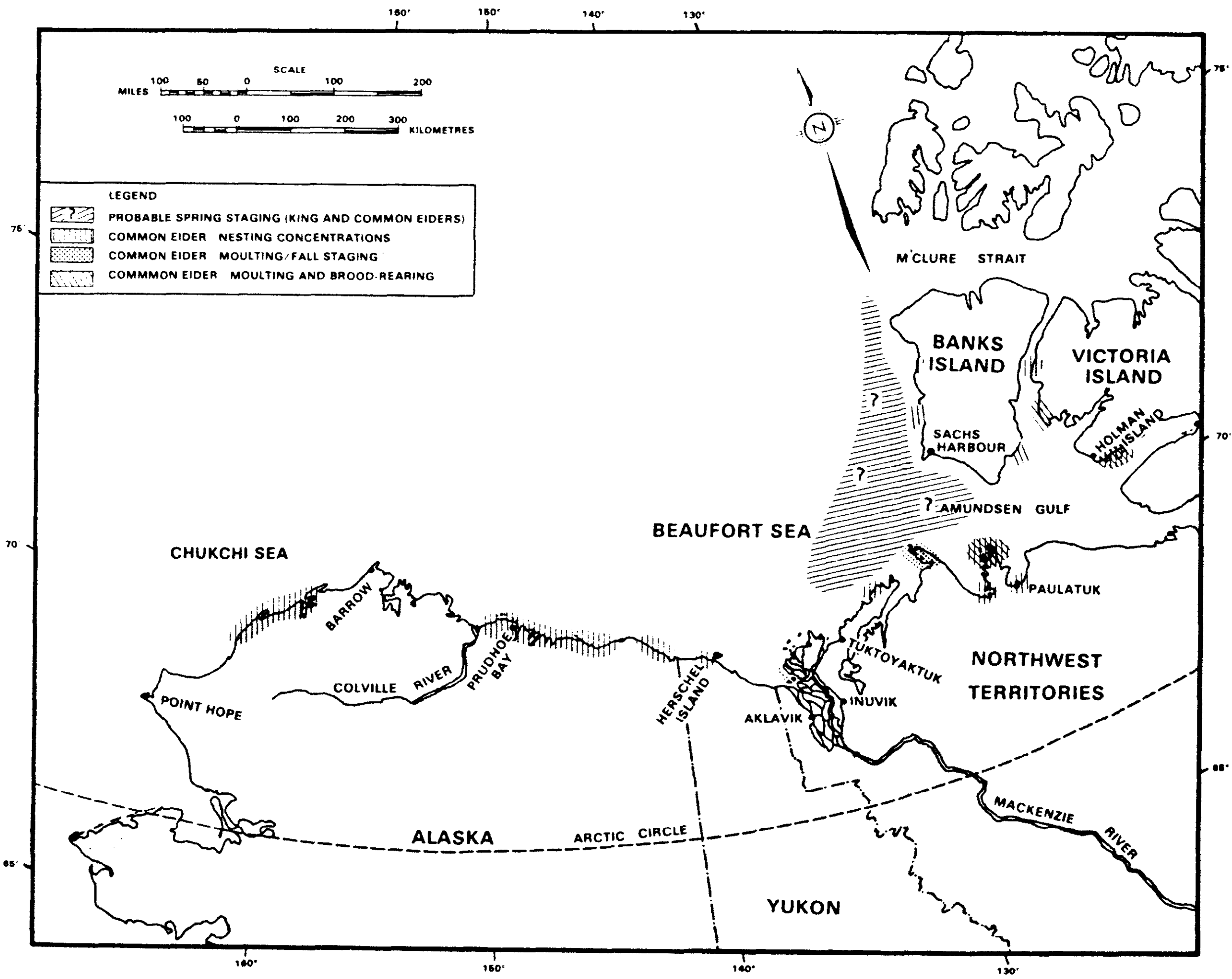

FIGURE 4.2-6 *Staging, nesting, brood-rearing and moulting areas of eiders in the Northeast Chukchi-Beaufort region (based on sources in text).*

enzie Delta in 1972-1974 (Slaney, 1975) and Kuyt (1974) suggested that few nested along the Tuktoyaktuk Peninsula. Three nesting areas are known for the Parry Peninsula area. Ward (1979) reported 50+ nests at Cape Parry and CWS (1972) reported 500 pairs of common eiders (T. Barry, pers. comm.) nesting at the base of the Parry Peninsula and in the deltas of the Hornaday and Brock rivers. Barry (pers. comm.) has also recorded several hundred common eiders nesting in the Langton Bay area on the western side of the Parry Peninsula. In the eastern Amundsen Gulf, Barry and Barry (1982) reported two colonies in the Investigator Islands in Prince Albert Sound, one numbering a minimum of 500 to 600 nesting birds and the other a minimum of 100. In Prince of Wales Strait, a colony of unknown size was located on the Princess Royal Islands. Other colonies have also been reported for Dolphin and Union Strait (McLaren and Alliston, 1981; Barry and Barry, 1982). On the west and south coasts of Banks Island, Manning, et al. (1956) reported a small colony (5 nests) in De Salis Bay and a colony of about 250 nesting common eiders on Moose Island at the mouth of the Big River. There are no recent reports on these two colonies.

The king eider also nests throughout most of the Beaufort - Chukchi region (Bellrose, 1976). The nests of king eiders are widely dispersed in coastal tundra areas with lakes, ponds and streams (Godfrey, 1966; Bellrose, 1976), although small numbers also nest on coastal barrier islands (Schamel, 1974; Divoky, 1978b; Johnson, 1979). King eiders are less associated with the sea during the breeding season than are common eiders. Approximately 10,000 king eiders are believed to summer along the Alaskan North Slope (Bellrose, 1976), but this species is absent or occurs only infrequently in areas between the Alaska-Yukon border and Bathurst Peninsula (Barry, 1967; Kevan, 1970; Slaney, 1974a; Salter et al., 1980). However, in the eastern Beaufort, Manning et al. (1956) estimated that 150,000 nested on Banks Island, while Barry (1960) estimated late summer populations of 100,000+ on Banks Island and 800,000 on Victoria Island.

Both species of eiders winter primarily in the Bering Sea (Gabrielson and Lincoln, 1959; Godfrey, 1966; Bellrose, 1976), although a few common eiders may winter in both the Chukchi and Beaufort seas (Gabrielson and Lincoln, 1959; Parmelee et al., 1967). In the Chukchi Sea, the spring migration of both species begins in April and is along the coast of Alaska (Myres, 1958; Johnson, 1971; Flock, 1973). However, after passing Point Barrow, most migrants probably travel far offshore across the Beaufort Sea on a direct route to the Arctic Islands (Flock, 1973; Richardson and Johnson, 1981). Although reliable estimates of the numbers of eiders migrating into and through the Beaufort-Chukchi region are not available, several authors have suggested that one million birds may be involved (Thompson and Person, 1963; Barry, 1968; Johnson, 1971; Timson, 1976). Barry (cited in Bellrose, 1976) suggested that approximately 75% of spring migrant eiders in the Beaufort Sea were king eiders (see also Richardson and Johnson, 1981).

Migrant eiders are believed to stage in offshore leads and polynyas in the northeast Chukchi and Beaufort seas until open water begins to appear in coastal areas (Flock, 1973; Richardson and Johnson, 1981). In the Beaufort Sea and Amundsen Gulf, spring migrant eiders generally first appear in mid to late May (for review see LGL and ESL, 1982). In early June of 1980, Barry et al. (1981) found both species on virtually all transects surveyed along the ice edges off the Tuktoyaktuk Peninsula, around the Amundsen Gulf polynya, and along the lead off western Banks Island (Figure 4.2-6). The highest densities of common eiders were found from Nuvorak Point to Cape Dalhousie at the eastern end of the Tuktoyaktuk Peninsula, and at Baillie Islands. In 1974, Searing et al. (1975) found 75,000 staging common eiders in a large lead off Liverpool Bay in this same general area. Barry et al. (1981) found high densities of king eiders using the lead off the west coast of Banks Islands between Bernard Island and Cape Kellett in 1980, and Barry and Barry (1982) found even higher densities in this area in 1981.

Both eider species move to nesting areas as soon as the areas are snow and ice-free, which occurs in late May or early June, and begin laying in mid to late June. Hatching occurs from about mid July to early August (Parmelee et al., 1967; Schamel, 1974, 1977; Divoky, 1978a). Female common eiders nesting on islands move their broods to the sea shortly after they hatch (Schamel, 1974), while those nesting in tundra areas, as well as most king eiders, may use freshwater areas for varying lengths of time before moving to the coast (Cooch, 1965; Parmelee et al., 1967; Bellrose, 1976; Ward, 1979).

Males leave the breeding areas soon after the females begin incubation and, in July, migrate westward to moulting areas in the Chukchi and/or Bering seas (Manning et al., 1956; Thompson and Person, 1963; Johnson, 1971; Schamel, 1974). However, not all non-nesters leave the Beaufort region during summer. Concentrations of presumably moulting common eiders have been recorded near Cape Parry (8,000; Ward, 1979), along the Tuktoyaktuk Peninsula and in Liverpool Bay (3,000; Barry, 1972), and off Banks Island (1,500; Manning et al., 1956). Smith (1973) also recorded moulting common eiders near Holman, Victoria Island.

The western movement of eiders across the Beaufort Sea apparently occurs offshore over a broad front

(Searing et al., 1975; Divoky, 1978c; Johnson and Richardson, in press) except at Cape Bathurst in the southeast Beaufort (Anderson, 1937) and at Point Barrow in the extreme west. Few have been recorded in intervening coastal areas (Gollop and Davis, 1974a; Johnson and Richardson, in press). At Point Barrow they follow the coastline closely when they round the point and head southwest through the Chukchi Sea (Johnson, 1971; Flock, 1973). Migrants passing Point Barrow prior to early August are primarily males; after this time females and, later, young predominate (Thompson and Person, 1963; Johnson, 1971; Timson, 1976). Migration continues until late October (Gabrielson and Lincoln, 1959). Estimates of numbers passing Point Barrow include 800,000 (5% common, 95% king) between July 13 and September 7, 1970 (Johnson, 1971) and 1,000,000 in total (Timson, 1976). The former estimate does not include maternal females and young and neither estimate includes eiders migrating offshore.

Migration of king and common eiders from the Beaufort area appears to be rapid; there is little evidence that many birds remain for long in offshore areas (Searing et al., 1975; Bartonek et al., 1977; Divoky, 1978c). However, staging may occur offshore in the Chukchi Sea between Point Lay and Cape Lisburne (Springer and Roseneau, 1979).

4.2.6.4 Scoters

Two species of scoters are relatively common summer residents of the Beaufort and northeast Chukchi seas: the surf scoter (*Melanitta perspicillata*) and the white-winged scoter (*M. deglandi*). Both species winter along the Atlantic and Pacific coasts, and migrate overland to the nesting areas in this region (Bellrose, 1976). The combined North American population for the above two species and the black scoter *(M. nigra)* is estimated at 1.5 million (Bellrose, 1976).

Most scoters nest in mainland areas south of the Beaufort and northeast Chukchi seas. Surf scoters are uncommon nesters in the Mackenzie Delta and in the Alaskan and Yukon North Slope areas (Bellrose, 1976), whereas the breeding range of the white-winged scoter extends from the Mackenzie Delta east to the Bathurst and Parry peninsulas. However, nesting white-winged scoters are only common in the Mackenzie and Anderson river deltas (Table 4.2-2) (Barry, 1967; Slaney, 1974a; Wiseley et al., 1977; Salter et al., 1980). Surveys of the outer Mackenzie Delta, the Yukon Coastal Plain and the tundra east of the Mackenzie Delta have recorded densities ranging from less than 0.1 to 1.6 white-winged scoters/km^2 (Calef and Lortie, 1971; Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977).

The peak of scoter activity in the Beaufort and Chukchi seas occurs during the period from late June to late August when thousands of surf and white-winged scoters, mostly males and non-nesting females, migrate from freshwater nesting grounds to coastal moulting areas (Johnson and Richardson, in press). The results of various studies suggest that the number of scoters summering in coastal areas of the Beaufort may vary from year to year. Several authors have reported up to several thousand surf scoters near Herschel Island in summer (Vermeer and Anweiler, 1975; Salter et al., 1980; Barry et al., 1981). Numbers of scoters have been observed in other areas during summer such as 200 to 300 in Harrison Bay, Alaska, in August 1971 (Hall, 1975); 980 males in Beaufort Lagoon, Alaska, on June 28, 1970 (Andersson, 1973); and 3,700 along the coast from Nunaluk Spit east to and including Tuktoyaktuk Peninsula during August 7 to 14, 1974 (Searing et al., 1975). Farther east, where white-winged scoters comprised 33-50% of the scoters seen, concentrations occurred at the head of Liverpool Bay (2,210 birds), in Wood Bay (2,024 birds), at Maitland Point (6,000 birds) and in Harrowby Bay (3,269 birds) (Barry et al., 1981). Several thousand scoters were recorded in McKinley Bay in 1981 and lesser numbers in 1980 (Boothroyd and Karasiuk, 1981; Scott-Brown et al., 1981).

4.2.6.5 Other Diving Ducks

Nesting red-breasted mergansers (*Mergus serrator*) are uncommon in the Beaufort Sea region (Barry, 1967; Campbell and Weber, 1973; Pitelka, 1974; Slaney, 1974a; Wiseley et al., 1977). They are occasionally seen along the ice-edge during spring, with the largest concentrations observed during surveys in June 1980 near the Moose River-Smoke River flats (Barry et al., 1981).

The number of moulting red-breasted mergansers (mostly males) in coastal areas varies among areas and years. For example, only a few were recorded in the southeastern Beaufort Sea during late July and early August 1974 (Searing et al., 1975), and Barry et al. (1981) counted only a few hundred mergansers along the coast of the southeastern Beaufort in July 1980. On the other hand, Ward (1979) observed 2,000 moulting birds in a relatively small area around Cape Parry in the Amundsen Gulf in late July 1979.

In the Beaufort-Chukchi region, spectacled eiders (*Somateria fischeri*) and Steller's eiders (*Polysticta stelleri*) nest as far east as the Alaska-Yukon border (Godfrey, 1966; Salter et al., 1980). Black scoters occur only as stragglers or uncommon transients in areas west of the Mackenzie Delta. Other species that occur regularly in low numbers in coastal areas of the Canadian Beaufort Sea region include canvasback (*Aythya valisineria*), common goldeneye (*Bucephala clangula*) and possibly ring-necked duck (*A. colla-*

ris). The canvasback is included in the 'blue list' of North American birds because the population is at a low level (Tate, 1981). The five remaining species that occur in very low numbers or are recorded in low to moderate numbers intermittently are redhead (*A. americana*), Barrow's goldeneye (*B. islandica*), bufflehead (*B. albeola*), harlequin duck (*Histrionicus histrionicus*) and common merganser (*Mergus merganser*) (LGL and ESL, 1982).

4.2.7 RAPTORS

Raptors (hawks, eagles, falcons and owls) are predators that hunt and kill other animals for their food. They are comparatively specialized feeders and some species prey primarily on birds (e.g., peregrine falcon), some on mammals (e.g., red-tailed hawk), some on fish (e.g., osprey) and some on insects (e.g., American kestrel in summer). Some species (e.g., bald eagle) also scavenge carrion.

Food supply is one of the most important factors influencing breeding success and productivity of raptors (Brown and Amadon, 1968; Newton, 1979). Populations that depend on prey whose numbers fluctuate from year to year (e.g., hares, microtine rodents, ptarmigan) also undergo fluctuations in numbers and may move from one location to another in response to prey availability. Many raptor species migrate from northern areas for the winter, when their prey have either migrated from the area or have become difficult to obtain under the snow. A few species do remain in northern areas throughout the winter, but even these often move locally in response to availability and abundance of food.

Raptors have a long breeding cycle and many species attend their nest sites for several months. The period of attendance usually includes time for pair formation, courtship, egg-laying, incubation and fledging of the young. The young may remain in the vicinity of the nest for several weeks after fledging.

Nests of raptors are built in trees (at the tree-top, among the branches, or in a cavity in the trunk), on ledges or cavities in cliffs, or on the ground; the type of nest site chosen depends on the species and available habitat. Some species, especially those that nest on cliffs and some that build in trees, may use the same nest year after year or may return to the same nest site after an absence of several years (or longer). Raptors usually maintain a territory around the nest; they defend their territory against other raptors of the same species and often against raptors of other species. The size of the defended territory varies with the species and with the individual bird. Raptors often hunt over a larger hunting range, which in some cases is also actively defended against other raptors.

Raptors are generally long-lived species with low reproductive potentials. The age of first breeding is two years for most species, but may be one year for smaller species such as merlins and American kestrels (Brown and Amadon, 1968) and may be four or more years for eagles (Snow, 1973).

Clutch sizes of hawks, eagles and falcons are usually five eggs or less, and it is mainly the smaller species that have clutches of five or more eggs (Godfrey, 1966). Clutch sizes of the owls that occur in the study area are usually seven eggs or less (Godfrey, 1966). Many raptors begin incubation before the clutch is complete. When the food supply is limited, the first young to hatch have the best chance of survival (Brown and Amadon, 1968). Mortality in raptors during the first year of life is often high (Brown and Amadon, 1968).

Because raptors are high level consumers, they are vulnerable to accumulation of chemical pollutants in the food chain. Chemical contaminants are considered to have been mainly responsible for declines in the numbers of peregrine falcons (Peakall, 1976) and some other raptors.

Raptors are also vulnerable to other impacts caused by man. Many species are sensitive to disturbance and will desert nest sites if disturbed at a critical time. In addition, many raptor species are in demand for the hobby of falconry. Some species command a sufficiently high price that it may be profitable (though illegal) to take birds from nests in remote areas. For this reason information on specific nest locations of raptors is usually kept confidential.

The species discussed in detail below are the relatively large species that nest in traditional locations. Protection of nest sites is more important for these species than for those which change their nest locations each year.

4.2.7.1 Golden Eagle

The golden eagle is widespread in western and northern North America. The golden eagle population in the Yukon and Northwest Territories is considered stable, but of low to medium abundance (Table 4.2-3; Fyfe, 1976).

Golden eagles are relatively early migrants, and may return to some northern breeding areas by mid March (Roseneau et al., 1981). They are not generally seen in the northern Yukon until early April (Irving, 1960; Fyfe and Prescott, 1973). They are fairly common nesters in the British and Richardson mountains and on the Yukon North Slope. For example, Campbell and Davies (1973) recorded 19 active and 34 inactive golden eagle nests in the Richardson Mountains, while Salter et al. (1980) recorded at least

TABLE 4.2-3

POPULATION STATUS OF RAPTORS IN THE YUKON AND NORTHWEST TERRITORIES[1]

Common Name	Scientific Name	Population trends	Relative abundance
Goshawk	Accipiter gentilis	fluctuating	medium-high
Sharp-shinned hawk	Accipiter striatus	unknown	low
Marsh hawk	Circus cyaneus	fluctuating	low-medium
Rough-legged hawk	Buteo lagopus	fluctuating	medium-high
Red-tailed hawk	Buteo jamaicensis	unknown	low-medium
Golden eagle	Aquila chrysaetos	stable	low-medium
Bald eagle	Haliaeetus leucocephalus	stable	low-medium
Osprey		stable	low
Gyrfalcon	Falco rusticolus	stable	low-medium
Peregrine falcon (anatum)	Falco peregrinus anatum	declining	rare-low
Peregrine falcon (tundrius)	Falco peregrinus tundrius	declining	rare-low
Merlin	Falco columbarius	unknown	low
American kestrel	Falco sparverius	stable	low-medium
Great horned owl	Bubo virginianus	stable	high
Short-eared owl	Asio otus	fluctuating	low
Snowy owl	Nyctea scandiaca	fluctuating	low-high
Great gray owl	Strix nebulosa	unknown	rare-low
Hawk owl	Surnia ulula	unknown	low-medium
Boreal owl	Aegolius funereus	fluctuating	low

[1]from Fyfe (1976).

19 nests on cliffs and buttes on the Arctic Coastal Plain. Golden eagles also nest east of the Mackenzie Delta along the Anderson, Kugaluk and Horton rivers (Fyfe and Beebe, cited in Campbell and Davies, 1973) and to the south of the Hornaday River (ALUR Program, 1977).

In the northern Yukon and Mackenzie Delta area, egg-laying occurs during the first 2 weeks of May, hatching during the first 2 weeks of June, and fledging from mid July to late August (Fyfe and Prescott, 1973; Salter et al., 1980). In Alaska both earlier laying dates (April 10) and later fledging dates (September 10) have been observed (Roseneau et al., 1981). The young may remain in the vicinity of the nest for 2 weeks after fledging (Brown and Amadon, 1968).

In the north, golden eagles usually nest in mountainous areas, primarily on cliffs, cutbanks and outcrops, and occasionally in trees (Fyfe and Beebe, cited in Campbell and Davies, 1973; various observers cited in Roseneau et al., 1981). Golden eagle nests are made of sticks and may be added to each year that they are in use (Plate 4.2-3). Although nests are traditional and may be used from year to year, pairs usually have several alternate nests and there may be up to 14 nests per pair (Brown, 1976). The eagles may move from 1 to 8 km to an alternate site in consecutive years (Nelson and Nelson, 1978). Golden eagles normally lay two eggs, but usually fledge only one young (Brown and Amadon, 1968). Golden eagles may not breed in some years, presumably due to lack of prey (cf. Brown and Amadon, 1968; Mosher and White, 1976).

Golden eagles usually migrate south in fall, beginning in September (Campbell and Davies, 1973; Salter et al., 1980; Roseneau et al. 1981). The majority probably spend the winter primarily in the southwestern United States and Mexico (Boeker and Ray, 1971). However, a few birds sometimes remain in the north throughout the winter (Godfrey, 1966; Campbell and Davies, 1973).

Golden eagles are both predators and scavengers. They take mostly mammalian prey, but will also take birds and carrion. Common prey includes ground squirrels, marmots, snowshoe hares, ptarmigan and waterfowl (Campbell and Davis, 1973; Roseneau et al., 1981). Carrion, particularly big game animals, may be especially important during spring and fall (Roseneau et al., 1981). Subadult golden eagles are

PLATE 4.2-3 *Golden eagle nest overlooking the Anderson River area. (Courtesy, D. Karasiuk).*

known to frequent the calving and post-calving grounds of caribou herds to feed on carrion and they occasionally kill caribou calves (Roseneau and Curatolo, 1976).

4.2.7.2 Bald Eagle

The bald eagle nests throughout much of forested North America. The southern subspecies (*Haliaeetus leucocephalus leucocephalus*) is considered endangered (United States Dept. Interior, 1973) but populations of the northern subspecies (*H.l. alascanus*) in the Yukon and Northwest Territories appear to be stable and of low to medium abundance (Table 4.2-3; Fyfe, 1976). The Alaskan population of this subspecies is large (about 7,500 pairs; Lincer et al., 1979).

Bald eagles nest primarily south of the treeline, and rarely occur in coastal areas adjacent to the Beaufort Sea (Porsild, 1943; Salter et al., 1980). The main nesting area within the Beaufort region occurs in the Mackenzie Delta where Campbell and Davies (1973) estimated the breeding population to be less than 50 pairs, presumably mostly in the inner forested areas. A few bald eagles also nest along the Kugaluk River (Beebe, cited in Campbell and Davies, 1973) and near large lakes in the forested parts of the Anderson and Horton river areas (Zoltai et al., 1979). Bald eagles nest primarily in trees when they are available, but will occasionally nest on cliffs (e.g. in the McConnell Range; Koski, 1977c).

Bald eagles probably arrive at the nest sites in the Beaufort region during April, although those nesting in the interior of Alaska arrive there in mid March (Roseneau et al., 1981). Porsild (1943) recorded a bald eagle on the Peel River on April 7, but most probably do not arrive until late April (Campbell and Davies, 1973). These authors indicate that egg-laying in the Mackenzie Delta occurs in April, hatching in late May, and most fledging by early August. These dates are earlier than the laying and hatching dates reported for bald eagles in the Mackenzie River Valley (Fyfe and Prescott, 1973; Finney and Lang, 1976). A pair may have up to six nests within a territory and a different nest site may be used from one year to the next (Brown, 1976). Alternate nests may be as much as 3 km apart (Howell and Heinzman, 1967), but are typically less than 1 km apart (Frenzel et al., 1973; Grier, 1973; Gerrard, 1973; Tull and Koski, 1981).

Bald eagles are opportunistic feeders, and are both predators and scavengers. Fish are particularily important prey in some areas (e.g. the Pacific coast), whereas birds and mammals are important prey in other areas. Eagles may take wounded or weak waterfowl and seabirds, or carrion (Roseneau et al., 1981). Bald eagles also pirate prey from other raptors, especially ospreys.

Bald eagles may remain at the nesting areas until late September, and some may remain around lake shores until freeze-up. Fall migration begins in September, and most birds have left the breeding areas by early October (Campbell and Davies, 1973). Migrant bald eagles probably move to the United States or the Pacific coast to winter, but a few may remain in northern areas if open water and food are available (Roseneau et al., 1981).

4.2.7.3 Gyrfalcon

The gyrfalcon (Plate 4.2-4) breeds in small numbers throughout the Arctic. Unlike the peregrine falcons described in Section 4.2.7.4, there is no evidence of a reduction in the Canadian breeding range of gyrfalcons and the production of young is good (Martin, 1978). Consequently, the gyrfalcon is not considered rare, threatened or endangered by COSEWIC. Fyfe (1976) considered the population of gyrfalcons in the Yukon and Northwest Territories to be stable, and of low to medium abundance (Table 4.2-3).

Gyrfalcons are known to breed on the North Slope of the Yukon and Northwest Territories, and in the British and Richardson mountains (Platt, 1975, 1976a). They nest in low numbers east of the Mackenzie Delta along the Horton and Anderson rivers (CWS, 1972). Gyrfalcons have also been observed in other areas of the coastal Beaufort region (e.g., Tuktoyaktuk Peninsula; Kevan, 1970).

Gyrfalcons nest much earlier than other raptor species. Some adults remain near their nests all winter, and pair formation may occur in February or March (Platt, 1976b; Roseneau et al., 1981). Early nesting may be an adaptation to renesting or to gain an advantage over other cliff nesting raptors in nest site selection (Platt, 1976a). Egg-laying usually occurs during April and early May and most eggs hatch by mid June. Fledging occurs during August and the young remain with the adults for 5 to 6 weeks (Cade, 1960; Platt and Tull, 1977; Roseneau et al., 1981). These times vary considerably both from year to year and among geographic areas (Cade, 1960; see also Tull and Koski, 1981).

Gyrfalcons nest primarily on cliffs, bluffs and outcrops, but they will occasionally nest on man-made structures or in trees (Cade, 1960; White and Roseneau, 1970; White and Cade, 1971; Kuyt, 1980). Eggs are laid in a scrape on a nest ledge or in an old stick nest of a rough-legged hawk, golden eagle or common raven (Cade, 1960; White and Cade, 1971; Roseneau, 1972; Campbell and Davies, 1973). Clutch size is usually 3 or 4 eggs, but may range from 2 to 6 (Cade, 1960).

Traditional use of nest sites by gyrfalcons is not as regular as that by peregrine falcons (Cade, 1960; White and Cade, 1971; Roseneau, 1972; Platt and Tull, 1977). In consecutive years, gyrfalcons may shift from one nest site to a nearby alternative site on the same or a nearby nest cliff, or to a nest cliff much further away (Roseneau et al., 1981). Local shifts

PLATE 4.2-4 *A white colour-phase gyrfalcon with its young. Gyrfalcon populations in the Yukon and Northwest Territories are considered to be stable and of low to medium abundance.*

may be due to local snow conditions (Platt and Tull, 1977) or to the collapse of nest ledges (Roseneau, 1972). Large shifts probably occur in response to reduced prey availability (Roseneau, 1972). It has also been suggested by some (and disputed by others) that gyrfalcons may not breed in years of low prey availability (cf. Cade, 1960; Roseneau, 1972).

The age of first breeding in wild gyrfalcons has not been documented, but those raised in captivity are not sexually mature until their fourth year (Platt, 1977). It is primarily the subadult birds that occur in southern Canada and the northern United States in winter (Platt, 1976a) but the routes and timing of migration of these birds are unknown. Adults generally remain near their nest sites or in other northern areas where prey is available during winter (Platt, 1976a).

Gyrfalcons have a more specialized diet than do peregrine falcons. Gyrfalcons typically rely on only a few prey species for the bulk of their diet (Cade, 1960; White and Cade, 1971; Roseneau, 1972). In summer, ptarmigan are often the principal prey and may constitute up to 70-90% of their diet; Arctic ground squirrels, and in some regions long-tailed jaegers, are also important (Cade, 1960; White and Cade, 1971; Roseneau, 1972). Ptarmigan are the main prey in winter (Platt, 1976a; Walker, 1977), but Arctic hares may be important in some areas (Muir, 1973). The extent of the hunting ranges used by gyrfalcons is variable. For example, Nelson (1978) observed a male in the Yukon that hunted 24 km from the nest, while Bente (1980) recorded a male in Alaska that hunted at or beyond 9 km from the nest, and a female that hunted only within 3 km of the nest.

4.2.7.4 Peregrine Falcon

Two subspecies of the peregrine falcon are generally recognized to occur in the Mackenzie Valley-Beaufort Sea area (Table 4.2-3). *Falco peregrinus anatum* breeds south of the treeline and is considered by COSEWIC to be 'endangered' in Canada, while *F.p. tundrius* breeds north of the treeline and is considered by COSEWIC to be 'threatened' in Canada. Both subspecies are considered 'endangered' under the United States Endangered Species Act (United States Dept. Interior, 1973).

Both subspecies have declined over much of their North American breeding ranges since the second world war, primarily from a decline in productivity associated with the widespread use of pesticides (e.g. DDT) (Hickey, 1969; Cade and Fyfe, 1970; Fyfe et al., 1976; Peakall, 1976). However, with decreased use of pesticides in Britain, peregrine populations have increased (Ratcliffe, 1980) and there is recent evidence to suggest that the numbers and productivity of both subspecies of peregrine falcon in Alaska have begun to recover slowly (Roseneau et al., 1981). In Canada, there is also evidence of a slow recovery for *F.p. anatum* in the north-central Yukon, although they are still heavily contaminated with pesticides (R.W. Fyfe, pers. comm.). In general, peregrine populations appear to be holding their reduced levels elsewhere in Canada (R.W. Fyfe, pers. comm.).

F.p. tundrius is known to nest along several river valleys on the Yukon North Slope. Twelve nest sites were examined on the North Slope in 1975, and five of the nests were occupied (Platt, 1976b). Hayes and Mossop (1978) indicate that in 1973, 13 sites were occupied there (9 pairs, 4 lone adults), but that pairs occupied only 2 sites in 1976 and 3 sites in 1977. No sites were occupied in 1980 (R.W. Fyfe, pers. comm.). *F.p. tundrius* also nests east of the Mackenzie Delta along the Anderson and Horton rivers and at other scattered locations (cf. Zoltai et al., 1979). Allison and Dick (1976) reported that 5 of 15 known nest sites on the Horton River were occupied by pairs of peregrine falcons in 1975. Peregrines, presumably *F.p. anatum*, nest in the Campbell Hills area, where Windsor (1977) found nine breeding pairs, two or three non-breeding pairs and one lone female in 1974.

Cliffs provide the primary nesting habitat for peregrine falcons, but they have also been observed to nest on man-made structures (e.g. buildings), in trees, and on level ground (Cade, 1960; Herbert and Herbert, 1965; Hickey, 1969; Campbell and Davies, 1973; Newton, 1976). Peregrine falcons are more limited by altitude in their choice of nest sites than are the other cliff-nesting raptors (cf. White and Cade, 1971; Roseneau, 1974). In Alaska, peregrines have not been recorded to nest at altitudes of greater than 800 m above sea level (Cade, 1960), although they have nested above 900 m in the central Yukon (Mossop, pers. comm., cited in Roseneau et al., 1981).

Nest sites are often traditional, and may be used by successive pairs (Newton, 1976). Unoccupied nests may remain unused for a few years (or longer) if an alternative nest site within a given territory is being used or if no birds are present, but the nest is likely to be occupied by new pairs at a future date (see Ratcliffe, 1980). Consequently, unoccupied historical sites have a protected status.

The timing of arrival and of breeding activities of *F.p. tundrius* in coastal areas adjacent to the Beaufort Sea are poorly known. Platt (1975) indicated that peregrines return to nest sites on the Yukon North Slope during May and begin laying during the last week of May. Hatching occurs during the first week of July, and fledging in mid August. Roseneau et al. (1981) indicate that the peak periods of activities for *F.p. tundrius* on the Arctic Slope of Alaska are April 25 to May 15 for arrival, May 15 to June 17 for egg-laying, June 25 to July 15 for hatching, and August 1 to 20 for fledging.

The timing of breeding activities varies with latitude, among years, with the nesting experience of the individual birds, and between subspecies. Latitudinal and year to year variability are probably due mainly to differences in climatic conditions (Roseneau et al., 1981). In general, *F.p. tundrius* nests one to two weeks later than *F.p. anatum* in Alaska (Roseneau et al., 1981).

Peregrine falcons migrate south from the Beaufort region to winter. Banding returns indicate that northern peregrines winter mostly in Latin America. The fall departure of *F.p. tundrius* from the coastal Beaufort area has not been well documented. Roseneau et al. (1981) indicate that the main period of departure from the Arctic Slope of Alaska is August 15 to September 10. D.G. Roseneau (pers. comm.) indicated that during fall, peregrines fly eastward along the Alaskan coast of the Beaufort Sea into the Yukon, and presumably as far east as the Mackenzie River. However, only two peregrines flying east and two flying west were recorded during fall migration watches at Nunaluk Spit in 1972 (Gollop and Davis, 1974a). Searing et al. (1975) reported 7 peregrines from mid August to mid September in the same year, presumably including the four seen at Nunaluk Spit.

Peregrine falcons feed primarily on birds taken in flight. They are opportunistic feeders, and take a wide variety of prey. Their principal prey includes shorebirds, waterfowl and passerines (Cade, 1960; Cade et al., 1968). Peregrines also take some mammalian prey (Roseneau et al., 1981). Peregrines hunt primarily over open areas, such as large rivers, where prey have little opportunity to find cover. Hunting ranges of breeding peregrines vary in size; for example, a male peregrine in Arctic Alaska hunted over a territory with a radius of about 11 km (White, 1974), while several *anatum* peregrines in interior Alaska and Canada hunted within 1.5 to 5 km of their nest sites (Roseneau et al., 1981). Further information on hunting is given in Tull and Koski (1981).

4.2.7.5 Other Raptors

At least six other species of hawks and falcons and six species of owls occur regularly in coastal areas of the Beaufort Sea region (Godfrey, 1966; Martell and Dickinson, 1982). The goshawk, sharp-shinned hawk, merlin and American kestrel, and the great horned owl, hawk owl, great gray owl and boreal owl all occur regularly in the forested portion of the Mackenzie Delta (Martell and Dickinson, 1982) and the osprey has been recorded there once (Patterson et al., 1977). On the other hand, the rough-legged hawk, marsh hawk, snowy owl and short-eared owl occur regularly (usually in small numbers) in tundra areas such as the Arctic Coastal Plain (Salter et al., 1980). Ospreys have also been recorded on the coastal plain (Salter et al., 1980) and in the Horton and Anderson river areas (Barry, cited in Zoltai et al., 1979). The population trends and abundances of these species in the Yukon and Northwest Territories are indicated in Table 4.2-3. Tate (1981) lists the osprey, marsh hawk and short-eared owl on the most recent 'blue list' of North American birds.

Snowy owls (Plate 4.2-5) may inhabit tundra areas (e.g. the Arctic Coastal Plain) throughout the winter (Salter et al., 1980), but the other species that occur on the Arctic Coastal Plain in summer winter in southern Canada or further south (Godfrey, 1966).

4.2.8 GROUSE

Grouse inhabit forested and open areas throughout Canada. The three species of grouse that occur regularly within the coastal Beaufort region are the sharp-tailed grouse (*Pedioecetes phasianellus*), willow ptarmigan (*Lagopus lagopus*), and the rock ptarmigan (*L. mutus*). The sharp-tailed grouse regularly occurs in bogs and open burned areas within coniferous forest as far north as the wooded portion of the Mackenzie Delta (Godfrey, 1966; Martell and Dickinson, 1982). This species is included in the 'blue list' as a result of population declines in some regions (Tate, 1981). Ptarmigan occur primarily in tundra areas, although the willow ptarmigan also breeds in northern forested areas. The willow ptarmigan breeds throughout the Coastal Beaufort region, while the rock ptarmigan occurs in the Arctic and alpine tundra areas (Zoltai et al., 1979; Salter et al., 1980; Martell and Dickinson, 1982). Grouse usually remain within their breeding ranges during the winter (Godfrey, 1966), although they may leave the northernmost or high-altitude areas.

In general, grouse have a high reproductive potential (Johnsgaard, 1973). Some grouse populations, most notably ruffed grouse and willow and rock ptarmigan, periodically undergo major fluctuations in size (Rusch and Keith, 1971; Weeden and Theberge, 1972). Grouse are important prey for several species of raptors and mammals.

Grouse in the coastal Beaufort region and Mackenzie Delta are generally dispersed during nesting, but are known to concentrate during certain other periods. For example, sharp-tailed grouse gather at communal courtship and mating areas during spring (for review, see Koski and Tull, 1981) and ptarmigan flock during winter.

Willow and rock ptarmigan form flocks during late summer that remain intact until April. Juvenile birds

PLATE 4.2-5 *Snowy owl on the Arctic Coastal Plain.*

may move south during winter, while adult males usually predominate in the flocks in the northernmost areas (Martell and Dickinson, 1982). Flocks of willow ptarmigan may include up to 400 or more birds (Slaney, 1974b; Platt, 1976a). The flocks are relatively mobile, and move readily between feeding areas (Slaney, 1974b). Winter flocks of willow ptarmigan in the Mackenzie Delta and on the Yukon North Slope occur primarily in riparian shrub habitat (Slaney, 1974b; Platt, 1976a). Willow buds and twigs are their most important winter food (West and Meng, 1966; Weeden, 1969), while the buds and catkins of dwarf birch are the most important winter food for rock ptarmigan (Weeden, 1969).

4.2.9 CRANES

Two species of cranes occur within the coastal Beaufort and Mackenzie Delta region: the sandhill crane (*Grus canadensis*) and rarely the whooping crane (*G. americana*). Cranes are terrestrial, and prefer open areas such as plains, marshy areas and tundra (Thomson, 1964; Walkinshaw, 1973). They usually nest in remote areas, and have declined as a result of human encroachment into their breeding areas (Thomson, 1964). Cranes nesting in Canada migrate to wintering areas in the southern United States and Mexico (Godfrey, 1966). They are solitary nesters, but congregate in flocks during migration and on the wintering grounds. Cranes feed on vegatation and opportunistically on small invertebrates, birds, and mammals.

The whooping crane is considered by COSEWIC to be 'endangered' in Canada. The world population of this species currently numbers about 120 individuals. The only area where wild whooping cranes are currently known to nest, is Wood Buffalo National Park on the Alberta-Northwest Territories border. However, stragglers have been sighted near Fort Good Hope (Kuyt, cited in Finney and Kondla, 1976) and along the Anderson River (Höhn, 1959).

Sandhill cranes have a low reproductive potential. They are long-lived, and take several years to mature. Nests are located on the ground, and clutches usually have 2 eggs (Godfrey, 1966). Incubation requires about one month and the precocial young require two months before fledging. Recruitment of young birds into the adult population is low (cf. Miller and Hatfield, 1974).

Most sandhill cranes probably migrate to the coastal Beaufort and Mackenzie Delta region via the Mackenzie Valley. They are known to arrive in the Mackenzie Delta as early as May 8 (Porsild, 1943), and as late as May 21 (Slaney, 1974a). Sandhill cranes begin nesting by the end of May (Campbell, 1973a). This species nests commonly in tundra areas of the outer Mackenzie Delta (Campbell and Weber, 1973; Slaney, 1974a; Wiseley et al., 1977) and probably the Tuktoyaktuk Peninsula (Kevan, 1970). During late June and early July, Campbell and Weber (1973) recorded breeding densities of 0.05 cranes/km^2 in the Blow River and Shallow Bay area, and 0.03 cranes/km^2 in the Kittigazuit Bay area. Breeding sandhill cranes are not common in the Horton and Anderson river areas (Zoltai et al., 1979). Salter et al. (1980) recorded sandhill cranes as uncommon visitors to the Yukon Coastal Plain, but found no evidence that they nest there.

Sandhill cranes congregate during the premigratory staging period in the Blow River and Shallow Bay areas of the Mackenzie Delta during late August and early September (Campbell and Weber, 1973; Wiseley et al., 1977). The number of sandhill cranes seen migrating eastward along the Yukon coast is small (e.g. Salter et al., 1980, report a maximum 1-day count of 18), and September 23 is the latest date that this species has been seen on the Yukon Coastal Plain (Salter et al., 1980). Most birds have probably left by September 1, the date when peak migration occurs in the Mackenzie Valley (Salter, 1974a).

4.2.10 SHOREBIRDS

Shorebirds are small to medium sized birds that are characterized by long legs and long bills. With the exception of phalaropes, which habitually swim, shorebirds are typically waders (Plate 4.2-6). They nest throughout Canada but the majority of species nest north of the treeline. At least 23 species nest in coastal areas adjacent to the Canadian Beaufort Sea (Table 4.2-4). All species that occur in the Beaufort region migrate south for the winter to the southern United States, the tropics, or southern South America.

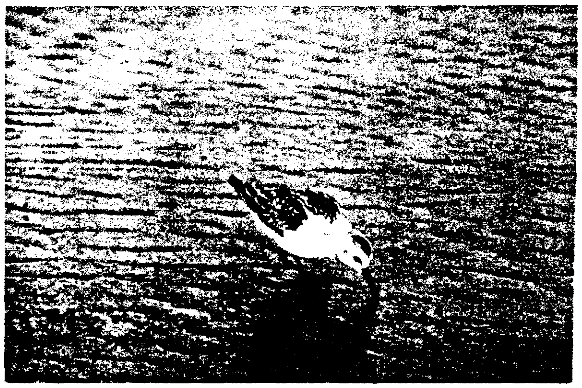

PLATE 4.2-6 *A sanderling shorebird feeding on the shore of the man-made island in McKinley Bay.*

TABLE 4.2-4

SHOREBIRDS BREEDING IN THE BEAUFORT AND NORTHEAST CHUKCHI SEA REGION
(Adapted from Godfrey, 1966)

American golden plover	Pluvialis dominica
Black-bellied plover	Pluvialis squatarola
Semipalmated plover	Charadrius semipalmatus
Dotterel[1]	Eudromias morinellus
Whimbrel	Numenius phaeopus
Bar-tailed godwit[1]	Limosa lapponica
Eskimo curlew[3]	Numenius borealis
Spotted sandpiper[2]	Astitis macularia
Lesser yellowlegs[2]	Tringa flavipes
Hudsonian godwit[2]	Limosa haemastica
Buff-breasted sandpiper	Tryngites subruficollis
Stilt sandpiper	Micropalama himantopus
Ruddy turnstone	Arenaria interpres
Pectoral sandpiper	Calidris melanotos
Red knot	Calidris canutus
Dunlin	Calidris alpina
Sanderling	Calidris alba
White-rumped sandpiper	Calidris fuscicollis
Baird's sandpiper	Calidris bairdii
Least Sandpiper	Calidris minutilla
Curlew sandpiper[1]	Calidris ferruginea
Semipalmated sandpiper	Calidris pusilla
Western sandpiper	Calidris mauri
Common snipe	Capella gallinago
Long-billed dowitcher	Limnodromus scolopaceus
Red phalarope	Phalaropus fulicarius
Northern phalarope	Lobipes lobatus

[1]Nests rarely or locally in northern Alaska
[2]Nests rarely or locally adjacent to the Canadian Beaufort Sea.
[3]Endangered species whose main nesting area is believed to be the Anderson River Valley (Gollop and Shier, 1978)

Shorebirds arrive at the Beaufort Sea from wintering areas in mid to late May and early June, and disperse rapidly to nesting sites. There is little or no use made of the still-frozen littoral areas in spring. Spring migration occurs across a broad front and primarily via overland routes. Spring migrant shorebirds rarely occur in large flocks.

Nesting habitat varies among species and includes wet, marshy tundra (e.g. stilt sandpiper, whimbrel), dry upland tundra (e.g. buff-breasted sandpiper, American golden plover), bogs and muskeg areas (eg. greater yellowlegs, short-billed dowitcher), and wooded lakeshores (e.g. spotted sandpiper) (Palmer, 1967). Mating systems also vary considerably among species (Pitelka et al., 1974). The majority of the species are monogamous; the female lays one clutch of three to four eggs, which is incubated by one or both adults. A few species are polygamous or promiscuous (buff-breasted sandpiper, pectoral sandpiper, white-rumped sandpiper). Of the species occurring in the Beaufort Sea area, the sanderling, red phalarope and northern phalarope are the only species known to be double brooded. Female sanderlings may lay two clutches, one of which she incubates and one of which is incubated by the male (Parmelee and Payne, 1973; Pitelka et al., 1974). Female phalaropes of both species may mate with and lay eggs for two successive males (Hilden and Vuolanto, 1972; Raner, 1972; Schamel and Tracy, 1977). All other shorebird species breeding in the area are believed to produce only one set of young each year. The reproductive potential is thus very similar for most shorebird species. Despite the short nesting cycle of northern shorebirds, which includes incubation periods of 18 to 27 days and fledging periods of 14 to 21 days (Godfrey, 1966), many individuals in High Arctic areas may not nest in years when spring is late (Alliston et al., 1976; Maltby, 1978). Populations can also be adversely affected by poor weather either in spring (Morrison, 1975) or later in the season, especially when the chicks are very young (Jehl and Hussell, 1966).

Mortality of shorebirds is high during the first year, but adult shorebirds may be relatively long-lived. Many shorebird populations were drastically reduced during the late 1800's as a result of heavy hunting pressure, and some populations have not recovered.

Young shorebirds are precocial and leave the nest shortly after hatching. They forage for themselves, but are brooded by a parent for a week or two after hatching.

The fall migration is protracted, partly because different age and sex classes leave the breeding areas at different times. In some species, one adult departs as soon as the clutch has been laid, while in some other species, the adults leave the young at different stages of the brood-rearing period. The adults of most species leave the breeding range before the juveniles (Parmelee et al., 1967; Alliston et al., 1976).

Flocks of shorebirds frequently stage prior to fall migration or at stopover points during migration. Many species stage along marine coastlines, while some stage along freshwater shorelines or on open upland habitats. At these staging sites, shorebirds build up energy reserves for their long, often non-stop, migratory flights. Staging shorebirds frequently occur in mixed flocks of several species.

Most species feed on small invertebrates found primarily along the shorelines of freshwater or marine waterbodies; although some feed partially on plant material, particularly berries in late summer and fall. Some species feed primarily on the shore, while others feed by wading in shallow water. A few species feed primarily in open upland habitats, and two species (phalaropes) feed from the water surface while swimming.

4.2.10.1 Eskimo Curlew

The Eskimo curlew is considered 'endangered' in Canada by COSEWIC. This species nests only in Canada, and is near extinction. The reasons for the decline have been debated, but hunting was a major factor (for a review see Banks, 1977). The present size of the population is poorly known, but Gollop and Shier (1978) estimate that fewer than 20 birds remain. Five sightings of this species were recorded during the 1970's (Gollop and Shier, 1978). These have been followed by one sighting in Manitoba (Gollop, 1980) and one at the Anderson River (T. Barry, pers. comm.) in 1980. The 1970's sightings consisted of one from the Anderson River, one from James Bay and three from the United States.

Former nesting areas of the Eskimo curlew included areas in the northern Mackenzie District from the Coppermine River to the Anderson River and south to Fort Simpson. However, no nests have been reported in these areas in more than 100 years (Gollop and Shier, 1978). The current breeding area(s) are unknown, but sightings within the last five years in the Anderson River area suggest that breeding may occur there. However, no nesting birds were seen there during a search in 1981 (T. Barry, pers. comm.). Eskimo curlews formerly migrated northward during spring via the prairie provinces and possibly the Mackenzie River Valley (Gollop and Shier, 1978), and the return fall migration occurred via Hudson Bay and Labrador. Current spring and fall migration routes are unknown.

4.2.10.2 Phalaropes

Phalaropes are unique among shorebirds in that they habitually swim and remain at sea during all but the nesting season. The two species that occur regularly in the Beaufort and northeast Chukchi seas, red and northern phalaropes, both winter at sea, mainly in the southern hemisphere (Godfrey, 1966).

The spring migration of red phalaropes to the Beaufort and northeast Chukchi seas probably occurs offshore, although little is known of the exact routes (Gabrielson and Lincoln, 1959). During the breeding season, red phalaropes are particularly abundant near Point Barrow (50 birds/km^2; Connors and Risebrough, 1977) and Point Storkersen in Alaska (15.6 to 37 birds/km^2; Bergman et al., 1977), and are also abundant on Banks Island (estimated population of 35,000; Manning et al., 1956). They are uncommon in the Mackenzie Delta, on the Tuktoyaktuk Peninsula and along the Yukon North Slope (Barry, 1967; Kevan, 1970; Johnson et al., 1975; Salter et al., 1980).

Some northern phalaropes follow a coastal migration route to and from the Beaufort Sea coastal area (Gabrielson and Lincoln, 1959), but this species is also common along an interior migration route across the prairie provinces. Northern phalaropes are uncommon nesters near Point Barrow and Point Storkersen, but are relatively common inland of these areas (Pitelka, 1974; Bergman et al., 1977; Connors and Risebrough, 1977), as well as in mainland coastal areas from the Yukon North Slope eastward (Barry, 1967; Salter et al., 1980). For example, Slaney (1974a) estimated that 25,000 northern phalaropes summered in the Mackenzie Delta area. The breeding density of northern phalaropes was 7.3 territories/km^2 on the lower Babbage River in 1972 (Gollop et al., 1974) and 1.3 territories/km^2 on the upper Babbage River in 1973 (Richardson and Gollop, 1974).

Phalaropes arrive in the Beaufort Sea region during late May or early June (Porsild, 1943; Höhn and Robinson, 1951; Johnson et al., 1975; Salter et al., 1980). Courtship takes place shortly after their arrival. Clutch initiation begins during early to mid June (Campbell, 1973a; Salter et al., 1980), and the males incubate the eggs. Females may lay a second clutch if they find a second mate. Second clutches have been documented in red phalaropes in Alaska (Schamel and Tracy, 1977) and on Bathurst Island (Mayfield, 1978), and in northern phalaropes in Finland (Hilden and Vuolanto, 1972; Raner, 1972).

The timing of breeding activities is similar in the two species (Williamson et al., 1966; Slaney, 1974a; Johnson et al., 1975; Bergman et al., 1977) and the following information is based primarily on studies of the better-known red phalaropes on Victoria Island (Parmelee et al., 1967) and in Alaska (Bergman, 1974; Connors and Risebrough, 1977; Schamel and Tracy, 1977; Connors et al., 1979). When incubation begins, the females leave the males and flock together for premigratory staging on tundra waterbodies. Most female phalaropes have migrated from the region by mid July. Hatching occurs during early July, and fledging in late July and early August. Males leave the breeding territories once the young have fledged (or the nest has failed) and move to coastal areas to stage. Most males have left the tundra breeding areas by early to mid August, whereas the young leave the breeding areas from early August to early September and stage in lagoons and other nearshore waters. During this period, large concentrations of juveniles of both species occur along the mainland coast between Cape Lisburne and the Yukon (Connors and Risebrough, 1977).

In early August 1973, Salter et al. (1980) recorded approximately 5,000 phalaropes staging along the south shore of Herschel Island. Northern phalaropes outnumbered red phalaropes by about 20 to 1. The former species has been recorded on the Yukon North Slope as late as September 17 (Salter et al., 1980). The fall migration of red phalaropes probably follows offshore routes, but the migration corridors followed by northern phalaropes are largely unknown.

4.2.10.3 Other Shorebirds

Twenty-four species of shorebirds, excluding phalaropes and the Eskimo curlew, regularly nest in coastal areas adjacent to the Beaufort and northeast Chukchi seas (Table 4.2-4) (Godfrey, 1966; Zoltai et al., 1979; Salter et al., 1980; Martell and Dickinson, 1982). Within the region, a few species such as the solitary sandpiper nest only in wooded areas in the Mackenzie Delta and inland areas to the east.

Although shorebird migration routes have not been well documented, there are apparently at least three main spring routes to the Beaufort Sea area (cf. Johnson et al., 1975). Several species that include pectoral sandpiper, buff-breasted sandpiper, Hudsonian godwit and stilt sandpiper, migrate across interior North America and presumably down the Mackenzie Valley. Some shorebirds, such as the semipalmated plover, migrate across Alaska from the Gulf of Alaska to the Beaufort Sea coast, while others, such as the dunlin, follow a coastal route around Alaska from the Bering Sea. Most species of shorebirds first arrive on the Yukon North Slope during mid to late May (Salter et al., 1980). In 1975, the peak of spring migration occurred between May 26 and June 9 (Johnson et al., 1975).

The nesting densities of shorebirds in arctic tundra areas in this region are comparatively high. In many areas, shorebirds are the most prominent group of birds encountered. In dry, upland tundra on the upper Babbage River, eight species of shorebirds, including phalaropes, occurred at a density of 14.4 territories/km^2 and constituted 7% of all birds present (Richardson and Gollop, 1974). During studies on wet tundra near Point Barrow, Alaska, as many as 10 species of shorebirds have been recorded on a 33 hectare plot at densities up to 113 territories/km^2. Shorebirds comprised up to 69% of the birds present (cf. Myers et al., 1980).

Fall migration is protracted, and occurs from July to mid September. In the outer Mackenzie Delta the peak movement occurs during about the third week of August (Searing et al., 1975). The early migrants are adults, and the later migrants juveniles. Migration routes are not well documented, although the Beaufort Sea coast is known to be an important route for some species (Campbell, 1973b; Gollop and Davis, 1974a; Vermeer and Anweiler, 1975). During surveys in 1972, eastward movement past Nunaluk Spit was more common than westward movement (Gollop and Davis, 1974a). During fall migration, shorebirds stage to build up energy reserves, but the locations and use of fall staging areas in the coastal Beaufort Sea are not well known. However they apparently include the south shore of Herschel Island, the northern tip of Richards Island, Warren Point, and the shore between Phillips Island and Cape Dalhousie on the Tuktoyaktuk Peninsula (Vermeer and Anweiler, 1975; Barry et al., 1981).

4.2.11 JAEGERS

Three species of jaegers nest in areas adjacent to the Beaufort and northeast Chukchi seas: pomarine jaeger (*Stercorarius pomarinus*), parasitic jaeger (*S. parasiticus*), and long-tailed jaeger (*S. longicaudus*). Although jaegers remain at sea for most of the year, they are largely terrestrial during the summer nesting season. Parasitic and long-tailed jaegers breed throughout the Beaufort region. The pomarine jaeger is a rare breeder but a common coastal migrant along the Yukon North Slope and in the Mackenzie Delta area (Porsild, 1943; Barry, 1967; Kevan, 1970; Slaney, 1974a; Zoltai et al., 1979; Salter et al., 1980). Although there are no reliable estimates of the jaeger populations in the region, parasitic jaegers are common along the mainland coast, while pomarine jaegers are abundant on Banks and Victoria islands and on Cape Bathurst during years of lemming abundance (Barry et al., 1981). The long-tailed jaeger is widely distributed throughout the Beaufort region.

The breeding biology of the three jaeger species is similar. The nests are widely dispersed over suitable tundra habitats. Both members of pairs share in nesting and brood-rearing activities, and chicks are attended until after fledging. The minimal time required for breeding is 80 to 90 days for the long-tailed jaeger and 90 to 100 days for the pomarine jaeger. Breeding time for the parasitic jaeger is intermediate between the other two species (Maher, 1974).

The population biology of jaegers is not well known. Clutch size for all species is normally two eggs (Maher, 1974). Age at first breeding is not known, but is thought to be three or four years for the long-tailed jaeger (Andersson, 1976). Adult annual mortality rates are believed to be low; Andersson (1976) suggests in the 9 to 16% range. Jaegers exploit a highly variable food supply, and when this supply is low, few or no adults may nest. This adaptation to a variable food supply reduces the reproductive potential of these species.

Pomarine jaegers prey primarily on lemmings during the breeding season and nest in a specific area only when lemming numbers are large, which is usually only one or two years out of every four. Long-tailed jaegers prey largely on microtines during the nesting season but also take a variety of other prey including insects and small birds. The parasitic jaeger also takes a variety of prey but depends largely on small birds (Maher, 1974; Martin and Barry, 1978).

Jaegers use the marine portions of the Beaufort region mainly during their spring and fall migrations. The numbers using marine areas during the breeding season may vary depending on nesting effort and success in a given year. Many adult jaegers are believed to return to marine areas after prospecting nesting areas in non-nesting years (Maher, 1974; Watson and Divoky, 1974; Richardson and Johnson, 1981). Few immature jaegers are believed to frequent the Beaufort region (Salomonsen, 1950; Frame, 1973; Maher, 1974; Watson and Divoky, 1974).

Jaegers reportedly migrate to the Canadian Beaufort Sea primarily along the north coast of Alaska (Kessel and Cade, 1958; Williamson et al., 1966; Maher, 1974). However, in some years large numbers of jaegers may follow overland routes via the eastern Brooks Range (Dean et al., 1976).

Spring migrant jaegers are first seen in the eastern Chukchi and western Beaufort during mid to late May (Maher, 1974) and by early June are present throughout the Beaufort-Chukchi area (Johnson et al., 1975; Martin and Barry, 1978). During spring migration jaegers travel singly, in pairs, or sometimes in loose flocks (Maher, 1974; Johnson et al., 1975; Dean et al., 1976) and some follow cracks and leads in the sea ice (P. Soralik cited in Maher, 1974; Barry, 1976). Numbers passing through the Beaufort-Chukchi area are not known, although Barry (1972, 1976) has made some rough estimates.

If conditions are favourable, jaegers begin nesting as soon as they arrive on the breeding grounds. However, if conditions are unfavourable, they may begin migration back toward their wintering areas. Richardson and Johnson (1981), after witnessing an eastward migration of jaegers along the Yukon coast during late May and early June of 1975, recorded a westward migration of pomarine and unidentified jaegers during mid to late June 1975.

When breeding conditions are favourable, jaegers occupy terrestrial habitats until their nest attempt fails or the young fledge. Fledging of the young occurs during August: pomarine during mid August, parasitic during early to mid August and long-tailed during mid to late August (see Johnson et al., 1975). In late July 1973 on the Yukon Coastal Plain, long-tailed jaegers were observed at or near 20 of 60 lakes surveyed, while parasitic jaegers were found at or near 17 of the 60 lakes (Sharp et al., 1974). The density of nesting parasitic jaegers, the only species of jaeger nesting in the area, was 0.04 pairs/km^2 in 1973 at the Anderson River delta (Martin and Barry, 1978).

Fall migration of successfully-nesting birds begins shortly after the young fledge in August and most adults are believed to have left the Beaufort Sea by mid September (see Johnson et al., 1975), and from the eastern Chukchi Sea by the end of September (Watson and Divoky, 1972). During fall migration through the Beaufort-Chukchi area, adult jaegers are widely dispersed in offshore waters and most frequently occur in groups of one to five birds, often of mixed species (Frame, 1973; Watson and Divoky, 1974; Divoky, 1978c). Young-of-the-year have not been observed in offshore areas (Watson and Divoky, 1974).

4.2.12 GULLS AND TERNS

Nine species of gulls occur in the Beaufort Sea region: glaucous gull (*Larus hyperboreus*), Thayer's gull (*L. thayeri*), herring gull (*L. argentatus*), mew gull (*L. canus*), Bonaparte's gull (*L. philadelphia*), ivory gull (*Pagophilia eburnea*), black-legged kittiwake (*Rissa tridactyla*), Ross' gull (*Rhodestethia rosea*), and Sabine's gull (*Xema sabini*). In addition, the Arctic tern (*Sterna paradisaea*) also occurs in the region. Ross' and ivory gulls are mainly fall transients in marine areas, while herring, mew and Bonaparte's gulls are rare north of the treeline but breed in the forested Mackenzie Delta and forested areas to the east (Zoltai et al., 1979; Martell and Dickinson, 1982). The remaining species of gulls and the Arctic tern nest in coastal regions of the Beaufort and Chukchi seas.

Gulls obtain their food at the water surface, but do not ordinarily dive for food. They search for much of their food while in flight. Terns also locate their prey in the water while in flight, and may pursue it by shallow dives. Terns rarely swim, and are more awkward on land then gulls; terns will readily perch, but usually do not walk. Gulls and terns feed primarily on small, near-surface fish and invertebrates, although some species of gulls are efficient scavengers.

Gulls and terns are generally long-lived birds (e.g. 10 to 20 years). Adult mortality is relatively low, while mortality of immature birds is considerably higher. Terns and the smaller gulls may mature in two years, but the larger gulls may require four or more years to mature. Gulls and terns normally lay clutches of two or three eggs, and incubate them for 20 to 28 days (Godfrey, 1966). The time from hatching to fledging may range from 21 to 28 days in terns (Fisher and Lockley, 1954) to 43 to 57 days in glaucous gulls (Swartz, 1966). The young leave the nest shortly after hatching, but are fed by the parents until, and in some cases after fledging. Depending on the species, gulls and terns nest as single pairs or in colonies ranging from a few to several thousand individuals.

Most gulls that summer in the Beaufort region probably winter on the Pacific coast from Alaska to California, but the Sabine's gull is known to winter off the coast of Peru (Chapman, 1969). The Arctic tern winters in southern oceans as far south as the Antarctic Ocean (AOU, 1957; Godfrey, 1966). Gulls frequently occur in mixed flocks during migration and at migration stopover locations.

4.2.12.1 Glaucous Gull

The spring migration of glaucous gulls (Plate 4.2-7) to the Beaufort and northeast Chukchi seas occurs primarily along coastal routes, although early migrants may travel far offshore. The migration period is protracted in comparison with most other species (Richardson and Johnson, 1981). The first gulls generally arrive in the Chukchi Sea by late April (Gabrielson and Lincoln, 1959) and in the Beaufort Sea by mid May (Manning et al., 1956; Johnson et al., 1975; Searing et al., 1975). The peak migration of glaucous gulls along the Yukon coast is during late May and the first three weeks of June (Johnson et al., 1975). During aerial surveys of the ice edge from Tuktoyaktuk to Baillie Islands, in the Amundsen Gulf polynya and along the southwest coast of Banks Island on June 5, 1980, Barry et al. (1981) observed glaucous gulls in 39 of 41 transects. Maximum recorded densities of glaucous gulls were 10.8 birds/km^2 near Masik River on Banks Island and 3.5 birds/km^2 off the Baillie Islands.

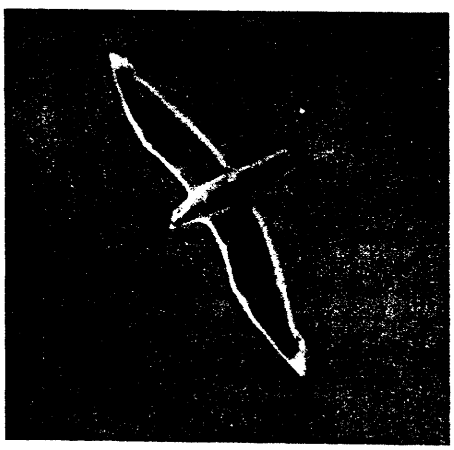

PLATE 4.2-7 *Glaucous gulls such as this one are common along the Beaufort Sea coast in summer. (Courtesy, D. Karasiuk).*

The glaucous gull is the most abundant nesting gull in the Beaufort-Chukchi region, except in the Cape Thompson-Cape Lisburne area of the Chukchi Sea where black-legged kittiwakes predominate. Glaucous gulls nest singly or in small loose colonies on sea cliffs, on offshore spits and islands, on barrier beaches, on river deltas, and on islands in inland lakes and ponds. Although estimates of the population of glaucous gulls in the region are not available, numbers nesting in coastal areas of the Canadian Beaufort Sea and Amundsen Gulf probably exceed numbers nesting in Arctic Alaska by a factor of 2 or 3 (see LGL and ESL, 1982). In 1976, approximately 500 pairs nested along the Alaskan coast adjacent to the Beaufort and northeast Chukchi seas, and an additional 150 pairs were observed nesting near Cape Thompson (Gavin, 1976; Divoky, 1978a; Springer and Roseneau, 1978).

Glaucous gulls nest on barrier islands along the Yukon coast (Salter et al., 1980), on offshore islands in the outer Mackenzie Delta and in other coastal and, to a lesser extent, inland areas. The largest recorded colony in the outer Mackenzie Delta had 85 pairs in 1972 (Boreal Institute, 1975; Slaney, 1975). Barry (1974) and Barry et al. (1981) identify several coastal nesting areas for this species in the southeastern Beaufort Sea (Figure 4.2-7), and Ward (1979) found glaucous gulls nesting at several locations near Cape Parry. The largest concentrations of glaucous gulls occur during the summer open water period in coastal areas near the nesting colonies (Searing et al., 1975). During aerial surveys of coastal areas of the southeastern Beaufort Sea during mid July, late July and mid August 1980, Barry et al. (1981) reported glaucous gulls in virtually all areas. The maximum recorded densities were 19.9 birds/km^2 at Shallow Bay and 11.4 birds/km^2 at Cape Bathurst during the mid July surveys. Feeding studies conducted in Simpson Lagoon, Alaska, during 1977 indicated that gulls in this area fed exclusively along shorelines and ate primarily isopods, amphipods, fish and small birds (Johnson and Richardson, 1981).

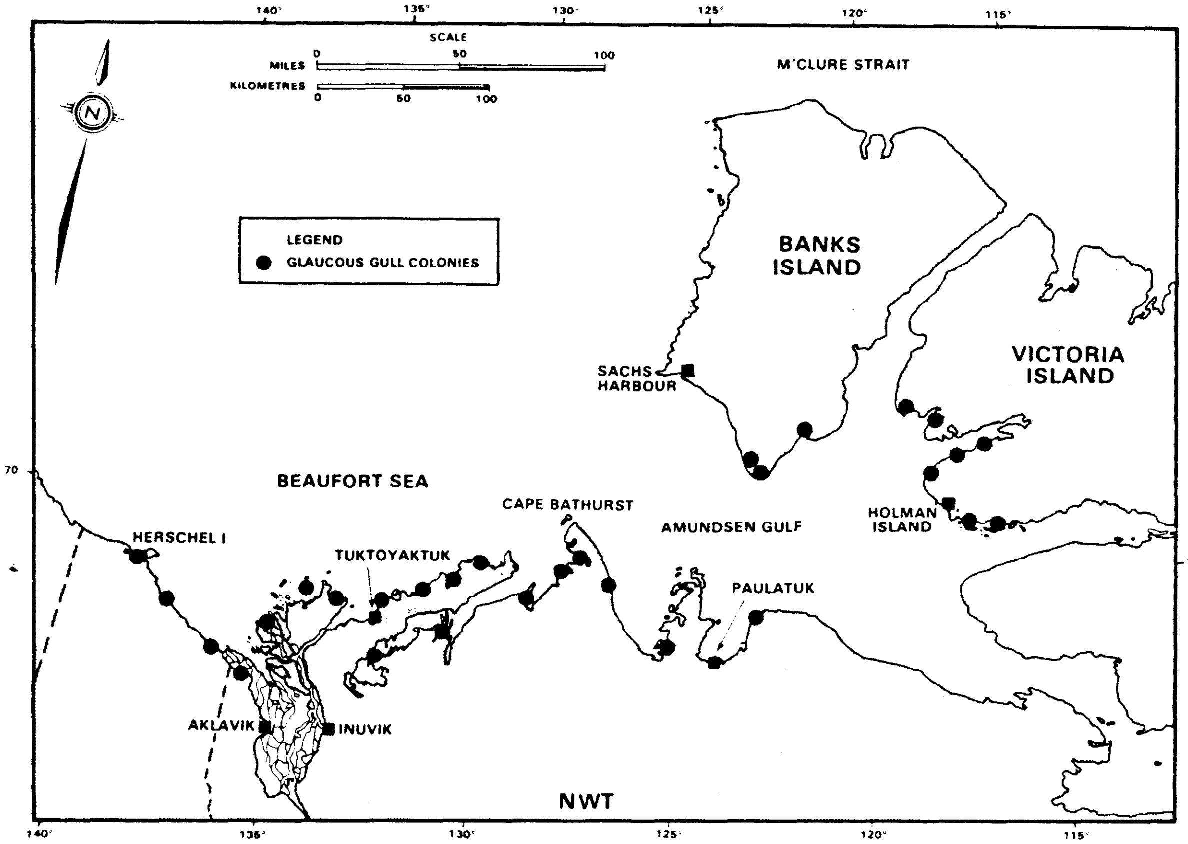

FIGURE 4.2-7 *Locations of glaucous gull colonies (from Barry, 1974; Barry et al., 1981)*

Glaucous gulls are less common inland on the Arctic Coastal Plain and were observed at only 3 of 22 lakes visited in 1972 by Gollop and Davis (1974b). Unidentified gulls were present at 10 of the 60 lakes surveyed there in 1973 by Sharp et al. (1974). Intensive aerial surveys in the outer Mackenzie Delta during mid July indicated glaucous gull densities of 0.27 gulls/km^2 in the Blow River-Shallow Bay area and 0.37 gulls/km^2 in the Kittigazuit Bay area (Campbell and Weber, 1973).

In the Beaufort Sea and Amundsen Gulf region, nesting begins in early June and the eggs have hatched by mid July (Campbell, 1973b; Salter et al., 1980). Most young have fledged by late August and early September (Parmelee et al., 1976; Campbell, 1973b; Schamel, 1974; Johnson et al., 1975). The fall migration follows a coastal route similar to the spring migration, and most glaucous gulls probably leave the eastern Beaufort Sea after mid September (Parmelee et al., 1967; Searing et al., 1975). They have been observed on the Arctic Coastal Plain at the end of September, and an immature was seen there on October 22, 1975 (Salter et al., 1980).

4.2.12.2 Black-legged Kittiwake

Black-legged kittiwakes of the subspecies *R. t. pollicaris* nest in large coastal colonies at Cape Lisbourne, Cape Lewis and Cape Thompson in Alaska. In 1977, there were an estimated 28,000, 4,000 and 20,000 nesting adult kittiwakes at these colonies, respectively (Springer and Roseneau, 1978). In other parts of the northeastern Chukchi Sea and in the western Beaufort Sea, a few immature black-legged kittiwakes are widely distributed throughout the area during summer (Swartz, 1967; Watson and Divoky, 1972, 1974; Frame, 1973; Bartonek et al., 1977; Divoky, 1978c). However, in the southeastern Beaufort Sea, black-legged kittiwakes only occur irregularly and in small numbers (Frame, 1973; Johnson et al., 1975; Searing et al., 1975).

Kittiwakes generally arrive at the nesting colonies during late May and occupy nesting ledges several days later (Swartz, 1966). Females probably first breed at the age of 3 or 4 years, while males first breed at 4 or 5 years of age (Coulson, 1966). Two-egg clutches are laid during the period from late June to early July, and fledging usually occurs between late August and mid September, although some may not fledge until early October (Springer and Roseneau, 1978, 1979). Aerial surveys conducted near Cape Lisburne in 1978 indicated that the largest numbers of breeding birds feed regularly near their nesting areas, but some feed in coastal areas more than 150 km from the colonies (Springer and Roseneau, 1979). By mid October most adult and young black-legged kittiwakes have left the region for wintering areas in the Pacific Ocean (Swartz, 1966).

4.2.12.3 Sabine's Gull and Arctic Tern

The breeding ranges of the Sabine's gull and the Arctic tern include coastal spits, barrier islands, and tundra lakes near the coasts of the Arctic mainland of Canada and Alaska, and the Arctic Islands. However, Sabine's gulls are relatively uncommon in the Beaufort and northeast Chukchi region, except on Banks and Victoria islands (Parmelee et al., 1967). Nesting Arctic terns are widely distributed throughout most interior and coastal regions of Alaska, the Yukon and Northwest Territories (Gabrielson and Lincoln, 1959; Godfrey, 1966). Both species winter at sea in the southern hemisphere (Johnson et al., 1975).

Sabine's gulls and Arctic terns migrate along coastal routes to reach nesting areas adjacent to the Beaufort and Chukchi seas, and most arrive during late May and early June (Williamson et al., 1966; Johnson et al., 1975). Both species nest singly or in small colonies, and clutches typically have 2 or 3 eggs. Arctic terns begin egg laying in mid June and the young hatch by mid July; many are capable of flight by early August (Salter et al., 1980).

Arctic terns nest on barrier islands along the Yukon coast (Salter et al., 1980) and on offshore islands in the Mackenzie Delta area. The largest recorded colony in the Delta had 24 nests in 1974 (Slaney, 1975). Kevan (1970) observed nesting Arctic terns at Atkinson Point, while Barry (1967) recorded this species as a fairly common nester in the Anderson River delta. Arctic terns were uncommon near Cape Parry (Ward, 1979). Arctic terns are relatively common inland on the Yukon Coastal Plain and in the Mackenzie Delta area. They were observed at 17 of 22 lakes surveyed on the Yukon Coastal Plain in 1972 (Gollop and Davis, 1974b) and at 45 of 60 lakes surveyed in 1973 (Sharp et al., 1974). During intensive aerial surveys in the outer Mackenzie Delta in 1972, Campbell and Weber (1973) recorded mid July densities of 0.60 Arctic terns/km^2 in the Blow River-Shallow Bay area and 1.21 Arctic terns/km^2 in the Kittigazuit Bay area. During incidental summer aerial surveys in 1972, Campbell and Weber (1973) recorded densities of Arctic terns/km^2 of 0.64 in the outer Mackenzie Delta, 1.21 in the southern Mackenzie Delta, 0.31 in tundra areas, 0.42 along the Yukon coast, and 0.12 in boreal forest areas.

Nesting areas for Sabine's gulls have not been well documented. On the Tuktoyaktuk Peninsula, they are reported to nest at Atkinson Point (Kevan, 1970) and Cape Dalhousie (Barry, 1976), and Barry (1967) suspected that breeding occurred in the Anderson and Mason river deltas. They also nest at Cape Bathurst and Langton Bay (Zoltai et al., 1979), and at Nunaluk Spit and Pelly Island (Barry et al., 1981).

Arctic terns may begin their fall migration during July, but movement past Nunaluk Spit in 1972 peaked during August 10 to 17 and continued into early September (Gollop and Davis, 1974a; Johnson et al., 1975; Searing et al., 1975). The latest record of this species in the Canadian Beaufort was of 3 birds in Shallow Bay on September 11, 1975 (Johnson et al., 1975). Sabine's gulls may not depart until late September and they probably migrate offshore (Searing et al., 1975; Johnson, 1979).

4.2.12.4 Other Gulls

Thayer's gulls winter along the Pacific coast and nest primarily in the eastern Arctic but their migration routes are still unknown (Godfrey, 1966; Johnson and Richardson, 1981). In the Beaufort-Chukchi region, colonies have been reported at Cape Kellett and Cape M'Clure (Manning et al., 1956). These colonies had about 200 birds in 1952 (Manning et al., 1956), but their current status is unknown.

The ivory gull (Plate 4.2-8) is considered rare by COSEWIC. Ivory gulls occur in Arctic and subarctic areas throughout the year, but are rarely observed in coastal areas of the Beaufort Sea during spring. They occur sporadically, alone or in small groups, from March to August along and off the north coast of Alaska (Frame, 1973; Kessel and Gibson, 1978). In that area, ivory gulls occur regularly and in largest numbers during September and October. The largest flock that has been recorded was 50 to 75 individuals at Point Barrow on October 25, 1977 (Kessel and Gibson, 1978).

PLATE 4-2-8 *Ivory gulls such as this one are present in the Beaufort Sea in autumn. (Courtesy, M. Bradstreet, LGL Ltd.)*

Ross' gulls nest in eastern Siberia. They are fairly common fall migrants, and casual spring migrants and summer visitants to the Chukchi Sea and Point Barrow (Bailey, 1948; Densley, 1977, 1979; Kessel and Gibson, 1978). However, they are rare or absent in coastal areas of the Beaufort Sea east of Point Barrow (Divoky, 1978b; Salter et al., 1980).

The herring gull, mew gull and Bonaparte's gull migrate to the Arctic via the Mackenzie River Valley and arrive in May (Porsild, 1943; Barry; 1976; Johnson et al., 1975). Herring gulls and mew gulls nest both in colonies, and as single pairs. They nest on islands or around lakeshores; nests are usually on the ground and occasionally in trees (Godfrey, 1966). Bonaparte's gulls usually nest singly in coniferous trees near muskeg ponds or lakes (Godfrey, 1966).

Campbell and Weber (1973) found the mew gull to be the most common species in forested areas of the Beaufort region (Table 4.2-5). In general, gull colonies in the forested portions of the Mackenzie Delta region have not been well documented, although Campbell (1973a) reports a herring gull colony with 29 nests on Sitidgi Lake.

TABLE 4.2-5

DENSITIES (birds/km²) OF THREE GULL SPECIES OBSERVED ON THE MACKENZIE DELTA AND ADJACENT AREAS IN SUMMER, 1972.[1]

	Outer Mackenzie Delta	Southern Mackenzie Delta	Tundra	Boreal Forest	Yukon Coast
Herring gull	0.001	0.002	0.002	0.002	0.00
Mew gull	0.05	0.16	0.06	0.41	0.005
Bonaparte's gull	0.003	0.04	0.00	0.06	0.00
Unidentified gulls	0.00	0.15	0.08	0.005	0.00

[1]Based on Campbell and Weber (1973).

4.2.13 ALCIDS

Alcids are highly aquatic seabirds that normally dive below the water surface to capture small fish and invertebrates. They only come ashore during the nesting period, and typically breed colonially on cliff ledges, in crevices, or amongst the rock rubble of talus slopes. Non-breeding adults and some prebreeding birds also are present at the colonies. Breeding birds have a strong tendency to retain the same nest sites and mates from year to year, and both adults share in incubation and feeding of the nestling(s). Alcids have a relatively low reproductive potential since they are slow to mature and typically have clutches of only one or two eggs.

In the Arctic the breeding distribution of alcids, and true seabirds in general, is influenced by the presence of open water areas in which food can be obtained during the breeding season, and by the presence of suitable nesting habitat such as cliffs, talus slopes, etc. The heavy ice conditions that prevail in the channels of the central Canadian Arctic and the lack of suitable nesting habitat adjacent to Amundsen Gulf and the Beaufort Sea practically preclude the use of these areas by breeding alcids, and other true seabirds. Alcids are rare in the entire area from west Barrow Strait to the Chukchi Sea. However, in the Chukchi Sea breeding conditions are favourable and large colonies of alcids, and other seabirds, occur. Eleven species of alcids occur in the northeast Chukchi Sea, and of these, seven nest there. Only two of these species, the thick-billed murre (*Uria lomvia*) and the black guillemot (*Cepphus grylle*), nest in the Beaufort Sea.

4.2.13.1 Murres

Two species of murres nest in the Beaufort and northeast Chukchi seas: the common murre (*Uria aalge*) and the thick-billed murre (*U. lomvia*). The thick-billed murre (Plate 4.2-9) is essentially circumpolar in its distribution; it breeds in the Arctic and boreal zones of the north Atlantic and Pacific, and in the Arctic Ocean. The common murre nests mainly in the boreal zones of the north Atlantic and Pacific (Tuck, 1960; Brown et al., 1975; Sowls et al., 1978). The biology of the two species is quite similar.

PLATE 4.2-9 *A thick billed murre. (Courtesy, M. Bradstreet, LGL Ltd.).*

Both murre species nest in generally large colonies on coastal cliffs. Common murres, and probably thick-billed murres first breed at 4 to 5 years of age and clutch size for both species is one egg (Tuck, 1960; Birkhead, 1974; Mead, 1974; Birkhead and Hudson, 1977). The incubation period for both murre species is 30 to 35 days (Godfrey, 1966) and the young generally leave the cliffs 18 to 25 days after hatching. At this stage the young are only partially grown and are not capable of sustained flight until 2 to 3 weeks later (Tuck, 1960). After cliff-leaving the chick is accompanied by an adult, generally a male (M.S.W. Bradstreet, unpubl. data). Adults moult at this time and they too are flightless for more than two weeks (Tuck, 1960). Flightless adults and young swim, aided by currents, toward their wintering grounds (Tuck, 1960).

Although murres are common seabirds, their numbers are believed to be declining, primarily because of human activities (Tull et al., 1972; Evans and Waterston, 1976): mainly egg collecting (Brody, 1976), the hunting of adults and young (Brody, 1976; Evans and Waterston, 1976; Kapel and Petersen, 1979), drowning due to entanglement in fishing gear (Tull et al., 1972; Evans and Waterston, 1976; Christensen and Lear, 1977) and exposure to marine oil spills, particularly in the southern portions of their range (e.g. Brown et al., 1973; Vermeer and Vermeer, 1975).

In the northeast Chuckchi Sea approximately 365,000 thick-billed and common murres currently occupy the colonies near Cape Lisburne and Cape Thompson, Alaska (Figure 4.2-8). The thick-billed murre is the more numerous of the two species (Springer and Roseneau, 1978, 1979). Estimated total murre populations along the Alaskan coast are 520,000 in the Chukchi Sea and 1.4 million on the Alaskan Bering Sea coast.

The spring migration of murres into the Chukchi Sea is typically in progress by late April (Swartz, 1966). Murres arrive at and occupy the nesting colonies in the Cape Thompson and Cape Lisburne area during late April or early May. Egg-laying takes place during late June or early July, although replacement

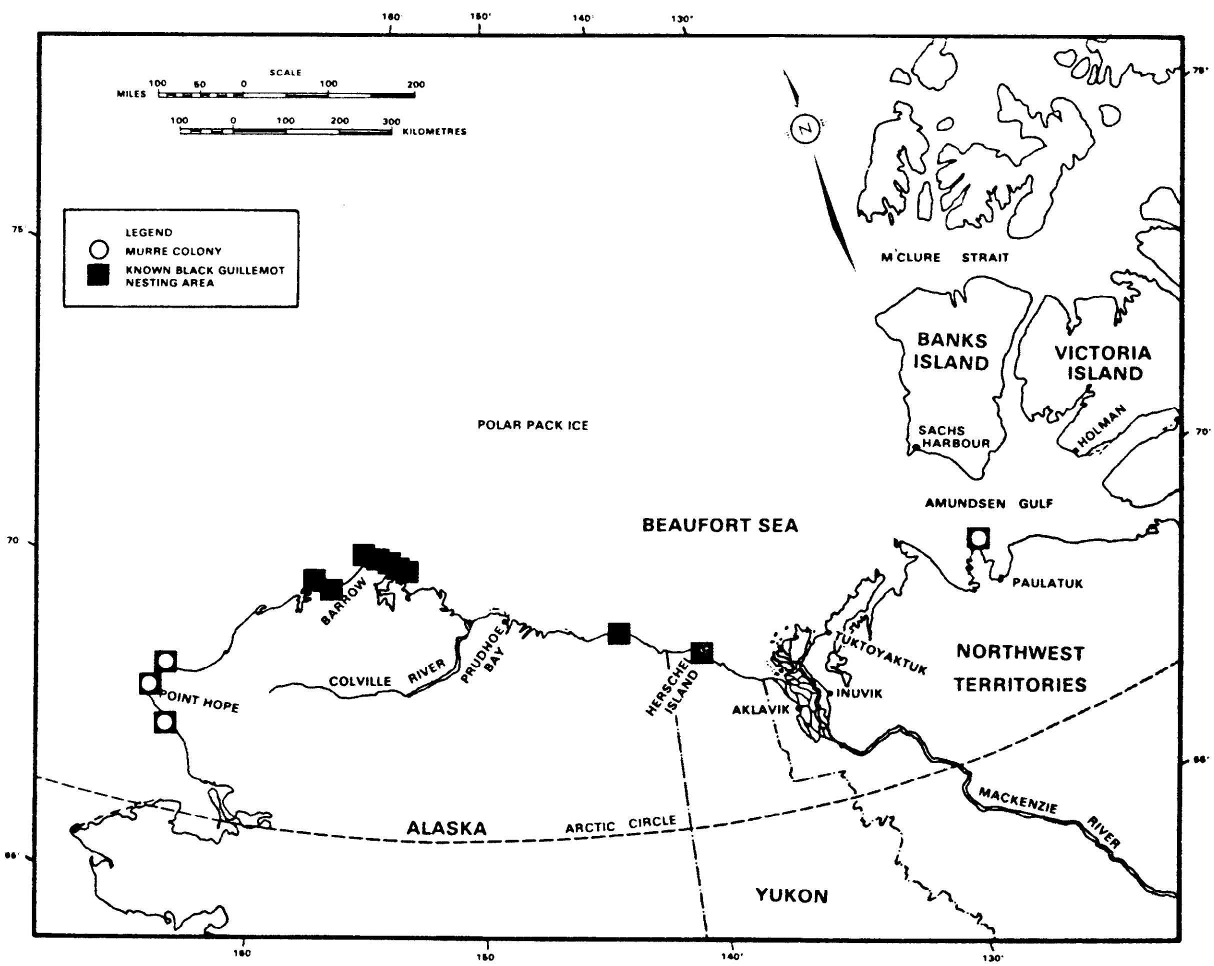

FIGURE 4.2-8 *Locations of murre colonies and known nesting areas for black guillemots.*

clutches may be produced until late July (Springer and Roseneau, 1978).

Both common and thick-billed murres from the Cape Lisburne and Cape Thompson colonies may forage more than 100 km offshore, although the highest densities probably occur within about 65 km of the colonies (Swartz, 1967). Aerial surveys conducted in the vicinity of the Chukchi Sea colonies during July and August, 1978, indicated that the largest flocks of murres were located within about 60 km of the coast, although some murres were observed in areas up to 120 km offshore (Springer and Roseneau, 1979). Cliff-leaving begins during mid August and often continues until late September (Swartz, 1966; Springer and Roseneau, 1978).

A small thick-billed murre colony of approximately 800 birds (Ward, 1979) at Cape Parry in Amundsen Gulf is the only murre colony in the Beaufort region (Plate 3.3-1). This colony is recently established and apparently growing (see LGL and ESL, 1982), but is far removed from any other colonies; the nearest colonies lie 1,200 km to the east and 1,600 km to the west. Because of its isolation and its recent establishment, this colony is a unique feature of the western Canadian Arctic, and is contained within a migratory bird sanctuary.

The timing and location of activities of thick-billed murres associated with the Cape Parry colony are poorly known. Johnson et al. (1975) suggested that these birds may be of the subspecies *arra* that winter south of the ice edge or possibly in leads further to the north in the Bering Sea. Spring migration of murres into the Chukchi Sea is in progress in April and it is possible that the Cape Parry murres arrive in the southeastern Beaufort Sea in late May following a route similar to that of the eiders. Spring staging may take place in the Bathurst polynya. The exact time the colony is occupied each year is not known; however, Barry (1970) reported murres at Cape Parry on June 8, 1970. Indirect evidence suggests that egg-laying does not begin before early July (cf. Höhn, 1955; Barry, 1968; Ward, 1979). Cliff-leaving probably occurs between late August and early September. The route and timing of the autumn migration of flightless adults and young are unknown.

4.2.13.2 Black Guillemots

The breeding distribution of the black guillemot is almost circumpolar and includes both boreal and Arctic coasts. Although this species is common through most of its range, it does not occur in the ice-infested waters of the central Canadian Arctic and only very small numbers occur in the Beaufort-Chukchi region. However, the small numbers of black guillemots that occur in this latter area constitute almost the entire western North American population (Divoky et al., 1974; Kuyt et al., 1976; Sowls et al., 1978; Ward, 1979).

In general, black guillemots nest in small colonies or as single pairs on coastal cliffs or in rock rubble and talus slopes along shorelines (Godfrey, 1966). Adults in an Arctic population first breed during their second or, more commonly, third year (Divoky, pers. comm., cited in LGL and ESL, 1982). In boreal populations, clutches very rarely have more than two eggs and a replacement clutch may be laid if the first clutch is destroyed (Winn, 1950; Preston, 1968). The incubation period is 27 to 33 days (Godfrey, 1966) and brood-rearing requires 35 to 49 days (Preston, 1968). Young birds are not capable of sustained flight when they leave the nests, but unlike murres, they are not attended by the adults (Cairns, 1978). Black guillemots feed primarily on benthic and pelagic organisms (mostly fish) obtained by diving.

The black guillemot has the most northerly wintering range of any seabird. Small numbers of mostly juveniles birds winter in areas of permanent open water in the low and high Arctic (Shortt and Peters, 1942; Salomonsen, 1950; Snyder, 1957; Gabrielson and Lincoln, 1959; Renaud and Bradstreet, 1980).

The distribution and activities of this species within the Beaufort-Chukchi region are best known for the Alaska portion. Sowls et al. (1978) reported that 323 black guillemots nest along the Alaskan Beaufort-Chukchi region (Figure 4.2-8); however, comparable survey data are not available for the Canadian Beaufort Sea and Amundsen Gulf. Thirty nests were reported on Herschel Island in 1973 but only 10+ in 1974 (Kuyt et al., 1976). At Cape Parry, 29 birds were recorded in 1978 (D. Karasiuk, pers. comm., cited in LGL and ESL, 1982) and 37 in 1979 (Ward, 1979), but no nests were seen in either year. However, Barry et al. (1981) recorded a nest at Cape Parry in 1980. More nesting areas may be present in the Canadian Beaufort Sea and Amundsen Gulf. In the Beaufort-Chukchi area nesting black guillemots are often found amongst driftwood, in burrows, in abandoned buildings, and in or under fuel drums (Swartz, 1966; MacLean and Verbeek, 1969; Divoky et al., 1974; Kuyt et al., 1976; Springer and Roseneau, 1978). Non-breeding birds are known to be widely distributed in areas as far as 200 km offshore (Frame, 1973).

In 1960 and 1961, black guillemots were first observed in the vicinity of Cape Thompson during early June (Swartz, 1966), and in 1977 egg-laying began during late June (Springer and Roseneau, 1978). Divoky (1978a) reported that guillemots nesting along the Alaskan coast of the Beaufort Sea also began egg-laying at about this time, and fledging probably occurred during late August.

In the Beaufort-Chukchi region black guillemots are known to winter as far north and east as Point Barrow (Gabrielson and Lincoln, 1959) and may winter as far east as Amundsen Gulf (Manning et al., 1956; Boles and Letkeman, 1976).

4.2.13.3 Other Alcids

The other species of alcids that occur in the northeast Chukchi Sea region include the pigeon guillemot (*Cepphus columba*). Kittliz's murrelet (*Brachyramphus brevirostris*). parakeet auklet (*Cyclorrhynchus psittacula*). crested auklet (*Aethia cristatella*), least auklet (*A. pusilla*). dovekie (*Alle alle*). horned puffin (*Fratercula corniculata*). and tufted puffin (*Lunda cirrhata*). With the exception of the dovekie, parakeet auklet, crested auklet and least auklet, all of these species nest in the Chukchi Sea area only as far north as Cape Lisburne (Sowls et al., 1978). The three auklet species nest in the Bering Strait, but occur in the Chukchi Sea as transients. In the Beaufort-Chukchi region, dovekies have been recorded only once, at Point Barrow (Bailey, 1948). All eight species winter in areas south of the Beaufort and Chukchi seas (Gabrielson and Lincoln, 1959).

The northernmost part of the nesting range of the pigeon guillemot includes Cape Thompson and Cape Lisburne (Sowls et al., 1978). However, the majority of pigeon guillemots occur in areas south of Bering Strait. For example, Sowls et al. (1978) reported 40,571 pigeon guillemots at 363 sites in Alaska, but only 14 birds in the Chukchi Sea.

Kittlitz's murrelets are scarce in areas north of Bering Strait and are only occasionally observed as far north as Cape Lisburne (Sowls et al., 1978). Small numbers of murrelets have been recorded as far north as Point Barrow (Watson and Divoky, 1972). The size of the Chukchi Sea nesting population of Kittlitz's murrelets has not been documented, but this species is believed to nest almost as far north as Cape Lisburne (Sowls et al., 1978).

An estimated 3,300 horned puffins nest at Cape Thompson and Cape Lisburne. These are the most northerly colonies of horned puffins and include only a small portion (less than 0.5%) of the total estimated number of this species nesting in Alaskan waters (Sowls et al., 1978). These authors estimated that approximately 768,000 horned puffins nest in Alaska. Tufted puffins also nest in the Cape Lisburne-Cape Thompson area, but in very low numbers. Most of the nesting population (estimated at 1.9 million birds) occurs at colonies in the Aleutians and Gulf of Alaska (Sowls et al. 1978). Tufted puffins occur only as stragglers in regions east and north of Cape Lisburne.

The remaining three species of alcids that occur in the Chukchi Sea (parakeet, crested and least auklets) are present only as visitants during the breeding period. The northernmost colonies of these three species are located in the Bering Strait (Sowls et al., 1978). Although small numbers of these species have been recorded in the Point Barrow area during May to October (Bailey, 1948), none have been recorded in coastal areas east of Point Barrow (Frame, 1973; Watson and Divoky, 1974; Searing et al., 1975; Bartonek et al., 1977; Divoky, 1978c). Small numbers of each species have been recorded offshore in the northeast Chukchi Sea near Cape Lisburne, Cape Thompson, Point Lay, Point Barrow, and at Wainwright (Swartz, 1967; Watson and Divoky, 1972; Bartonek et al., 1977; Divoky, 1978c).

4.2.14 OTHER SEABIRDS

Three other species of true seabirds occur as transients and/or in small numbers in the Beaufort and northeast Chukchi seas: fulmar (*Fulmarus glacialis*), short-tailed shearwater (*Puffinus tenuirostris*), and pelagic cormorant (*Phalacrocorax pelagicus*).

Although the northern fulmar (*F.g. rodgersii*) does not nest in the Beaufort or northeast Chukchi seas, small numbers (probably non-breeders) occur in the Chukchi Sea during spring, summer and fall (Watson and Divoky, 1972; Gill et al., 1979). This species has been collected near Point Barrow (Bailey, 1948; Gabrielson and Lincoln, 1959). Recently 0.1 fulmars/km^2 were observed during cruises in the western Beaufort in August, and in the northern Chukchi in September (Divoky, 1978c); however, few or no fulmars were recorded during earlier cruises (Swartz, 1967; Watson and Divoky, 1972, 1974; Frame, 1973).

The short-tailed shearwater is the only species of shearwater that occurs in the Beaufort and Chukchi seas. This species breeds colonially in the southern hemisphere during the austral summer (Palmer, 1962), and occurs in the Canadian Arctic as a sporadic and non-breeding visitant during July to early September (Watson and Divoky, 1974; Brown et al., 1975; Gill et al., 1979). It has been estimated that 10 million shearwaters summer in the Bering Sea (Gill et al. 1979), but relatively few occur in the Beaufort and Chukchi seas. For example, September surveys indicated that 0.1 shearwaters/km^2 occurred offshore in the Alaskan Beaufort (Divoky, 1978c), and only small flocks of 15 and 25 birds were observed near Point Barrow, Alaska (Watson and Divoky, 1974). In the Chukchi Sea several large flocks of up to 1,000 birds were reported near Cape Thompson (Swartz, 1967), and 1 to 10 shearwaters/km^2 were seen along transects in the northeast Chukchi Sea during September (Divoky, 1978c).

The only species of cormorant that occurs in the northeast Chukchi Sea is the pelagic cormorant. Known colonies are located in coastal areas between Cape Lisburne and Point Hope, Alaska. In 1977, 80 nesting pairs were observed in these areas (Springer and Roseneau, 1977). Pelagic cormorants occur near the nesting colonies in the Chukchi Sea from late May until their southward migration to wintering areas in September (Swartz, 1966). Bailey (1948) suggested that pelagic cormorants occur only as stragglers in the western Beaufort Sea.

4.2.15 PASSERINES AND 'NEAR-PASSERINES'

Passerines are a large and diverse order that constitute more than 50 percent of all species of birds. They are all adapted to perch in trees and shrubs. Although passerines occur most commonly in forested habitats, they occur in virtually all terrestrial areas. Woodpeckers are discussed in this section as 'near passerines' because they are similar to passerines in many of their characteristics.

In general, the reproductive potential of these species is high. The clutch size of most species is usually within the range from 3 to 7 eggs (Godfrey 1966), and some species may raise two broods in a year. Nests are built on branches, in holes in trees, on the ground, or on cliffs. The young remain in the nest for some time after hatching, and are looked after by the parents until after fledging. Most species breed at one year of age, and their life expectancy is short (Thomson, 1964). Consequently, there is a rapid population turnover. Although a few species nest colonially (e.g. some swallows), most are territorial and their nests are widely dispersed.

Passerines have a wide range of feeding habits, but all woodpeckers are insectivorous. Many passerines, such as the flycatchers, swallows, and warblers, are also insectivorous, and most species prey heavily on insects during the breeding season. Many other species such as the finches feed primarily on seeds. The northern shrike *(Lanius exubitor)* preys on small birds and mammals, while the gray jay *(perisoreus canadensis)* and common raven *(Corvus corax)* are scavengers.

At least 46 species of passerines and woodpeckers probably occur in the coastal Beaufort and Mackenzie Delta area, although only 28 of these regularly occur north of the treeline (Godfrey, 1966; Zoltai et al., 1979; Salter et al., 1980; Martell and Dickinson, 1982). In addition, there are other species that have been recorded rarely in this region. Most passerines and 'near-passerines' in the coastal Beaufort area are migratory and winter in southern Canada, the United States, or the tropics. Nine species are known to winter in the Mackenzie Delta area (Martell and Dickinson, 1982), but only one species, the common raven, is known to winter on the Arctic Coastal Plain of the northern Yukon. There is some evidence that the dipper (*Cinclus mexicanus*) may also winter there (Salter et al., 1980; P.C. Craig, pers. comm.).

Passerines and near-passerines breed throughout the region in forest, scrub, muskeg and tundra habitats. Studies of their abundance and densities were conducted at numerous sites in the Mackenzie Delta and the Arctic Coastal Plain from 1971 through 1975 (Schweinsburg, 1974; Tull et al., 1974; Koski, 1975b; Patterson et al., 1977). Results of these studies indicated densities were usually highest in closed deciduous scrub habitat, and five species or species groups, savannah sparrow (*Passerculus sandwichensis*), tree sparrow (*Spizella arborea*), Lapland longspur (*Calcarius lapponicus*), yellow warbler (*Dendroica petechia*) and redpolls, constituted 63% of the birds seen on transects in the Mackenzie Delta area (Patterson et al., 1977). Lapland longspurs constituted 29% and redpolls constituted 11% of the birds seen on transects in the Arctic Coastal Plain (Koski, 1975b).

Seed-eating passerines are the first to arrive in the coastal Beaufort and Mackenzie Delta region during spring. Some snow buntings (*Plectrophenax nivalis*) arrive at the Arctic Coastal Plain during mid April and some Lapland longspurs by early May (Salter et al., 1980). They both probably arrive earlier in the Mackenzie Delta area. Insectivorous passerines do not usually arrive at the Arctic Coastal Plain until early June (Salter et al., 1980). The southward migration probably begins in August, but many species may remain at the Arctic Coastal Plain until mid to late September (Salter et al., 1980).

Passerine migration through the Mackenzie Delta area is quite noticeable, at least in fall (Campbell 1973b; Searing et al., 1975). In contrast, migration along the Yukon coast was not obvious during spring or fall, with the exception of an eastward movement of snow buntings in mid September (Gollop and Davis, 1974a; Johnson et al. 1975; Richardson et al., 1975). A few species of passerines that breed on the Arctic Coastal Plain migrate to and from the area via Alaska. Two of these species, the yellow wagtail (*Motacilla flava*), and the bluethroat (*Luscinia svecica*), are known to nest within the coastal Beaufort region in Canada (Black 1972; Taylor et al. 1974) but not in other parts of Canada.

Tate (1981) includes the ruby-crowned kinglet (*Regulus calendula*) and yellow warbler on the most recent 'blue list' of North American species because of population declines in many parts of their ranges. Nevertheless, both remain widely distributed and numerous.

4.3 FISH

Fish populations in the rivers, lakes and streams of the onshore Beaufort region were studied extensively during the 1970's when several energy projects were proposed. Waterbodies along the Yukon coast were investigated to evaluate the possible effects of the Canadian Arctic Gas Pipeline. The Mackenzie Delta was studied because of proposed gas and oil pipeline developments, oil and gas exploration activities and relative to logistics in support of offshore exploration. The area east of the Mackenzie Delta has been surveyed less intensively. The following section summarizes information on fish species in the onshore Beaufort region largely with respect to their freshwater habitats and life histories. Fish populations in Beaufort coastal marine and offshore habitats in the region are described separately in Section 3.4 of this volume.

4.3.1 SPECIES COMPOSITION, DISTRIBUTION, AND RELATIVE ABUNDANCE

A total of 25 fish species have been captured to date in streams and lakes along the coast (Table 4.3-1). All 25 species occur in the Mackenzie Delta (Table 4.3-2), with fewer species in smaller drainages west and east of the Delta. Locations of waterbodies listed in Table 4.3-2 are shown in Figures 4.3-1 and 4.3-2. Most of the species listed are either exclusively freshwater or anadromous, with the latter spending part of their life history in marine environments along the coast (see Section 3.4). The fourhorn sculpin, primarily a marine species, is included since it inhabits a few floodplain lakes in the outer Mackenzie Delta. The Mackenzie Delta also supports several species (e.g. grayling and northern pike) at or near the northern limit of their North American range, and some, including yellow walleye, goldeye, and flathead chub are not found in any other Beaufort Sea drainage. (Scott and Crossman, 1973; McCart *et al.*, 1974)

The Mackenzie Delta provides habitat for the most diverse fish fauna within the coastal development region from Herschel Island to Paulatuk. The large and complex system of lakes, connecting rivers, and

TABLE 4.3-1

FISH OCCURRING IN STREAMS AND LAKES ALONG THE BEAUFORT SEA COAST BETWEEN THE ALASKA-YUKON BORDER AND PAULATUK

Common Name	Code	Scientific Name	Type[1]	Spawning Period[2]
Arctic lamprey	ARLM	Lampetra japonica (Martens)	A	S
Pink salmon	PINK	Oncorhynchus gorbuscha (Walbaum)	A	F
Chum salmon	CHUM	Oncorhynchus keta (Walbaum)	A	F
Arctic char	CHAR	Salvelinus alpinus (Linnaeus)	A	F
Lake trout	LKTR	Salvelinus namaycush (Walbaum)	F	F
Arctic cisco	ARCS	Coregonus autumnalis (Pallas)	A	F
Least cisco	LSCS	Coregonus sardinella Valenciennes	A	F
Humpback whitefish	HMWT	Coregonus clupeaformis (Mitchell)	A	F
Broad whitefish	BDWT	Coregonus nasus (Pallas)	A	F
Round whitefish	RDWT	Prosopium cylindraceum (Pallas)	A	F
Inconnu	INCO	Stenodus leucichthys nelma (Pallas)	A	F
Arctic grayling	GRAY	Thymallus arcticus (Pallas)	F	S
Pond smelt	PONS	Hypomesus olidus (Pallas)	F	S
Boreal smelt	BORS	Osmerus eperlanus (Mitchell)	A	S
Northern pike	PIKE	Esox lucius (Linnaeus)	F	S
Lake chub	LKCB	Couesius plumbeus (Agassiz)	F	S
Flathead chub	FLCB	Platygobio gracilis (Richardson)	F	S
Longnose sucker	LNSK	Catostomus catostomus (Forster)	F	S
Burbot	BURB	Lota lota (Linnaeus)	F	W
Ninespine stickleback	NNST	Pungitius pungitius (Linnaeus)	F	S
Trout-perch	TRPH	Percopsis omiscomaycus (Walbaum)	F	S
Yellow walleye	WALL	Stizostedion vitreum vitreum (Mitchell)	F	S
Slimy sculpin	SLSC	Cottus cognatus (Richardson)	F	S
Spoonhead sculpin	SPSC	Cottus ricei (Nelson)	F	S
Fourhorn sculpin	FHSC	Myoxocephalus quadricornis quadricornis (Linnaeus)	M	S

[1]Type:
A - anadromous
F - freshwater
M - marine

[2]Spawning Period:
S - spring
F - fall
W - winter

TABLE 4.3-2

KNOWN FISH SPECIES DISTRIBUTION ALONG THE BEAUFORT SEA COAST. FOUR LETTER FISH CODES ARE PROVIDED IN TABLE 4.3-1. SOURCES LISTED IN TEXT AND LOCATIONS SHOWN ON FIGURES 4.3-1 and 4.3-2

Waterbodies	Location	CHAR	LKTR	ARCS	LSCS	HMWT	BDWT	RDWT	INCO	GRAY	PONS	BORS	PIKE	LKCB	LNSK	BURB	NNST	TRPH	SLSC	SPSC	FHSC
Craig Creek	1	X						X		X							X		X		
Backhouse River	2									X											X
Lake 26	3																X				
Fish Creek	4	X		X	X			X	X	X							X		X		X
Fish Creek Springs	5	X																			
Malcolm River	6	X		X	X			X	X	X							X		X		X
Malcolm River Springs	7	X								X											
Firth Spring	8	X																			
Lake 104	9	X															X				
Lake 103	10	X															X				
Joe Creek	11	X								X											
Firth River	12	X		X	X			X	X	X		X					X		X		X
Kugaryuk Creek	13									X											
Okpioyuak Creek	14									X											
Firth Camp Lake 1	15																X				
Lake 107	16									X											
Lake 105	17		X		X					X							X				
Lake 100 (Roland Lake)	18					X	X			X	X						X				
Lake 109 (Furbearer's Lake)	19					X	X			X											
Stream 1000	20		X							X							X				
Stream 1001	21									X											
Stream 1002	22	X																			
Roland Creek	23	X								X											
Spring River	24	X			X	X	X	X		X							X		X		
Crow River	25	X						X		X							X		X		
Peatbog Creek	26									X											
Crow River Spring	27	X								X											
Lake 106	28				X				X												X
Trail River	29	X						X		X							X		X		
Lake 38 (101)	30				X		X			X											
Philip Creek	31	X								X											
Trout Lake Outlet	32									X											
Babbage River	33	X						X		X							X		X		
Deep Creek	34	X				X	X	X		X							X		X		
Fish Hole Creek (Canoe River)	35	X								X											
Lake 41	36									X											
Lake 42	37																X				
Running River (Walking River)	38	X				X	X	X		X							X		X		
Tundra Creek	39									X											
Lake 46	40					X															
Anker Creek	41	X						X		X											
Blow River	42	X				X	X	X	X	X							X		X		
Purkis Creek	43	X						X		X											
Rapid Creek	44	X				X		X		X						X	X		X		
Stream 1003	45									X											
Fish River (Big Fish River)	46	X							X					X	X		X				
Little Fish Creek (Cache Creek)	47	X						X		X											
Canoe Lake	48									X			X								
Cache Creek	49							X		X											
Martin Creek	50									X											
Willow River	51									X					X	X					
Fish Creek (tributary to Rat River)	52	X								X									X		
Rat River	53	X					X			X	X		X	X	X		X		X		
West Channel	54	X		X	X	X		X	X							X	X	X		X	
Middle Channel	55		X	X	X	X	X		X			X	X		X	X		X		X	
East Channel	56		X	X		X	X		X	X		X	X	X	X	X	X	X		X	X
Sitidgi Lake	57		X							X											
Eskimo Lakes	58	X	X	X		X	X		X	X		X	X		X	X	X		X		X
Kugaluk River	59				X				X												
Anderson River	60				X			X	X	X					X	X		X			
Simpson Lake	61		X			X		X		X			X			X					
Mason River	62													X					X		
Horton River	63	X						X		X							X		X		

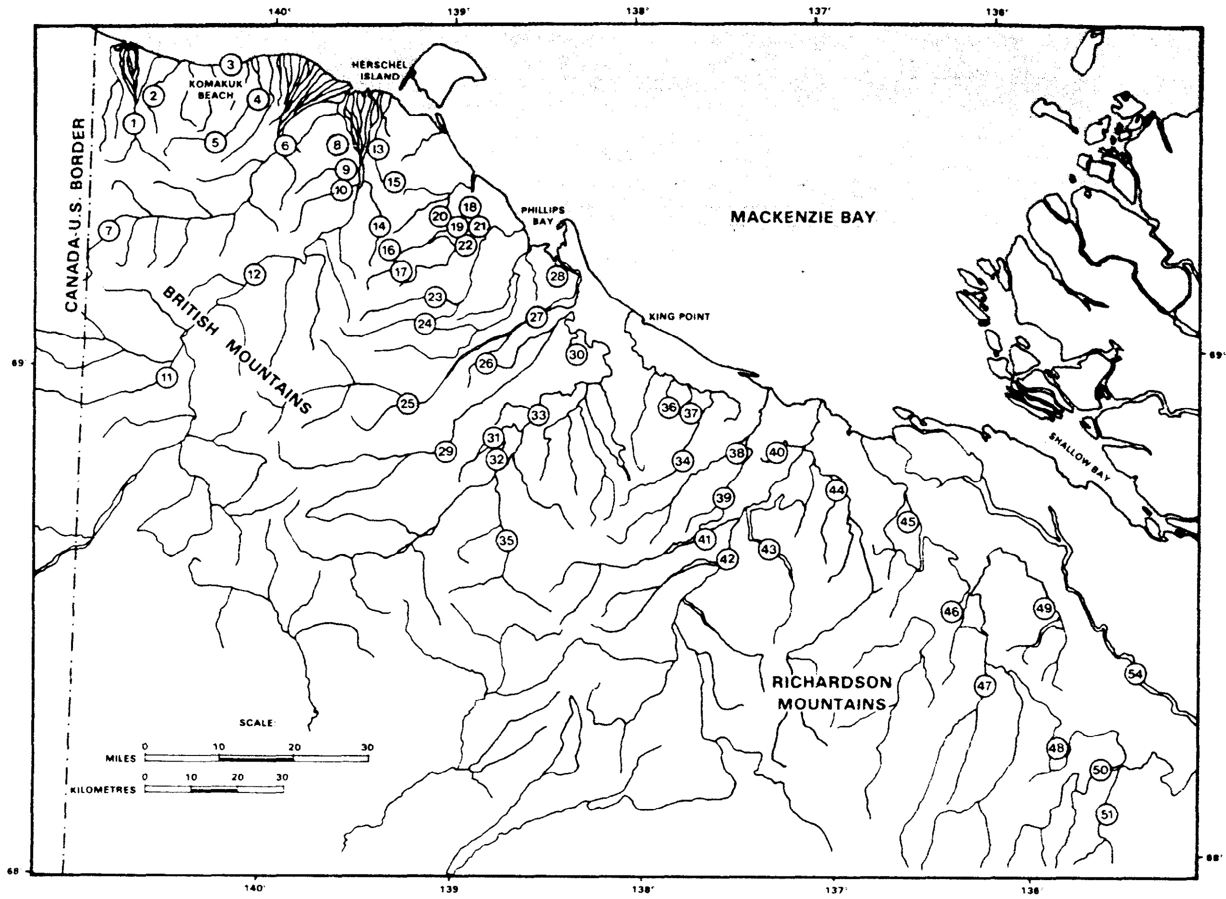

FIGURE 4.3-1 *Location of waterbodies listed in Tables 4.3-2 and 4.3-3.*

estuaries supports large populations of fish, and the numerous channels in the Delta area serve as important migratory corridors for anadromous species. Craig and McCart (1975) have identified the Mackenzie Delta as one of the most important stock sources for anadromous species in the western Arctic. Of these, the most abundant and sought after species are Arctic char, ciscos, whitefish, and inconnu. Cisco and whitefish are the most abundant and comprise the largest portion of domestic fish harvests, in the region (see Section 4.6.2). Within the Mackenzie River drainage, Arctic char populations are found only in tributaries of the Peel and Big Fish rivers, and they migrate only through the western channels of the Delta (McCart and Bain, 1974; Jessop *et al.*, 1974, Jessop and Lilley, 1975). Although the timing of migrations may vary with species maturity and habitat, most of the anadromous fish generally move downstream into coastal feeding habitats during the summer, and return to spawn and overwinter in freshwater during the fall (see Section 3.4). Boreal smelt are also common in the Mackenzie Delta, but unlike other anadromous species, they usually only penetrate fresh water channels to spawn during the spring. Northern pike are the most abundant strictly freshwater species in the Mackenzie Delta, although longnose sucker, slimy sculpin, and pond smelt are locally abundant. Several marine species in addition to fourhorn sculpin are known to intrude into the outer Delta, but are generally confined to brackish water (Percy, 1975). These include Pacific herring, Arctic and starry flounder, and Arctic and saffron cod.

Yukon coastal streams (Figure 4.3-1) are usually dominated by populations of Arctic char and Arctic grayling (Table 4.3-2). Many Yukon coastal streams support both anadromous and non-migratory stream-resident populations. Char populations in Cache Creek, the Babbage River, and the Firth River have been the subject of intensive life history investigations (McCart and Bain, 1974; Bain, 1974; Glova and McCart, 1974). Mutch and McCart (1974) classified 53 springs on the Yukon North Slope, many of which are known to support stream-resident Arctic char populations. Some lake-resident populations of Arctic char are present in this area, but char are most common in streams.

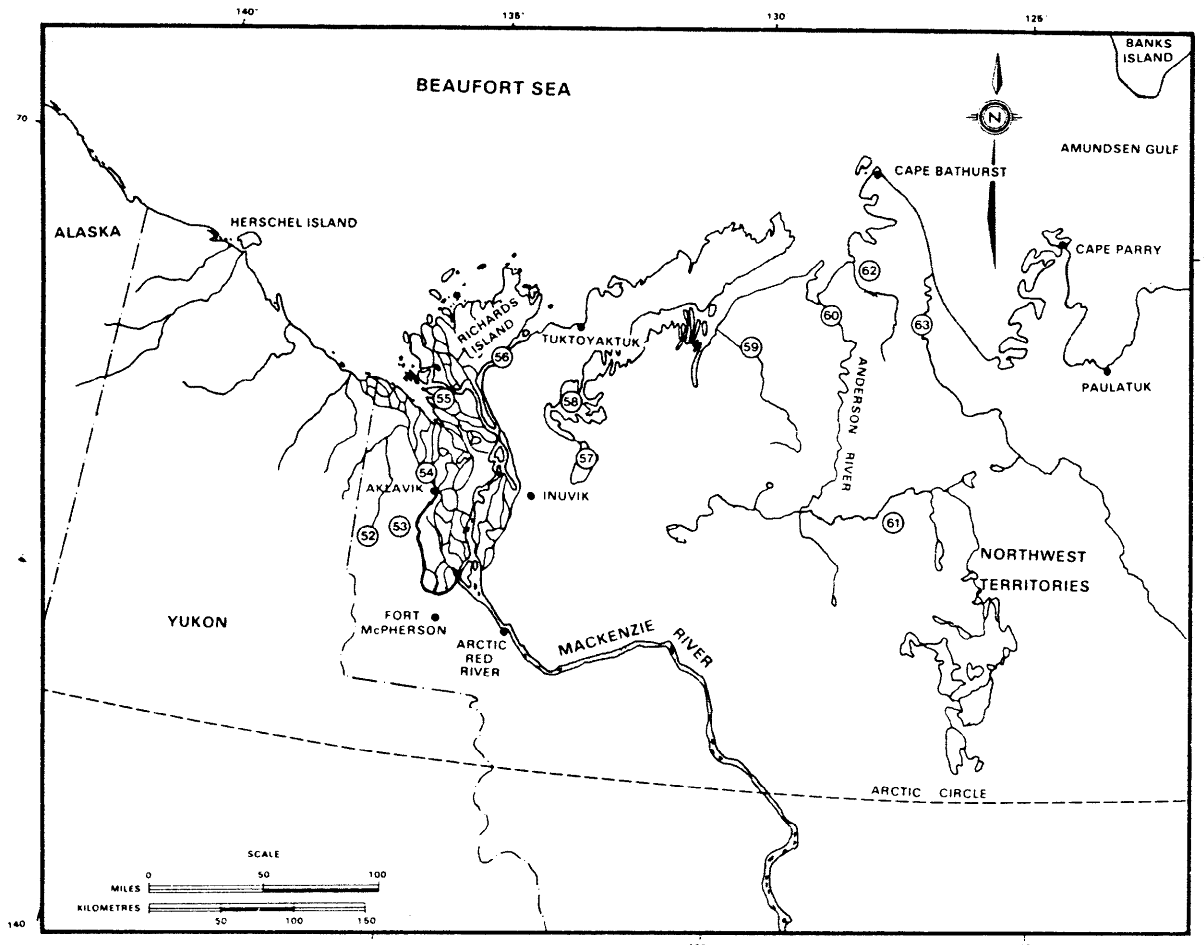

FIGURE 4.3-2 *Locations of waterbodies listed in Tables 4.3-2 and 4.3-3.*

The Firth, Babbage, Blow River, and Cache Creek systems are the most important streams for anadromous char. Although accurate population estimates do not exist for these watercourses, Stein *et al.* (1973) estimate that the Arctic char population in Cache Creek, a tributary of the Big Fish River, is approximately 17,000 fish, and Glova and McCart (1974) report that the migrant Arctic char population of the upper Firth River is approximately 32,000 individuals. Data from limited tag return studies in other areas are inadequate to determine population sizes. Only the lowest 75 km of the Babbage River are accessible to migratory char, since a major waterfall forms a barrier to upstream movements, and only dwarf resident char occur above the falls. While large numbers of ciscos and whitefish are known to utilize Yukon coastal waters during summer feeding migrations from the Mackenzie River, these species are only rarely captured in the lower reaches of Yukon coastal streams.

Grayling populations have received intensive life history and distribution studies along the Yukon coast (de Bruyn and McCart, 1974). Along the Yukon coast, grayling typically inhabit the headwater areas of both mountain and tundra streams and are found throughout some of the larger stream systems such as the Blow, Babbage, and Firth river drainages. Lakes both in the tundra area and in the foothills provide summer feeding habitat and, in many cases, year round habitat for grayling. Several of these lakes also support populations of least cisco (Mann, 1974), broad whitefish (de Bruyn and McCart, 1974), lake trout, pond smelt (de Graaf, 1975), humpback whitefish, and ninespine stickleback.

Lakes and small streams along the Tuktoyaktuk Peninsula harbour populations of least cisco, humpback and broad whitefish, lake trout, northern pike, grayling, pond smelt, and ninespine stickleback. While many of these lakes and streams are small and shallow, recent studies by the Department of Fisheries and Oceans (M. Lawrence, pers. comm.) indicate that this area is an important for overwintering ciscos, and that many small streams and lakes are important summer feeding areas for migratory Mackenzie River populations of ciscos and whitefish. Unlike the Yukon coastal streams, it appears that large numbers of Mackenzie River migrants actually enter small coastal streams along the Tuktoyaktuk Peninsula to feed intensively for one to three months before returning to the Mackenzie Delta in late summer and fall. For example, preliminary summer feeding studies in the Parlaiyut Creek and lake system on the Tuktoyaktuk Peninsula indicate that nearly one million whitefish and least cisco enter the system annually and depart in late summer (M. Lawrence, pers. comm.). Similar feeding runs have not been observed in Yukon coastal streams despite intensive sampling. Preliminary surveys by the Department of Fisheries and Oceans suggest that as many as ten stream systems on the Tuktoyaktuk Peninsula may support similar runs. The reasons for the heavy use of Tuktoyaktuk Peninsula streams by migratory species are not clear, but an important factor may be the apparent high productivity of these streams compared to Yukon coastal streams (M. Lawrence, pers. comm.).

Another unusual feature of fish distribution along the Tuktoyaktuk Peninsula is the absence of Arctic char from streams or coastal waters in this region. None of the streams on the Tuktoyaktuk Peninsula offer char habitat, and fish migrating from the western Mackenzie Delta and from char supporting streams to the east (e.g. Hornaday River) do not appear to reach the coastal waters of the Tuktoyaktuk Peninsula (Jones and Den Beste, 1977).

Streams draining into Eskimo Lakes and Liverpool Bay along the southeast side of the Tuktoyaktuk Peninsula connect to lakes which commonly support northern pike, lake trout, grayling, least cisco, and humpback whitefish (Slaney, 1977). It is not known if this region supports Mackenzie River fish on summer feeding runs, but available information suggests that freshwater areas are used mostly by resident fish.

Studies conducted east of Liverpool Bay indicate several streams in this region support Arctic char, broad and humpback whitefish, grayling, and least cisco. A few lakes in this region also support least cisco, grayling, whitefish species, and lake trout. Little is presently known, however, regarding life history patterns of these species in this portion of the onshore development zone. The Horton River and the Hornaday River support major populations of Arctic char.

4.3.2 LIFE HISTORIES

The life histories of fish species determine their potential to be impacted by development. For example, disruption of key spawning, incubation, rearing, migration, or overwintering areas can seriously impact local or regional populations, and the magnitude of the effects of specific disturbances vary with life history characteristics. While the abundance of non-migratory species throughout the Beaufort coastal region may vary little with the seasons, anadromous and migratory freshwater species (e.g. Arctic grayling) may become concentrated in high numbers during migrations to and from feeding, overwintering, or spawning areas. The following section provides a brief summary of life history aspects of important species.

4.3.2.1 Arctic Char

The Western Form of Arctic Char inhabits tributaries of the Mackenzie River and streams along the Yukon coast (Plate 4.3-1) (McCart, 1980). East of the Mackenzie River, char populations consist of the Eastern Form (McPhail, 1961). The two forms differ in several meristic and morphometric characteristics. The most significant life history difference between these populations is that the Western Form of Arctic char spawns exclusively in streams, while many populations of Eastern char spawn in lakes (McCart, 1980).

Within the Beaufort coastal zone, four life history patterns have been reported for Arctic char populations (McCart, 1980). Briefly, these are:

1) Isolated stream-resident populations occupying spring-fed stream channels and separated from populations further downstream by falls or other blockages to upstream movements.

2) Lake-resident populations of char. While a few of these fish may enter tributary streams on feeding excursions during summer, these populations are almost exclusively confined to lakes.

3) Anadromous populations with a component which migrates to the sea to feed during summer months. In this region, anadromous char spawn and overwinter only in streams near perennial groundwater sources.

4) Residuals. These are almost exclusively males which are associated with anadromous populations but which mature without having undertaken a seaward migration.

The only lake-resident populations identified in this area to date are found in two small lakes in the Firth River drainage. These populations are actually isolated populations of the Eastern Form Arctic char, their only known occurrence in Canada west of the Mackenzie River.

Isolated stream-resident populations are confined entirely to streams fed by perennial springs, mostly west of the Mackenzie Delta. Arctic grayling are

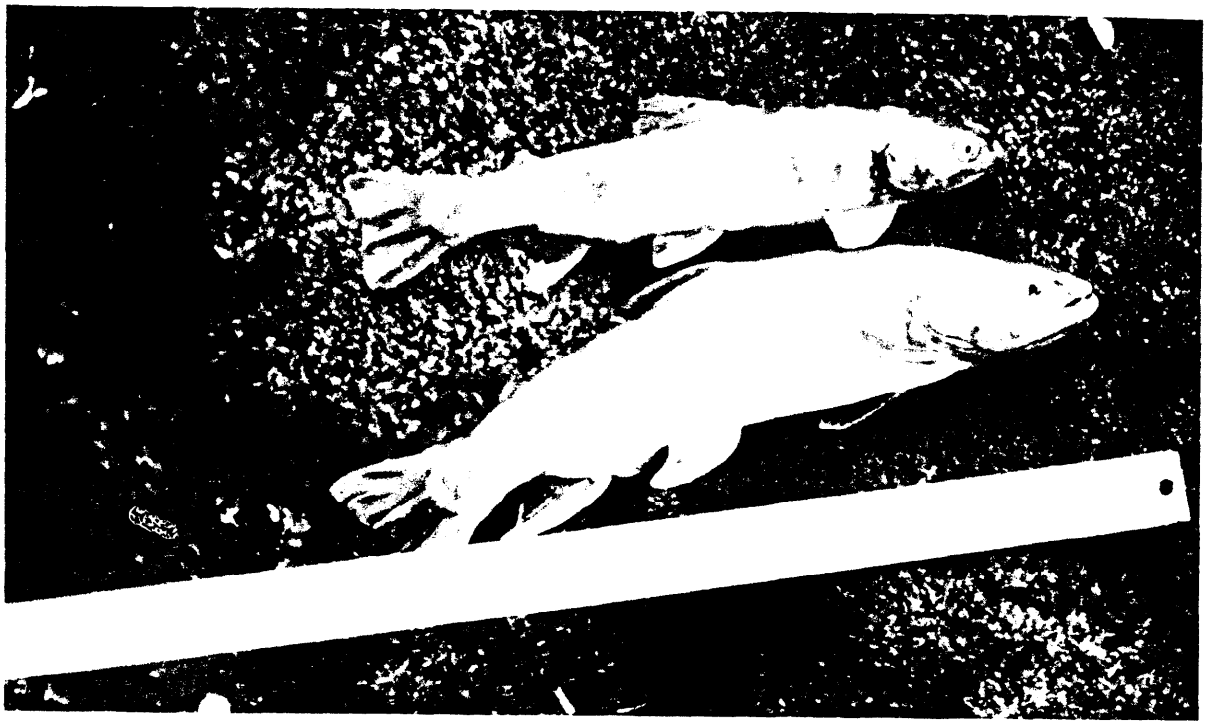

PLATE 4.3-1 *Western form Arctic char inhabit tributaries of the Mackenzie River and streams along the Yukon coast. These freshwater resident char were caught in spawning colouration. (Courtesy, Aquatic Environments Ltd.).*

found with the isolated stream-resident char population in the lower Babbage River, but at all other locations along the Beaufort coast, isolated stream-residents do not occur in conjunction with other species.

Characteristics of anadromous char populations have been summarized by Marshall (1977) and McCart (1980). The maximum reported age for anadromous char in the western Arctic ranges from 10 to 14 years, in contrast to ages of up to 25 years for the Eastern Form. The maximum size of char seldom exceeds 600 mm. Most char appear to mature in 4 to 6 years. In all char populations studied to date, the percentage of spawning fish present each year is low, ranging from 2 to 15% (Hunter, 1970; Campbell, and Johnson, 1976; Sopuck, 1977; de March *et al.*, 1977). Once mature, individuals spawn only every two to three years.

Anadromous char typically spend the first 2 to 5 years in fresh water before their first seaward migration (Craig and McCart, 1975; Kendel *et al.*, 1975). Seaward migrations begin in May and June, about the time of river breakup, and upstream migrations from coastal waters occur from mid summer to early fall. A run of Arctic char is reported to occur in Husky Channel in the Mackenzie River during late August and early September (Stein *et al.*, 1973). Similar runs have been observed in the Firth River (Glova and McCart, 1974), the lower Babbage River (Bain, 1974), and in the Hornaday River (R. Barnes, pers. comm.).

The advantages of anadromy are discussed in detail by McCart *et al.* (1972) and are reflected by increased growth rates in char returning from the sea for the first time after several years of slow growth in fresh water. Char are opportunistic in their food habits, and eat a wide variety of organisms often including other char. Many char captured during migrations to and from coastal feeding usually have empty stomachs, thus showing a tendency to cease feeding during migrations (de Graaf and Machniak, 1977; Glova and McCart, 1974). Percy (1975) suggests that empty stomachs might also cause increased stress if delays occur during migration.

Comparative growth curves for various types of char populations are presented by McCart (1980). Isolated stream-resident and residual male char grow much slower than anadromous char, often reaching a size of only 150 mm by age 5 (McCart and Bain, 1974). Stream-resident populations are generally short lived with a few individuals reaching age 10 and few fish exceeding 300 mm in length. The two known lake-resident populations in the Yukon appear to be intermediate in growth rate between anadromous populations and stream resident populations (AEL, unpublished data).

Typically, residual males engage in some movements within streams, particularly between spawning sites, overwintering areas, and summer feeding areas. Isolated stream-resident populations, by contrast, display little or no migratory movement, often spawning, overwintering, and feeding in the same stream or spring-fed area. Some isolated stream-resident populations exist in areas only 1.5 km long in spring-fed creeks (McCart, 1980). Due to the obvious habitat limitations imposed on isolated stream-resident populations, any reduction in habitat could cause a significant decline in local populations, particularly where domestic fishing pressure is already high.

4.3.2.2 Lake Trout

Lake trout (actually a char) are the largest and are among the longest lived freshwater fish in the Northwest and Yukon territories (Plate 4.3-2). Because of its great weight (to 30 kg) and the palatability of its flesh, this species is highly sought after by sport, subsistence and to some degree, commercial fishermen.

The distribution, human use, and life history of lake trout are summarized in a bibliography prepared by Marshall and Keleher (1970). Growth curves for populations in Ya-Ya Lake (Machniak, 1977; McCart *et al.*, 1979) and a wide range of other northern waterbodies (Falk *et al.*, 1973, 1974; Bond, 1973, 1975) show that they grow slowly and have a long life span. Individuals commonly exceed 30 years of age with some individuals reaching age 60 or more. Falk *et al.* (1973) report a gradual decline in growth rate with increasing latitude, thus populations near the Beaufort coast are probably among the slowest growing in the Northwest Territories and Yukon.

The earliest lake trout spawning reportedly occurs at age 8 and some individuals do not begin to spawn until age 22 (Falk *et al.*, 1973, 1974; McCart *et al.*, 1979). Northern lake trout usually spawn in alternate years after reaching maturity, occasionally spawning only every third year.

Lake-dwelling populations commonly move into shallow water, less than 12 m deep during the fall to spawn, usually on coarse rock or rubble substrates (Scott and Crossman, 1973). Spawning has been reported as early as mid August in Great Bear Lake (Miller and Kennedy, 1948) but most authors report that spawning in northern areas occurs in late September or October. Little is known about spawning of stream-dwelling populations in the Mackenzie River.

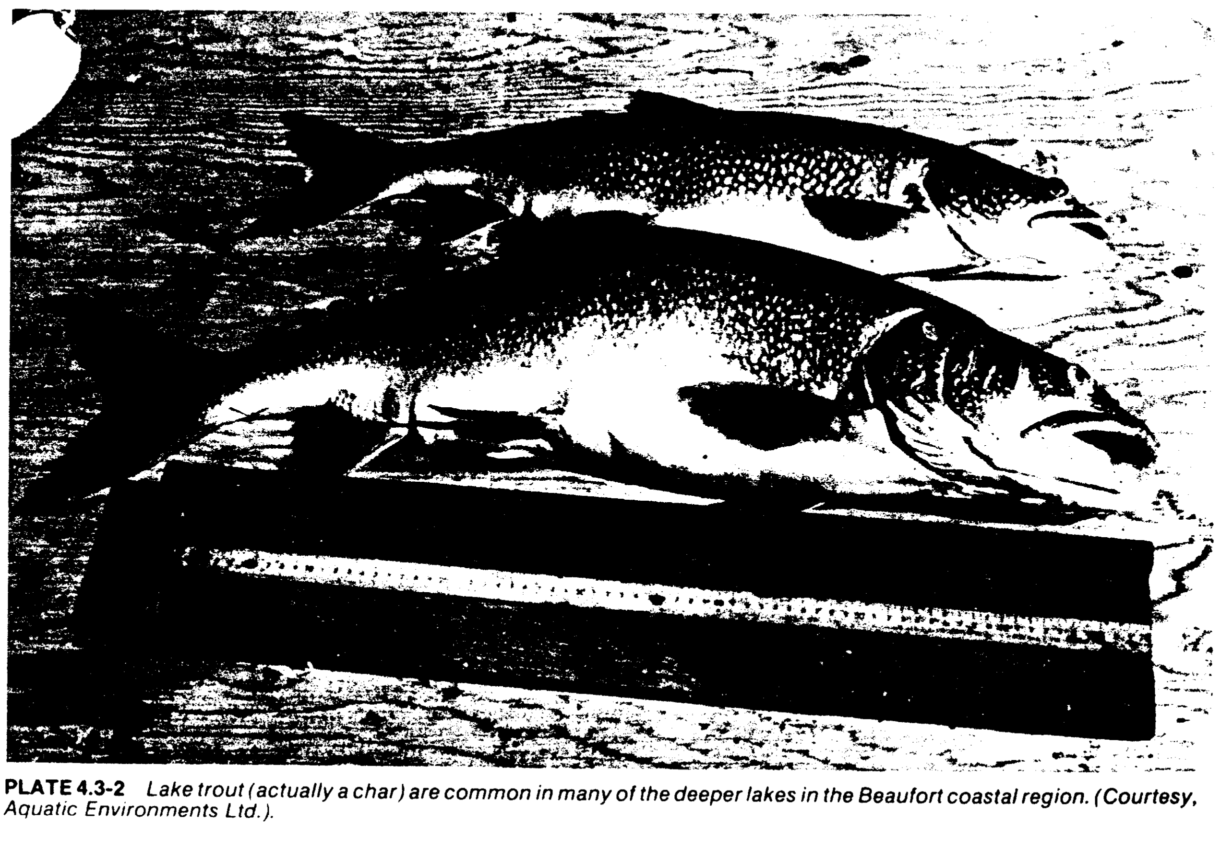

PLATE 4.3-2 *Lake trout (actually a char) are common in many of the deeper lakes in the Beaufort coastal region. (Courtesy, Aquatic Environments Ltd.).*

While there is some evidence that lake trout return to the same spawning areas, homing is generally considered to be incomplete (Martin, 1960). Incomplete homing combined with the wide ranging movements of this species suggest that natural mixing of stocks is common and recolonization would occur in areas where populations have been reduced or eliminated. Studies by Johnson (1972, 1976) indicate that many northern lake trout populations experience very low adult mortality and have a higher percentage of old, mature fish (greater than 10 years old) with mean lengths of 500 to 600 mm. As a result of low adult mortalities, low fecundities, and generally poor spawning success, the recruitment of juveniles to the population in unexploited lakes is usually relatively low. Furthermore, lake trout appear to be less capable of recovering from some impacts compared to species with a higher reproductive capacity, such as Arctic char or whitefish. (McCart and Den Beste, 1979)

Data on the food habits of lake trout in the onshore region are generally not available, but data from Great Slave and Great Bear Lakes, as well as other areas, indicate that fish are the most important food for most northern lake trout. Lake trout which feed exclusively on crustaceans are slower growing, reach a smaller maximum size, and are shorter lived than trout which eat mainly fish (Martin, 1966). Machniak (1977) and McCart *et al.* (1979) report that lake trout in Ya-Ya Lake feed almost exclusively on crustaceans and grow slowly.

4.3.2.3 Broad and Humpback (Lake) Whitefish

With the possible exception of Arctic char which until recently were harvested from streams near Paulatuk, whitefish are probably the most important fish species to area residents. Broad whitefish are the most sought after whitefish because of their palatability (Corkum and McCart, 1981).

The life history patterns of both broad and humpback whitefish are generally similar. Mackenzie Delta whitefish are usually semi-anadromous, spending brief periods in brackish water, and reach lengths of 600 to 700 mm at maximum ages of 15 to 25 years. Lake dwelling and other completely freshwater forms of both species are somewhat slower growing than semi-anadromous populations (Percy, 1975). However, Machniak (1977) reports a lake-dwelling broad whitefish population in the Mackenzie Delta containing the largest individual collected to date in this region (800 mm, 11.7 kg). Slaney (1974) also reported that growth of broad whitefish in some lakes in the Mackenzie Delta was faster than in the Mackenzie River's mainstem. While some of the reported variability in growth rate may be an artifact of aging technique, it is apparent that isolated populations differ significantly in growth. In the Mackenzie Delta, broad whitefish are usually larger than humpback whitefish. Broad whitefish mature as early as age 3 or 4 (Percy, 1975) and as late as age 7 to 10 (de Graaf and Machniak, 1977). Humpback whitefish reach sexual maturity after 7 to 9 years in most areas. Some of the variability in determinating the age of first reproduction may also be an artifact of the aging technique.

Both humpback and broad whitefish appear to be consecutive year spawners indicating that a single individual could conceivably spawn up to 13 times during a lifetime. Whitefish populations in this region reproduce rapidly in comparison with other highly migratory species, thus enabling them to rapidly replace individuals lost through natural causes or exploitation. Fry and young juvenile whitefish are abundant in the Mackenzie Delta, in coastal lakes, and in coastal brackish water (Section 3.4) throughout the summer months.

Both broad and humpback whitefish migrate short distances into brackish coastal waters during the summer months, occasionally using coastal streams as summer feeding areas. Their numbers begin increasing in the Mackenzie Delta during August, reaching peak levels in late September and early October (Stein *et al.*, 1973; Jessop *et al.*, 1974; Jessop and Lilley, 1975; de Graaf and Machniak, 1977). There is evidence that spawning occurs in back eddies of the Mackenzie River near Arctic Red River (Jessop *et al.*, 1974) and in the lower reaches of the Arctic Red River (Jessop and Lilley, 1975). Much of the annual domestic harvest is taken during the spawning migrations (Jessop *et al.*, 1974). Portions of the whitefish populations of this region are nonmigratory, remaining in freshwater channels of the Mackenzie River and in coastal streams to the east of the Mackenzie River.

The times of spawning in lake-dwelling broad whitefish are not well known, but data from streams in the eastern part of the onshore region indicate that spawning tends to occur at the same time as in the Mackenzie River (R. Barnes, pers. comm.).

4.3.2.4 Arctic And Least Cisco

Ciscos comprise a major fraction of the annual fish harvest in the Mackenzie Delta and in coastal waters near Tuktoyaktuk (Corkum and McCart, 1981). Arctic and least cisco have some life history differences which are also expressed in different growth patterns. Arctic cisco stocks originate in the Mackenzie River, migrate to coastal areas through the Mackenzie Delta during the summer, and return to the Mackenzie River during the fall to spawn and overwinter (Craig and McCart, 1976). Mackenzie River least cisco also follow this pattern, but unlike Arctic Cisco, least cisco spawn and overwinter in other coastal drainages. The region also contains numerous lake-dwelling populations of least cisco which do not migrate at all (Mann, 1974).

Cisco grow relatively slowly, with the maximum sizes of Arctic and least cisco rarely exceeding 500 mm and 350 mm, respectively. Migratory Arctic cisco are generally faster growing and longer lived than migratory least cisco (Craig and Mann, 1974; Griffiths *et al.*, 1975, 1977; Jones and Den Beste, 1977). The age of maturity in both species ranges from 4 to 9 years, but due to differences in aging techniques probably ranges from 5 to 8 years. The larger size of Arctic cisco makes them more desirable to domestic fishermen than least cisco.

Growth rates of non-migratory least cisco are generally slower than those of migratory fish. Extremely slow growing populations of dwarf least cisco (less than 150 mm) are also known to exist (Mann, 1974), but these lake dwelling populations of small ciscos are uncommon.

A high percentage of the migratory populations of both Arctic and least cisco consist of mature non-spawners. Both species tend to spawn only every second or third year and available evidence suggests that many spawning fish do not migrate to sea in the year of spawning.

Cisco spawn in the fall months as the water cools. Spawning areas for Arctic cisco are not well documented, but spawning is believed to occur in tributaries of the Mackenzie River (e.g., the Peel River) over gravel substrates. Least cisco are known to spawn in both lakes and rivers over sand or gravel substrates.

Cisco are typically plankton feeders, but occasionally they feed on aquatic and terrestrial insects. They are an important link in the food chain between plankton and the larger piscivorous (fish eating) fish which prey on cisco extensively. Data on the annual mortality of these species are not available, but some studies suggest that food availability may be limiting to cisco populations, compared to the effects of predation and human harvests (Scott and Crossman, 1973).

4.3.2.5 Inconnu

Inconnu inhabit the Mackenzie River and several streams to the east on the Tuktoyaktuk Peninsula. They are anadromous, entering coastal waters during summer months and returning to fresh water for spawning and overwintering. Inconnu stocks may also occur in the Blow, Kugaluk, and Anderson rivers, since some were collected in these streams during summer months (Sutherland and Golke, 1978). However, these individuals may have originated from Mackenzie River stocks.

Studies of the life history of inconnu in the Mackenzie River and adjacent coastal waters include Hatfield *et al.* (1972), Stein *et al.* (1973), Jessop *et al.* (1973, 1974), Percy (1975), de Graaf and Machniak (1977), and connu are the fastest growing and largest of Jones and Den Beste (1977). In the whitefish. Individuals weighing from 5 to 15 kg are common in Mackenzie Delta fisheries. Females live longer and grow larger than males (Alt, 1969) and in the Mackenzie Delta, de Graaf and Machniak (1977) reported that all fish beyond age 14 were females. The maximum age reported for inconnu in the Northwest Territories was 22 years for a fish caught in the Mackenzie Delta (Stein *et al.*, 1973). Inconnu mature between the ages of 6 to 14 with most individuals maturing at ages 8 to 11 (de Graaf and Machniak, 1977).

Spawning movements of inconnu are poorly documented in the Northwest Territories and no data are available on spawning habitats, timing, fecundity, or rearing areas for young, although juveniles are abundant in coastal waters during the summer season. It has been reported that an upstream migration of spawners begins in late June in most areas of the Delta and continues throughout the summer (Stein *et al.*, 1973; Jessop *et al.*, 1974). Although tributaries of the Peel River, Arctic Red River, and Rengleng River, are suspected to contain spawning areas, there have been no direct observations of spawning in Canadian waters (Scott and Crossman, 1973; Stein *et al.*, 1973; Jessop *et al.*, 1974; de Graaf and Machniak, 1977). In Alaska, spawning occurs in late September in swift water at depths from 1.5 to 1.8 m over coarse gravel substrates (Alt, 1969). After spawning, a large downstream run has been reported in rivers draining into Great Slave Lake and in the lower Mackenzie River. Mature inconnu are believed to spawn only every 2 to 4 years and seldom venture into the sea in the year they spawn (de Graaf and Machniak, 1977; Jones and Den Beste, 1977).

Inconnu eat mostly fish such as other whitefish and smaller inconnu, although northern pike, ninespine stickleback, sculpin, and pond smelt are also eaten (de Graaf and Machniak, 1977). Crustaceans and insects have been reported in inconnu stomachs from the Mackenzie River, but these items generally appear to have been eaten along with fish. Inconnu in some areas are reported to gorge themselves with smaller inconnu (Scott and Crossman, 1973). No useful estimates of mortality or other population parameters are available for this species.

4.3.2.6 Arctic Grayling

Arctic grayling are probably the most widely distributed fish along the Beaufort coast, but little information is available on their migratory patterns and productivity. De Bruyn and McCart (1974) present the only detailed life history information on Arctic Grayling for this region, although well documented studies are available for this species near Norman Wells (Tripp and McCart, 1974; D. Tripp, in prep.).

Grayling seldom venture into brackish coastal waters, and their movements in streams are generally associated with spawning, overwintering, and summer feeding. Grayling are spring spawners and are commonly found in large aggregations prior to spawning, and again in the fall prior to overwintering. This feature of grayling life history is exploited by domestic fishermen who periodically harvest the species when they aggregate. Grayling are too small for commercial purposes, but are used for dog food and sport fishing (McCart and Den Beste, 1979).

Arctic grayling grow relatively slowly with mature individuals seldom exceeding 500 mm fork length. Individuals usually mature by age 7 with maximum ages ranging from 15 to 20 years. Fecundity in Yukon coastal streams is reportedly low relative to that for whitefish, ranging from only 4,000 to 14,500 eggs compared to a maximum of 60,000 eggs in whitefish (de Bruyn and McCart, 1974). Once mature, spawning occurs every year, generally in small headwater streams. After spawning in June adults migrate to summer feeding habitats. Usually while adults feed in downstream habitats, fry and juveniles remain in shallow upstream areas. It has been postulated that this separation limits competition between adults and juveniles since both groups feed extensively on stream drift and surface insects (D. Tripp, pers. comm.). Where fry and adults are found together, adults generally occupy large pools and riffles while juveniles occupy shallow areas, backwaters, and side channels (de Bruyn and McCart, 1974).

A number of small lakes in the region support grayling populations, but spawning usually seems to occur in tributary streams (de Bruyn and McCart, 1974). De Bruyn and McCart (1974) report that spawning occurs in mid May through late June in Yukon coastal streams and fry emerge in July.

4.3.2.7 Other Species

Round whitefish, longnose sucker, ninespine stickleback, and slimy sculpin are the only other species widely distributed within the Beaufort coastal region. Northern pike, the most abundant truly freshwater fish in the Delta, are less common elsewhere and are rarely found on the Yukon coast (McCart *et al.*, 1974). Pond smelt are common inhabitants of lakes on the Tuktoyaktuk Peninsula and have also been intensively studied by de Graaf in a lake on the Yukon North Slope. Boreal smelt are common in nearshore coastal waters, including the outer Mackenzie Delta (Percy, 1975).

While round whitefish are considered semi-anadromous by some authors, the number of individuals caught in brackish coastal waters is usually small (Kendel *et al.*, 1975; Griffiths *et al.*, 1975; Percy, 1975; Jones and Den Beste, 1977). Although not abundant in the Mackenzie Delta (Stein *et al.*, 1973), they are abundant in several tributaries, in Yukon coastal streams, in the Anderson River, and in the Horton River. Round whitefish spawn during late September and October, often forming large prespawning aggregations. Due to poor human access to streams supporting this species, its relatively small size, and low densities of fish in populated areas, round whitefish are only a minor species in domestic harvests. A review of the life history of round whitefish (de Graaf and Machniak, 1977) suggests that the species, though smaller and slower growing than other whitefish species in the region, follows a similar life history pattern to broad and humpback whitefish.

Longnose suckers, a forage species, are not considered to be important in domestic or commercial harvests within the region, but they are widely distributed. Suckers generally confine themselves to freshwater and have been observed undertaking local spawning migrations into clear-water tributaries of the Mackenzie River during May and June. Data on the life history of longnose sucker are presented by Hatfield *et al.* (1972), Stein *et al.* (1973), Tripp and McCart (1974), Percy (1975), and de Graaf and Machniak (1977). Individuals reach lengths of up to 600 mm and have been reported to reach 20 years of age. They are sexually mature by age 8 and appear to spawn every year thereafter. Both lakes and streams may serve as spawning habitat for longnose sucker.

Information on the life history of other regional species is reviewed by de Graaf and Machniak (1977) and more generally by Scott and Crossman (1973).

4.3.3 SENSITIVE HABITATS AND LIFE HISTORY STAGES

Fish populations are generally considered to be most sensitive to environmental disruptions during periods of spawning, incubation, emergence, rearing, overwintering, and migration. Large juvenile and adult fish are generally more widely dispersed during other phases of their life history and are not particularly sensitive at these times to environmental disturbances.

During environmental studies on behalf of earlier oil and gas development proposals, sensitive habitats were identified in many waterbodies adjacent to the

TABLE 4.3-3

FISH HABITAT UTILIZATION IN WATERBODIES ALONG THE BEAUFORT SEA COAST. FOUR LETTER FISH CODES ARE PROVIDED IN TABLE 4.3-1 SOURCES SUMMARIZED IN McCART ET AL. (1974) AND SUTHERLAND AND GOLKE (1978). LOCATIONS ARE SHOWN ON FIGURES 4.3-1 and 4.3-2.

Waterbodies	Location	Habitat Use and Sensitivity
Craig Creek	1	Ws (CHAR, GRAY)
Fish Creek	4	S, R, W (CHAR)
Malcolm River	6	Ss (CHAR)
Malcolm River Springs	7	R (CHAR, GRAY)
Firth Spring	8	S, R, W (CHAR)
Lake 104	9	S, R, W (CHAR)
Lake 103	10	S, R, W (CHAR)
Joe Creek	11	S, R, W (CHAR, GRAY)
Firth River	12	S, R, W (CHAR, GRAY); S (ARCS, LSCS, BORS, FHSC)
Kugaryuk Creek	13	S, W (GRAY)
Lake 107	16	W (GRAY)
Lake 105	17	Ss (GRAY) in outlet stream; Ws (LKTR, LSCS, GRAY, NNST)
Lake 100 (Roland Lake)	18	S, R (HMWT, BDWT, PONS, NNST) W (HMWT, BDWT, GRAY, PONS, NNST)
Lake 109 (Furbearer's Lake)	19	S, R, W, (HMWT, BDWT); W (GRAY)
Stream 1000	20	S, R (GRAY)
Stream 1001	21	S, R (GRAY)
Roland Creek	23	R (CHAR, GRAY)
Spring River	24	S, R (CHAR, GRAY): R (LSCS, HMWT, BDWT)
Crow River	25	S, R, Ws (GRAY); Ss, Ws (CHAR)
Peatbog Creek	26	S, R (GRAY)
Crow River Spring	27	Ws (CHAR, GRAY)
Lake 106	28	Rs (CHAR, GRAY)
Trail River	29	S, R (GRAY)
Lake 38 (101)	30	S, R (BDWT); W (LSCS, BDWT, GRAY)
Philip Creek	31	S, R (GRAY)
Trout Lake Outlet	32	Ms (GRAY, Whitefish spp.)
Babbage River	33	S, M, R (CHAR); Ss, R (GRAY); R (Whitefish spp.)
Deep Creek	34	S, R (GRAY); R (Whitefish spp.)
Fish Hole Creek (Canoe River)	35	S, R, W (CHAR); Ss, R, W (GRAY)
Lake 41	36	Ws (GRAY)
Running River (Walking River)	38	S, R (GRAY)
Tundra Creek	39	S, R (GRAY)
Anker Creek	41	S, R (GRAY)
Blow River	42	S, R (GRAY); R (Whitefish spp.)
Purkis Creek	43	S, R (GRAY); R (Whitefish spp., BURB)
Rapid Creek	44	S, R (GRAY)
Stream 1003	45	S, R (GRAY)
Fish River (Big Fish River)	46	S, R (GRAY); M (CHAR); R (RDWT)
Little Fish Creek (Cache Creek	47	S, R (CHAR, GRAY); W (GRAY)
Cache Creek	49	S, R (GRAY); R (RDWT)
Willow River	51	S, R (GRAY)
Fish Creek (tributary to Rat River)	52	S, R, W (CHAR, GRAY)
Rat River	53	S, R (GRAY); S, R, W (CHAR)
West Channel	54	Sr (CHAR, HMWT, BDWT, INCO, ARCS, LSCS)
Middle Channel	55	Sr (HMWT, BDWT, INCO, ARCS, LSCS); Ws (HMWT, INCO, LNSK, BURB, BORS)
East Channel	56	Sr (LSCS, ARCS, HMWT, BDWT, INCO); W (LSCS, BDWT, LNSK, BURB)
Eskimo Lakes	58	Sr (LSCS, INCO, Whitefish spp.)
Anderson River	60	Sr, R, W (LSCS, Whitefish spp., INCO)
Mason River	62	S, R (BORS, NNST)
Horton River	63	Sr, M, Ss, R, W (CHAR, Whitefish spp., GRAY, Sucker spp.)

S - spawning
Ss - suspected spawning
Sr/M - spawning run/migratory route
Srs/Ms - suspected spawning run/suspected migratory route
R - rearing
Rs - suspected rearing
W - overwintering
Ws - suspected overwintering

Beaufort Sea. Table 4.3-3 summarizes the available information on sensitive habitats for the larger streams and waterbodies within the region. Information in Table 4.3-3 is from Stein *et al.* (1973), McCart *et al.* (1974), Jones (1977), Jones *et al.* (1976), DOE (1977), de Graaf and Machniak (1977), Slaney (1977), Sutherland and Golke (1978), and Aquatic Environments Ltd. (unpublished data). Data for streams and lakes on the Tuktoyaktuk Peninsula were not available for inclusion in Table 4.3-3 (M. Lawrence, pers. comm.). Since the data cover relatively few areas, and few sample times, Table 4.3-3 is not a complete catalogue of all sensitive watercourses.

4.3.3.1 Migration

Virtually all watercourses contain spawning habitat for anadromous species, grayling or longnose sucker (Table 4.3-3). The most important migratory routes occur in the Mackenzie Delta where a high percentage of the total regional population of anadromous Arctic cisco, least cisco, whitefish species, and inconnu migrate, as well as some Arctic char from the Big Fish River and the Peel River drainages. The Delta therefore, supports large numbers of fish throughout the year, with higher concentrations occurring during migrations to coastal feeding habitats after breakup, and upon returning in the fall (July-September) to overwinter. The majority of anadromous fish migrating to coastal waters are mature non-spawners.

Anadromous char migrate mainly through the West Channel of the Mackenzie Delta. Sampling conducted to date in the West Channel and adjacent coastal waters indicates that the number of migrating char is relatively small compared with those in many Yukon coastal streams (de Graaf and Machniak, 1977; Percy, 1975; Slaney, 1974). The numerous char in Yukon coastal waters during early summer (Kendel *et al.*, 1975; Griffiths *et al.*, 1975) originate from migratory runs in streams such as Fish Creek, the Firth River, the Babbage River, and Fish Hole Creek, all west of the Mackenzie Delta. In June, there are large scale downstream movements associated with breakup; later there is more gradual movement back into fresh waters in mid August. Many spawners do not undertake a seaward migration in the year of spawning (char generally spawn only in alternate years), but remain in freshwater (Bain, 1974; Griffiths *et al.*, 1975). Due to the 2 to 3 week earlier breakup of the Mackenzie Delta compared with Yukon coastal streams, seaward migrations tend to occur two to three weeks earlier in the Delta, but there appears to be little difference in the timing of return migrations.

During mid summer, large numbers of ciscos and whitefish enter coastal streams along the Tuktoyaktuk Peninsula on summer feeding migrations. These fish return to the Mackenzie Delta by late September. Studies conducted in this region indicate that few of these ciscos and whitefish are potential spawners.

The Horton River east of the Tuktoyaktuk Peninsula supports an anadromous char population which appears to follow a migratory pattern similar to that reported for Yukon coastal streams. Other streams east of the Tuktoyaktuk Peninsula also support small populations of least cisco and whitefish which infrequently foray into coastal waters. There is little information on these populations (Sutherland and Golke, 1978).

Both freshwater and anadromous species inhabiting watercourses in the region undergo short migrations associated with spawning, overwintering, and summer feeding. Anadromous species (e.g. char, ciscos, and whitefish) generally migrate further than strictly freshwater species (e.g. grayling, pike, longnose sucker), often using larger streams for feeding prior to spawning in headwater tributaries. Recent studies of grayling migrations near Norman Wells indicate that adults leave spawning grounds for downstream feeding areas soon after spawning, thereby providing the adaptive advantage of reducing competition between juveniles and adults (D. Tripp, in prep.). Several authors have also reported fall downstream movements from smaller tributaries by fish en route to overwintering areas (Stein *et al.*, 1973; Glova and McCart, 1974).

Movements of spring spawning species (e.g. Arctic grayling) occur during May and June, while migrations of fall spawning species occur from August to October, and in some locations, later. Both spring and fall spawning species may be sensitive in some watercourses prior to freeze-up when moving to overwintering areas.

4.3.3.2 Spawning

Many waterbodies in the region are known to contain spawning habitat for one or more species, but the locations of most of it remains unknown. Spring spawning species often spawn during periods of high water when increased turbidity and difficult access prevents an accurate assessment of spawning habitats. Although fall spawning species such as inconnu, ciscos, and whitefish appear to use the Mackenzie River and its tributaries upstream of the Delta for spawning (Stein *et al.*, 1973), few actual spawning sites have been identified to date.

Table 4.3-3 indicates streams where spawning habitat has been identified to date or is suspected to exist. Undoubtedly, other streams and lakes also contain spawning habitat.

Several watercourses draining into the Yukon coast provide extensive spawning habitat for char and grayling, particularly in headwater sites near groundwater sources. Char spawning sites in streams along the Yukon coast have been mapped by McCart (1980) and is probably better documented here than for other areas in the region. Large spawning concentrations of char have been observed in Fish Creek, in the Firth River, in the Babbage, and in Fish Hole Creek (Canoe Creek) as well as in other areas. A number of lakes along the Yukon coast have also been identified as potential spawning areas for resident populations of least cisco, grayling, char, broad whitefish, humpback whitefish, and lake trout (Mann, 1974; McCart *et al.*, 1974; Bain, 1974; de Bruyn and McCart, 1974; Glova and McCart, 1974).

The spawning areas for broad whitefish, humpback whitefish, and least cisco along the Tuktoyaktuk Peninsula are not well known. Studies in progress by the Department of Fisheries and Oceans, and others by McCart et al. (1976) and Slaney (1977), indicate that self-sustaining resident populations are present in most of the larger creek-lake systems in a broad area east of the Mackenzie Delta. Studies in the Parsons Lake-Eskimo Lakes area to the south show that many lakes and creeks also possess spawning areas for least cisco, broad whitefish, humpback whitefish, lake trout, and northern pike (McCart *et al.*, 1976; Slaney, 1977).

East of the Tuktoyaktuk Peninsula, the Horton River provides spawning habitat for char, least cisco, and whitefish species. Several lakes support resident populations of these species and may also provide important spawning habitat for lake trout. The Anderson River does not appear to support char but does provide spawning habitat for cisco and whitefish (Sutherland and Golke, 1978).

In general, spawning areas occupied by spring spawning species during May and June are sensitive to environmental disturbance until early July following emergence of fry from the gravel. Since the Mackenzie River generally breaks up 2 to 3 weeks earlier than Yukon coastal streams and the more easterly drainages, the timing of spring spawning and emergence also tends to be earlier in the Delta area. Where these areas serve as nurseries, they would remain sensitive to disturbance considerably longer. Eggs of fall spawning species remain in the gravel over the winter, emerging at break-up usually in June. Harsh conditions, such as low oxygen levels, low stream discharge, and ice scour, limit survival in many areas. Because of the relatively long period of incubation (up to 7 or 8 months) eggs of fall spawning species may be sensitive for longer periods.

Streams providing habitat for both spring and fall spawning species may be sensitive throughout most of the year, except for a short period between late summer, following emergence of spring spawning species, and the fall when fall spawning begins.

4.3.3.3 Nursery Areas

The spawning areas identified in Table 4.3-3 generally also provide nursery (rearing) habitat for the same species. Many small tributary streams with insufficient discharge to support spawning fish, or with no flow during winter months, may also serve as important nursery areas, particularly for grayling, char, pike, longnose sucker, and slimy sculpin. Typically, young-of-the-year fish either frequent shallow areas in lakes, or side channels in rivers, or they use deep areas of lakes (e.g. lake trout) to avoid predation.

Studies by Stein *et al.* (1973), Slaney (1974), Percy (1975), and de Graaf and Machniak (1977) indicate that the Mackenzie River Delta probably provides the most important nursery habitat in the region for whitefish and ciscos, which spawn further upstream in the Mackenzie, Peel, and Arctic Red rivers. While some young-of-the-year fish use coastal waters for summer feeding, they are not as abundant as other year classes and are usually preyed on heavily by other species (Percy, 1975; Kendel *et al.*, 1975; Jones and Den Beste, 1977).

Several coastal streams and lakes in the Yukon are important rearing areas for char and grayling fry (Bain, 1974; Glova and McCart, 1974; de Bruyn and McCart, 1974; McCart *et al.*, 1974). Similarly, the abundant lakes on the Tuktoyaktuk Peninsula and in the Parsons Lake-Eskimo Lakes area support large numbers of young-of-the-year least cisco, humpback whitefish, and broad whitefish (McCart *et al.*, 1976; Slaney, 1977; M. Lawrence, pers. comm.). The Horton River and a number of lakes in adjacent areas east of the Tuktoyaktuk Peninsula provide nursery habitat for Arctic char, while many lakes in this area support large numbers of young-of-the-year least cisco and whitefish (Sutherland and Golke, 1978; R. Barnes, pers. comm.).

4.3.3.4 Overwintering

Potential overwintering habitats in Yukon coastal streams and lakes were examined by Craig and McCart (1973), McCart *et al.* (1974), and Jones (1977). Data for the Mackenzie Delta are presented by Mann (1975) and Stein *et al.* (1973). Studies on the Tuktoyaktuk Peninsula are not yet available (M. Lawrence, pers. comm.). McCart *et al.* (1976) present overwintering information for the Parsons Lake-Eskimo Lakes region as well as for lakes in the Mackenzie Delta. No information is currently available for waterbodies east of the Tuktoyaktuk Peninsula in the vicinity of the Anderson River and Horton River, although winter surveys were carried out along a proposed Polar Gas pipeline alignment.

Reduced stream flows, low water levels, heavy ice scour, and reduced dissolved oxygen levels combine to limit the availability of suitable overwintering habitats in many waterbodies in the region. Fish occupying overwintering habitats are considered sensitive during the entire period from freeze-up to break-up (October to late May), but may be particularly sensitive during mid to late winter when ice thickness is greatest and dissolved oxygen concentrations may be lowest.

4.4 LOWER TROPHIC LEVELS

4.4.1 FACTORS CONTROLLING AQUATIC PRODUCTIVITY

Primary production in northern freshwater environments is limited by the reduced winter light regime, low water temperatures, high sediment loads, and low nutrient levels (McCart and Den Beste, 1979). Except broadly, it is not yet possible to demonstrate the relationship between primary production in northern waters and the productivity of progressively higher aquatic trophic levels, particularly fish. The productivity of higher trophic levels is also influenced by such factors as drainage morphology, discharge patterns, micro-habitat, species composition and human resource use. In addition to these factors, fish are further isolated from the limitations of lower trophic levels by their high mobility, their ability to exploit localized areas of high productivity, their specialized habitat requirements, their irregular distribution and their dramatic population changes when exploited.

The region is without direct sunlight from early November through February, consequently productivity drops to zero or near zero (Kalff and Welch, 1974). Thus there is a pattern of declining productivity late in the fall and increasing productivity in the spring as available sunlight changes.

Similarly, water temperatures are generally cooler with increasing latitude, reducing the rate of metabolic activity in aquatic organisms and thereby resulting in slower growth and lower production. The Mackenzie River mainstem tends to moderate this effect by carrying a stream of southern warm water northward. This warming causes Mackenzie River ice to break up 2 to 3 weeks earlier than the ice in Yukon coastal streams (de Bruyn and McCart, 1974), and to freeze up 2 to 3 weeks later each year. The productivity of the Mackenzie Delta is thus enhanced by warmer summer water and a longer period of above freezing water temperatures as compared to other drainages in the region. Despite this moderating influence, winter water temperatures remain at or near 0°C for 6 to 8 months annually, serving to limit productivity throughout the region.

Sedimentation inhibits aquatic production by reducing light penetration, covering aquatic organisms, interfering with respiration, and eliminating or reducing available habitat (Cordone and Kelly, 1961; Phillips, 1971). Studies on the effects of sedimentation on aquatic habitats in the Mackenzie Valley have been done by Brunskill *et al.* (1973), McCart and de Graaf (1974), Porter *et al.* (1974), Rosenberg and Snow (1975), and McCart *et al.* (1979). These authors present data showing community modifications and decreases in certain trophic levels as a result of sedimentation. While sedimentation has adverse effects on spawning, overwintering and emergence, fish in the Mackenzie River system exist with periodic ambient suspended sediment loads reaching 2,000 mg/L during the summer months (Brunskill *et al.*, 1973). Highly migratory fish species have developed strategies to avoid the adverse effects of high ambient sediment levels by using clear tributary streams and coastal waters (anadromous species) to a certain extent. Information on sediment transport in the Mackenzie River is presented in Volume 3C, Section 1.3.

Nutrients in the northern drainages of Canada are generally sparse due to the presence of extensive bedrock material, poor soil development, a minimal active layer available for leaching, limited runoff which restricts the transport of nutrients, the slow microbial breakdown of organic material and recycling of their nutrients, and even the general absence of thunderstorms which assist in the nitrification process (McCart and Den Beste, 1979).

Concentrations of nutrients in the Mackenzie River drainage tend to be higher than in most other Arctic drainages due to the sedimentary nature of underlying material and the steady input of nutrients from southern portions of the drainage (McCart *et al.*, 1974a; McCart and Den Beste, 1979).

During the winter, soils remain frozen and concentrations of nutrients usually decrease (Brunskill *et al.*, 1973; Reid *et al.*, 1975). In small watercourses which freeze more completely and for longer periods compared to larger watercourses, the period of low nutrient availability is comparatively longer. Thus, small streams along the Yukon coast and east of the Mackenzie Delta usually possess lower nutrient levels than waterbodies connected to the Mackenzie River. Also, the moderating influence of the large Mackenzie River system, which originates further south, creates a warmer nutrient-rich environment in the

Mackenzie Delta and in some surrounding areas. In fact, some waterbodies in the Delta do not have lower nutrient levels in winter, being higher in February than in the summer months (McCart *et al.*, 1976). These authors speculate that these higher concentrations are due to reduced primary production, the release of nitrogen from decomposing material, and the expulsion of ions as the ice cover grows.

Data on macronutrient concentrations in the coastal region are presented by McCart *et al.* (1974a) for Yukon coastal streams and by McCart et al. (1974a), Brunskill *et al.* (1973), Reeder (1973), and by Reid *et al.* (1975)for the Mackenzie Delta. Some macronutrient data have also been collected by the Department of Fisheries and Oceans in streams along the Tuktoyaktuk Peninsula, but these data have not yet been published (M. Lawrence, Winnipeg, pers. comm.)

During summer months, total nitrogen and phosphorus levels in Yukon coastal streams have ranged from 0.01 to 0.31 mg/L and 0.01 to 0.55 mg/L respectively (McCart *et al.*, 1974a; Aquatic Environments Limited, unpublished data). Concentrations in the Mackenzie Delta have been slightly higher, from 0.3 to 0.6 mg/L nitrogen and 0.3 to 0.5 mg/L phosphorus (Reid *et al.*, 1975). Total organic carbon levels in this region generally do not exceed 15 mg/L (McCart *et al.*, 1974b, 1976; Reid *et al.*, 1975). McCart *et al.* (1976, 1979) and Brunskill *et al.* (1973) also present data for numerous lakes in the Mackenzie Delta and adjacent areas to the east. Total dissolved nitrogen values in this area range from 0.2 to 1.3 mg/L and total dissolved phosphorus concentrations range from 0.03 to 0.5 mg/L. Preliminary results of sampling along the Tuktoyaktuk Peninsula suggest that streams here may have higher levels of available nutrients than comparable Yukon coastal streams but lower values than recorded for the Mackenzie Delta (M. Lawrence, pers. comm.).

4.4.2 PRIMARY PRODUCTION

All food webs depend on primary producers to fuel other life forms. In freshwater environments, primary producers include phytoplankton (open water algae), periphyton (attached algae), and higher plants (Section 4.5). In northern latitudes, these organisms produce biomass at a much slower rate than in more temperate regions, thus limiting the production of all higher trophic levels. Primary production is usually measured as grams of carbon produced per unit area of lake surface or stream bottom, per unit time (e.g. g $C/m^2/yr$).

The low productivity of northern fresh waters has not been apparent to many observers since these waters often support large populations of consumer organisms, particularly fish. However, these localized areas of high fish density result from migration, limited overwintering habitat, return of anadromous fish representing production from marine waters, or any number of other factors not related to local productivity. A wide range of feeding dispersal strategies have evolved to compensate for the small share of the already low productivity which each year class of fish receives.

Studies of primary production in lakes in the region which have been undertaken include summer surveys at two Yukon coastal lakes (McCart *et al.*, 1974b), in a tundra pond near Tuktoyaktuk (Sheath *et al.* 1975) and in Ya-Ya Lake in the Mackenzie Delta (McCart *et al.* 1979). Primary production in Yukon coastal lakes ranged from 0.38 to 19.22 mg $C/m^2/d$. In a shallow pond near Tuktoyaktuk production ranged from 11.6 to 46 mg $C/m^2/d$, and at Ya-Ya Lake production ranged from 1.4 to 129 mg $C/m^2/d$.

Average daily summer production from northern Canadian Shield lakes ranges from 15 to 48 mg $C/m^2/d$ (Schindler, 1972; Kalff and Welch, 1974; de March *et al.*, 1977). Values for sewage polluted Meretta Lake on Cornwallis Island are higher than in other lakes on the northern Canadian Shield, reaching 173 mg $C/m^2/d$ as a result of high phosphorus concentrations. Southern portions of the Canadian Shield are considerably more productive as evidenced by midsummer production values ranging from 179 to 1,103 mg $C/m^2/d$ in the Experimental Lakes Area (Schindler, 1972).

Although no data exist on annual production rates along the Beaufort coast, values from that area are probably higher than in comparable lakes and streams from the Canadian Shield due to the higher nutrient loadings present in the Mackenzie Valley drainages. Daily production from the Mackenzie Delta region indicates that annual production rates probably fall within the oligotrophic range (0-100 g $C/m^2/d/yr$). In other northern lakes located on the Canadian Shield where seasonal information has been recorded, annual primary production rates range from 4 to 11 g $C/m^2/yr$ (Table 4.4-1). Comparable waterbodies in the Experimental Lakes region produce an average annual assimilation of 39 g $C/m^2/yr$ (Schindler, 1972).

Studies on the production of periphyton in lakes and streams in the area have not been conducted to date. Data presented by Rigler (1974) and Kalff and Welch (1974) based on studies in the eastern Arctic indicate that the productivity of benthic algae is much more important than planktonic productivity, representing 70 to 80% of total annual primary production. It is not known if this occurs in the more nutrient-rich waterbodies along the southern Beaufort Sea coast.

TABLE 4.4-1

ANNUAL ESTIMATES OF PRIMARY PRODUCTION FROM SEVERAL NORTHERN LAKES DRAINING THE CANADIAN SHIELD

Lake	Latitude	gC/m²/yr.	Source
Char	75	4.2	Kalff & Welch (1974)
Meretta	75	11.3	Kalff & Welch (1974)
Immerk	75	4.3	Minns (1977)
Fish	75	6.1	Minns (1977)
Stanwell-Fletcher	73	4.8	de March et al. (1977)
Eastern Great Bear	66	4	Schindler (1972)
McLeod Bay (Great Slave)	63	10	Schindler (1972)
Average of 11 Experimental Lakes, northeastern Ontario	50	39 (24-81)	Schindler (1972)

Total productivity would be expected to be highest in shallow, clear lakes rather then deep, turbid lakes where water temperatures are lower and light penetration reduced (Welch and Kalff, 1974). Due to the steady supply of nutrients, clear, shallow tundra streams would be expected to have relatively high benthic algae productivities compared with lake productivity. Deep turbid channels in the Mackenzie Delta would be expected to be relatively low in benthic algae productivity. These assumptions are supported by available data on the productivity of higher trophic levels in these habitats.

Availability of light is one of the major determinants of primary productivity. Studies by McCart *et al.* (1979) indicate that turbidity may significantly reduce primary production in northern lakes. For example, a highly turbid site in Ya-Ya Lake (Richards Island in the Mackenzie Delta) was 100 times less productive than a similar site with low turbidity. In addition, primary production virtually ceases in all waterbodies for approximately 2 months during winter as a result of low light levels.

Some data are available on the species composition and relative abundance of phytoplankton and phytobenthos in the vicinity of the Mackenzie Delta (Slaney, 1974, 1977; McCart *et al.*, 1976; Koivo and Ritchie, 1978; McCart *et al.*, 1979), but information for streams along the Yukon coast and east of the Mackenzie Delta has not been collected to date. In the Mackenzie Delta lakes and channels, phytoplankton and phytobenthic communities are relatively cosmopolitan and include a large number of species common to more temperate locales.

4.4.3 INVERTEBRATES

Zooplankton (free-swimming invertebrates) and zoobenthos (bottom dwelling invertebrates) occupy an intermediate position in most aquatic food chains. They are primary consumers (grazers) in some instances and are secondary or tertiary consumers in others, often altering their trophic position during various life history stages. Ultimately, invertebrates provide the link in aquatic food chains between primary producers and higher trophic levels such as fish, birds, and mammals.

4.4.3.1 Zooplankton

Zooplankton communities have been studied in lakes in the vicinity of the Mackenzie Delta, in Parsons and Eskimo lakes (Slaney, 1974, 1977; McCart *et al.*, 1976, 1979), in the brackish waters of the Mackenzie estuary (Slaney, 1975, 1976) and in the brackish waters along the Tuktoyaktuk Peninsula and Yukon coast (Jones and Den Beste, 1976; Grainger and Grohe, 1975; Griffiths *et al.*, 1975). These studies show that zooplankton communities in the region are relatively homogeneous and that species common to the region are widely distributed; also the species composition of populations occurring at these northern latitudes are similar to those in more temperate waters.

Studies of zooplankton communities in Ya-Ya Lake during the summer (McCart *et al.*, 1979) showed that several species migrate vertically in response to changing sunlight, despite 24 hour daylight. Although the vast majority of lakes have shallow muskeg drainages which are not likely to be temperature stratified, some vertical migration of zooplankton species probably occurs.

Zooplankton communities in the onshore region are dominated by rotifers, copepods, and waterfleas (cladocerans). Generally, brackish coastal waters, particularly those influenced by the Mackenzie River, contain fewer rotifers and higher densities of copepods in comparison to fresh waters (Griffiths *et al.*, 1975, Jones and Den Beste, 1977). Others investigators report that rotifers are most abundant in upland lakes in the Mackenzie Delta although copepods dominate some lakes during mid and late winter months (Slaney, 1974, 1975; McCart *et al.*, 1976, 1979). The relative abundance of copepods also increases during winter months in some deep channels of the Mackenzie River as its turbidity reduces (Brunskill *et al.*, 1973). Copepods are a major item in the diet of numerous fish species in the region, particularly for lake dwelling populations of least cisco, broad whitefish, and lake cisco (Mann, 1974; McCart *et al.*, 1979).

Zooplankton reproduce rapidly so they can be expected to recover rapidly from the effects of environmental disturbances. Zooplankton also appear to be more tolerant of high sediment loads than the zoobenthos (de March *et al.*, 1977) and may, in some instances, be dependent on nutrients carried in silt laden waters (Daborn, 1975). However, McCart *et al.* (1979) report that zooplankton communities in the Mackenzie Delta may vary considerably within and between lakes with similar physical features.

Densities of zooplankton species reported for lakes in the region are highly variable, and dependent on a wide range of factors including water depth, temperature, nutrients, turbidity, currents, season, and water sources. The relative influence of many of these factors is disputed by various authors and the sensitivity of zooplankton communities to changes in these and other environmental parameters is not yet well understood. For instance, while there is evidence to support the conclusion that zooplankton can thrive in some heavily silt laden waters (Daborn, 1975; de March *et al.*, 1977), studies by Slaney (1975) in the Mackenzie estuary indicate that copepods disappeared from some areas when turbidity was high (540-680 ppm), but were found again when turbidity decreased to 150 to 400 ppm. Also, Rawson (1956) noted that occasionally high turbidity due to silt loading from the Slave River was associated with decreased zooplankton abundance at some Great Slave Lake stations.

4.4.3.2 Zoobenthos

Studies of zoobenthos in lakes and streams within the region have varied in scope and detail. Numerous waterbodies along the proposed Canadian Arctic Gas Pipeline route across the Yukon North Slope were examined by McCart *et al.* (1974a). Zoobenthos of the Mackenzie Delta were investigated by Brunskill *et al.* (1973), McCart *et al.* (1974a, 1976, 1979), Slaney (1974), de Graaf and Machniak (1977) and others. Information from the Department of Fisheries and Oceans on research in lakes and streams along the Tuktoyaktuk Peninsula is in preparation (M. Lawrence, pers. comm.). A limited amount of information has been collected in the Eskimo Lakes - Parsons Lake area by Slaney (1977). Unpublished information has been collected in the area of Liverpool Bay and the Anderson River by J. Hunter of the Arctic Biological Station. The most important general conclusions of these studies were:

- Benthic communities in lakes and streams tend to be dominated by chironomids (blackflies and related species).

- Densities and taxonomic diversities of benthic communities are low in comparison with similar systems in temperate locations.

- Small coastal streams tend to support higher standing crops than large coastal streams.

- Yukon coastal streams appear to be somewhat less productive than coastal streams along the Tuktoyaktuk Peninsula.

- Mud substrates in lakes commonly support the highest densities of zoobenthos in the region, but often are low in species diversity due to a preponderance of one or two chironomid species.

- Turbid waters in the Mackenzie Delta are less productive than clearer streams along the Yukon coast and Tuktoyaktuk Peninsula.

- Mountain streams along the Yukon coast support higher densities of clear water species (e.g., stoneflies and mayflies) than the Mackenzie Delta or tundra streams farther east.

- Several fish species make summer feeding runs into coastal streams along the Tuktoyaktuk Peninsula presumably to feed on dense benthic populations. Fish stomachs from streams in this area contained more zoobenthos and were full a higher percentage of the time than fish elsewhere in the region, suggesting high productivity in these streams (M. Lawrence, pers. comm.).

Studies of zoobenthic drift have not been conducted in most streams of the region. In the Mackenzie Valley generally, zoobenthic drift declines significantly during winter months in all but the most turbid streams (Brunskill *et al.*, 1973). In contrast, the Mackenzie Delta has a relatively steady drift of zoobenthos throughout the year, despite the reduction in turbidity during winter months.

4.5 VEGETATION

Vegetation studies in the Beaufort region have focused primarily on the Mackenzie Delta and the adjacent Tuktoyaktuk Peninsula. East of the Delta, regional surveys have been done of the Horton-Anderson rivers area and the vegetation north of Great Bear Lake to the Arctic coast. Additional site specific investigations of this region have been completed for the lower Anderson River, the northern Parry Peninsula, McKinley Bay and for northern Cape Bathurst. West of the Delta, descriptions of major vegetation types are available for the Yukon Coastal Plain and the Richardson and British mountains, while regional overviews are available of northern Yukon vegetation. The vegetation of the upper Firth River valley in the British Mountains and succession in subalpine tundra communities in the Richardson and British mountains have also been described. The following sections describe the vegetation in the three basic zones comprising the onshore Beaufort area. These zones are the Mackenzie Delta, the Yukon Coastal Area and the Anderson Plain-Tuktoyaktuk Peninsula (Figure 4.5-1). To assist the reader, the scientific and common name for each of the plant species discussed is provided in Table 4.5-1, while Table 4.5-2 is a glossary of key vegetation-related terms.

4.5.1 MACKENZIE DELTA

4.5.1.1 Regional Descriptions

Southern portions of the Mackenzie Delta are forested whereas northern parts are covered with tundra. Mackay (1963) and Kerfoot (1975) described three major vegetation regions in the Delta. There is a 'sedge and willow' region on the outer alluvial islands, which is characterized by sedge tussocks in poorly drained areas and a few small willows on slightly higher ground (Plate 4.5-1). A 'willow-alder-poplar' region occurs inland from this sedge-willow zone and along the west side of the Delta to the west of Shallow Bay (Plate 4.5-2). This latter region has scattered small clumps of poplars on levees, and alders and willows along the channel banks and on the island flats, while low areas support marshy vegetation (fens). The 'spruce-willow-alder-poplar' region covers the largest portion of the Delta, and extends south from inner Shallow Bay (Plate 4.5-3). In this region, forests, primarily white spruce, occur as ribbons along the channels, with the remainder of the area being dominated by willow, alders and sedges. White spruce generally grows only above the spring flood level, and the northward limit of this species generally corresponds to the 3 m levee height limit (Kerfoot, 1975). Forest cover decreases from about 40%, at the head of the Delta, to 20% at Inuvik and 10% at Aklavik (Mackay, 1963).

Where the permafrost table is low, such as under some well drained terraces, white spruce may attain sawlog size. In general, however, there is far more nonforested than forested land in the Mackenzie Delta region.

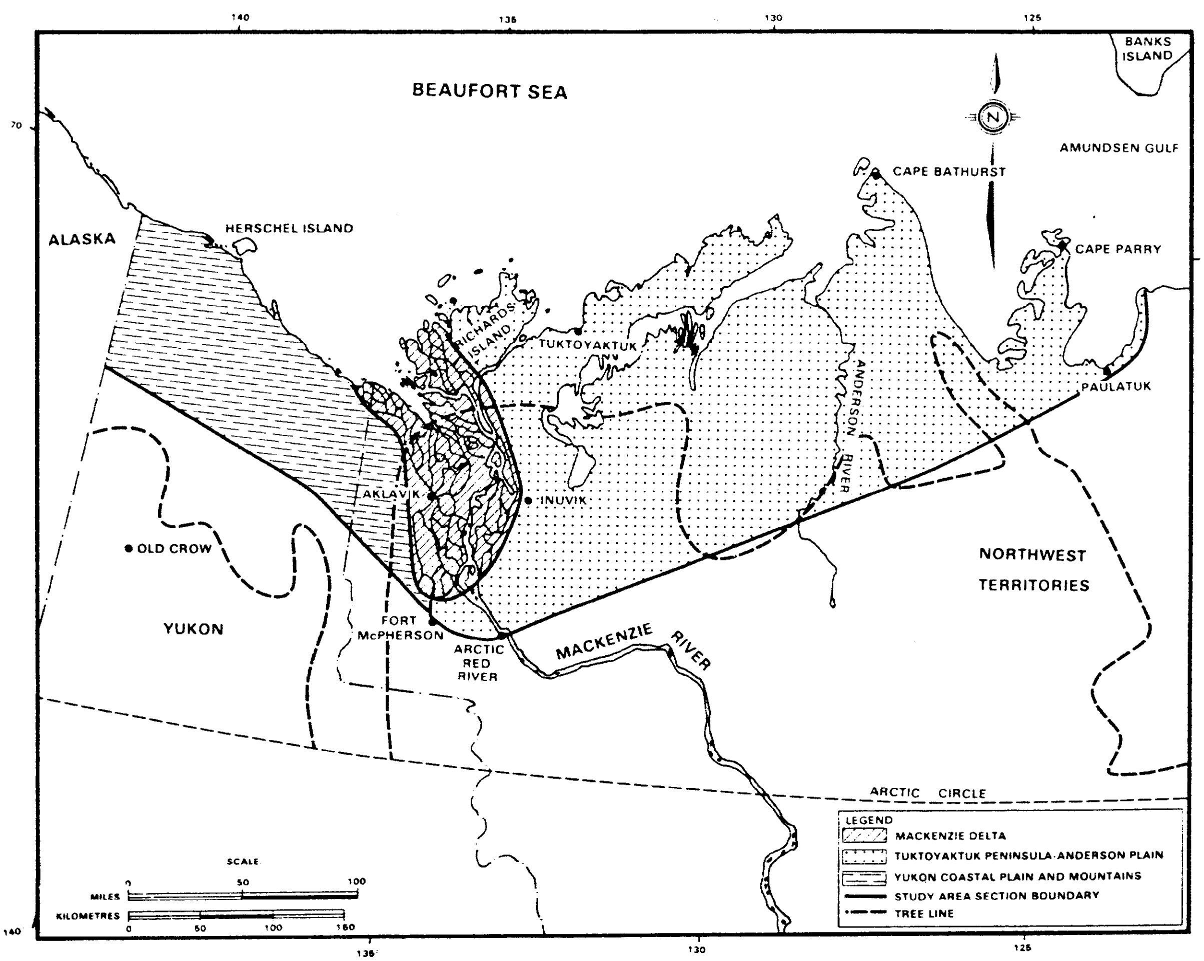

FIGURE 4.5-1 *Location map of the Beaufort onshore region, showing the three basic zones for which the vegetation is described.*

TABLE 4.5-1

COMMON AND SCIENTIFIC NAME EQUIVALENTS OF PLANT SPECIES MENTIONED IN VEGETATION DESCRIPTIONS OF THE ONSHORE BEAUFORT AREA

TREE SPECIES	
Aspen	Populus tremuloides Michx.
Birch, white	Betula papyrifera Marsh
Fir, subalpine	Abies lasiocarpa (Hook.) Nutt.
Poplar, balsam	Populus balsamifera L.
Spruce, black	Picea mariana (Mill.) B.S.P.
Spruce, white	Picea glauca (Moench.) Voss
Tamarack	Larix laricina (Du Roi) K. Koch
SHRUB SPECIES	
Alder, green	Alnus crispa (Ait.) Pursh
Birch, dwarf	Betula nana Michx.
Birch, shrub	Betula glandulosa Michx.
Labrador tea	Ledum groenlandicum and L. decumbens (Ait.) Lodd.
Rose, prickly	Rosa acicularis Lindl.
Rosemary, bog	Andromeda polifolia L.
Soapberry	Shepherdia canadensis (L.) Nutt.
Willow	Salix spp. L.
Willow, Alaska	Salix alaxensis (Anderss.) Cov.
Willow, Bebb's	Salix bebbiana Sarg.
Willow, glaucous	Salix glauca L.
Willow, plane-leaf	Salix planifolia Pursh
Willow, sandbar	Salix interior Rowlee
Willow, Scouler's	Salix scouleriana Barratt
HERB AND DWARF SHRUB SPECIES	
Arnica	Arnica spp. L.
Asphodel, false	Tofieldia coccinea Richards.
Avens, mountain	Dryas integrifolia M. Vahl. and D. octopetala L.
Baked-apple berry	Rubus chamaemorus L.
Bearberry, alpine	Arctostaphylos rubra (Rehd. & Wils.) Fern.
Bistort	Polygonum viviparum L.
Blueberry, alpine	Vaccinium uliginosum L.
Bluegrass	Poa glauca M. Vahl. and Poa spp. L.
Buckbean	Menyanthes trifoliata L.
Bunchberry	Cornus canadensis L.
Cassiope, lapland	Cassiope tetragona (L.) D. Don
Cloudberry	see "baked-apple berry"
Coltsfoot	Petasites frigidus (L.) Fries; also P. hyperboreus Rydb.
Cottongrass	Eriophorum spp. L.; may include E. vaginatum L., E. scheuchzeri Hoppe
Crowberry	Empetrum nigrum L.
Douglasia	Douglasia arctica Hook.
Draba	Draba cinerea Adams; also D. corymbosa R. Br.
Fireweed	Epilobium angustifolium L.
Gale, sweet	Myrica gale L.
Grass, hair	Deschampsia caespitosa (L.) Beaur.
Grass, polar	Arctagrostis latifolia (R. Br.) Griseb.
Grass, trisetum	Trisetum spicatum (L.)Richt.
Grass, tundra	Dupontia fischeri R. Br.

TABLE 4.5-1 (Cont'd)

COMMON AND SCIENTIFIC NAME EQUIVALENTS OF PLANT SPECIES MENTIONED IN VEGETATION DESCRIPTIONS OF THE ONSHORE BEAUFORT AREA

HERB AND DWARF SHRUB SPECIES Cont'd	
Groundsel	Senecio residifolius Less.
Hedysarum	Hedysarum alpinum L.
Hornwort	Ceratophyllum sp. L.
Horsetail, common	Equisetum arvense L.
Larkspur	Delphinium glaucum Wats.
Leather leaf	Chamaedaphne calyculata (L.) Moench
Lingonberry	Vaccinium vitis-idaea L.
Locoweed	Oxytropis deflexa (Pall.) D.C.
Lousewort	Pedicularis lanata Cham. & Schlecht.
Lupine, Arctic	Lupinus arcticus S. Wats.
Mare's-tail	Hippuris vulgaris L.
Marigold, marsh	Caltha palustris L.
Milfoil, water	Myriophyllum sp. L.
Milkvetch	Astragalus alpinus L.
Minuarta	Minuarta biflora (L.) Schinzl. & Thell.
Moss campion	Silene acaulis L.
Mustard	Draba hirta L.
Saxifrage	Saxifraga spp. L.
Sedge	Carex spp. L.
Sedge, aquatic	Carex aquatilis Wahlenb.
Sedge, maritime	Carex maritima Gumm.
Sorrel, mountain	Oxyria digyna (L.) Hill
Spike moss	Selaginella sibirica (Milde) Hieron
Starwort, water	Callitriche sp. L.
Sundew	Drosera anglica Huds. and D. rotundifolia L.
Thoroughwax	Bupleurum triradiatum Adams
Twinflower	Linnaea borealis L.
Wintergreen	Pyrola spp. L.
MOSS AND LICHEN SPECIES	
Feathermoss	Pleurozium schreberi (Brid.) Mitt.
	Hylocomium splendens (Hedw.) B.S.G.
	Ptilium crista-castrensis (Hedw.) De Not.
Feathermoss, layered	Hylocomium splendens (Hedw.) B.S.G.
Lichen	general; includes one or several of:
	Alectoria spp.
	Cetraria spp.
	Cladina spp.
	Cladonia spp.
	Parmelia spp.
	Stereocaulon paschale
	Thamnolia subuliformis (Ehrh.) W. Culb.
Moss, aulacomnium	Aulacomnium acuminatum (Lindb. et Arn.) Par.
Moss, dicranum	Dicranum spp. Hedw.
Moss, drepanocladus	Drepanocladus sp. (C. Mull.) Roth
Moss, scorpidium	Scorpidium scorpoides (Hedw.) Limpr.
Moss, sphagnum	Sphagnum spp. L.

TABLE 4.5-2

GLOSSARY OF COMMON VEGETATION-RELATED TERMS USED IN THE E.I.S.

Alluvial	Pertaining to stream deposits of comparatively recent time.
Bog	Peat-covered or peat-filled area with a high water table but little standing-water usually covered by peat moss, heaths and black spruce.
Boreal	A Zone encircling the globe south of the Arctic where forests are usually formed by a very limited number of species belonging to a few coniferous and hardwood genera: *Picea, Larix, Pinus, Abies, Betula, Populus, Alnus.*
Bryophyte	A member of the division Bryophyta consisting of mosses and liverworts which lack vascular tissue and are attached to the substratum by rhizoids.
Cereal	A flowering plant of the grass family whose seeds are used as food.
Climax	The final or stable community in a development series which is self-perpetuating and in equilibrium with the physical habitat.
Closed forest	A forest in which the crowns or peripheries of trees are mostly touching or overlapping.
Colluvium	A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity.
Community	Any naturally occurring group of different populations of organisms inhabiting a common environment, interacting with each other through food relationships, and relatively independent of other groups.
Coniferous	Pertaining to members of the order Gymnospermae bearing cones and needle-shaped leaves, e.g., pine, spruce and fir.
Cover	A measure of species dominance determined as the percentage of ground covered by the crown or above ground parts of a species.
Cuttings	A portion of a plant which has been cut from the parent plant for the purpose of planting and producing another plant.
Deciduous	Plants which shed their leaves at certain seasons.
Deltaic Formation	A land form of alluvial deposits, usually triangular, formed at the mouth of a river.
Diurnal	Recurring every day.
Drumlin	An elongate or oval hill of glacial drift, commonly glacial till, deposited by glacial ice and having its long axis parallel to the direction of ice movement.
"Drunken" Forest	A forest characterized by trees which are leaning in all directions due to the retardation of root growth and the influence of thermokarst in permafrost regions.
Edge Effect	The tendency for increased variety and density of species in the transition between two or more diverse communities.
Emergent Vegetation	Species whose roots are submerged while most of the leaves and flowers are above the water surface.
Ericaceous	Belonging to the family Ericaceae.
Fan	An accumulation of debris brought down by a stream descending through a steep ravine and debouching in the plain beneath, where the detrital material spreads out in the shape of a fan, forming a section of a very low cone.
Fen	Peat or peat-filled area with the water table at or near the surface dominated by a sedge, grass and reed community, at times, with shrub cover and a scanty tree layer.

TABLE 4.5-2 (Cont'd)

GLOSSARY OF COMMON VEGETATION-RELATED TERMS USED IN THE E.I.S.

Floodplain	That portion of a river valley, adjacent to the river channel, which is built of sediments during the present regime of the stream and which is covered with water when the river overflows its banks.
Fluvial	Of, or pertaining to rivers; growing or living in streams or ponds, produced by river action, as, a fluvial plain.
Fluviatile	Belonging to a river, produced by river action, growing or living in fresh water rivers.
Fluviatile-marine	Deposits brought into the sea, and thus often containing remains of land, freshwater, and marine animals.
Frost Action	The weathering process caused by repeated cycles of freezing and thawing.
Genome	The set of all different chromosomes found in each nucleus of a given species.
Glaciolacustrine	Pertaining to glacial lake conditions, as in glaciolacustrine deposits, sediment deposited in lakes marginal to a glacier by glacial meltwater streams.
Ground Ice	Denotes bodies of more or less clear ice in permanently frozen ground.
Heath	A community dominated by members of the heath family.
Herbaceous	Having no persistent parts above ground, as distinct from shrubs and trees.
Hummock	A small mound.
Ice Wedge	Vertical, wedge-shaped vein of ground ice.
Key Species	Any species of plants which because of pattern or other characteristics may be used in estimating degree of utilization, trend, or condition of the range.
Marsh	Grass-sedge-rush communities water-covered for one or more months in the year.
Meadow	A community dominated by herbaceous aquatic vegetation.
Mesic	Describes moisture regimes intermediate to the extremes of the given region.
Microhabitat	The immediate environment of an organism.
Microrelief	Minor differences in topography such as small mounds or pits with differences in elevation of about three feet or less.
Moraine	An accumulation of earth and stones carried and finally deposited by a glacier. Ground Moraine - A moraine of which the predominant material is till, but some stratified drift is present.
Mound	A low hill of earth, natural or artificial; in general any prominent, more or less isolated hill.
Muskeg	An old Algonquin Indian term applied to a large expanse of Sphagnum peatland bearing stunted black spruce and tamarack with ericaceous shrubs prominent.
Ombrotrophic	Generally refers to bogs which receive nutrients in the form of precipitation rather than from stream flow or water table.
Organic Terrain	A tract of land comprised of a superficial layer of living material (vegetation) and a sub-layer of peat or fossilized plant detritus of any depth existing in association with various hydrological and underlying mineral formations.
Palsa	A round or elongated hillock or mound, up to 10 m in height with a core of ice and peat, rarely mineral soil, found in the sporadic permafrost zone.

TABLE 4.5-2 (Cont'd)

GLOSSARY OF COMMON VEGETATION-RELATED TERMS USED IN THE E.I.S.

Patterned Ground	A group term for the more or less symmetrical forms such as circles, polygons, nets, steps and stripes, that are characteristic of, but not necessarily confined to, mantle subject to intensive frost action.
Peat Plateau	An ombrotrophic bog with a raised or appreciably sloping surface containing an ice core but with few fissures and no thaw pocket.
Permafrost	The thermal condition of earth materials such as soil and rock, when their temperature remains below 0° C continuously for a number of years.
Permafrost (continuous)	Terrain with the -5° C isotherm of mean annual ground temperature measured just below the zone of annual variation.
Permafrost (discontinuous)	A region where areas of frozen and unfrozen layers occur together.
Physiographic	Of, or pertaining to the study of the genesis and evaluation of landforms.
Pingo	An ice-covered hill, typically conical in shape, which can only grow and persist in permafrost.
Pioneer	A plant, animal or community that first invades a disturbed area.
Polygon	Sorted and non-sorted ground surface features, resulting from frost action, with many angles or sides.
Productivity	Rate of organic matter production in a ecosystem.
Profile	When pertaining to soil it is a vertical section showing the horizontal layers and their relationships to each other.
Resident Soil	Soil formed from, or resting on, consolidated rock of the same kind as that from which it was formed and in the same location.
Riparian	Pertaining to the banks of a body of water.
Scarp	An escarpment, cliff, or steep slope of some extent along the margin of a plateau, mesa, terrace or bench.
Sedge	A plant, resembling grass in appearance, in the family Cyperaceae, usually with solid triangular stems, tree-ranked leaves, and closed-leaf sheaths.
Sediment Load	The amount of suspended matter in a stream.
Solifluction	The process of slow flowage from higher to lower ground of masses of waste saturated with water.
Stand	A piece of vegetation that is essentially homogeneous in all layers and differs from contiguous vegetation types by either quantities or qualitative characters.
Strangmoor	String bog with alternating low bog ridges and wet sedge hollows orientated across the major slope of the peatland at right angles to water movement.
String Fen	Peatland occurring on slopes with low parallel ridges, separated by water-saturated hollows orientated across the slope.
Subclimax	A stage in succession normally preceding the climax yet long-persisting due to some factor or form of disturbance.
Succession	An orderly process of community development that involves changes in species structure and community, processes with time resulting from modification of the physical environment by the community culminating in a stabilized ecosystem.

TABLE 4.5-2 (Cont'd)

GLOSSARY OF COMMON VEGETATION-RELATED TERMS USED IN THE E.I.S.

Surficial	Characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially consisting of unconsolidated residual, alluvial, or glacial deposits lying on the bedrock.
Swamp	Wooded area with a saturated soil which is water-covered for part of the year.
Terrace	Relatively flat, horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side.
Thermokarst	Settling or caving of the ground due to the melting of ground ice.
Transpiration	The loss of water vapour from living plants.
Ubiquitous	Found in many different communities.
Understory	Any stratum in a community occurring below the uppermost vegetation later, usually referring to shrubs and herbs.
Weathering	The group of processes, such as the chemical action of air and rainwater and of plants and bacteria and the mechanical action of changes of temperature, whereby rocks, on exposure to weather, change, decay and finally crumble into soil.
Wet Meadow	A community with some peat accummulation which is dominated by reed, bentgrass and fowl bluegrass.

PLATE 4.5-1 *'Sedge-willow' vegetation is characteristic of the outer alluvial islands of the Mackenzie Delta. (Courtesy, Hardy Associates, 1978, Ltd.)*

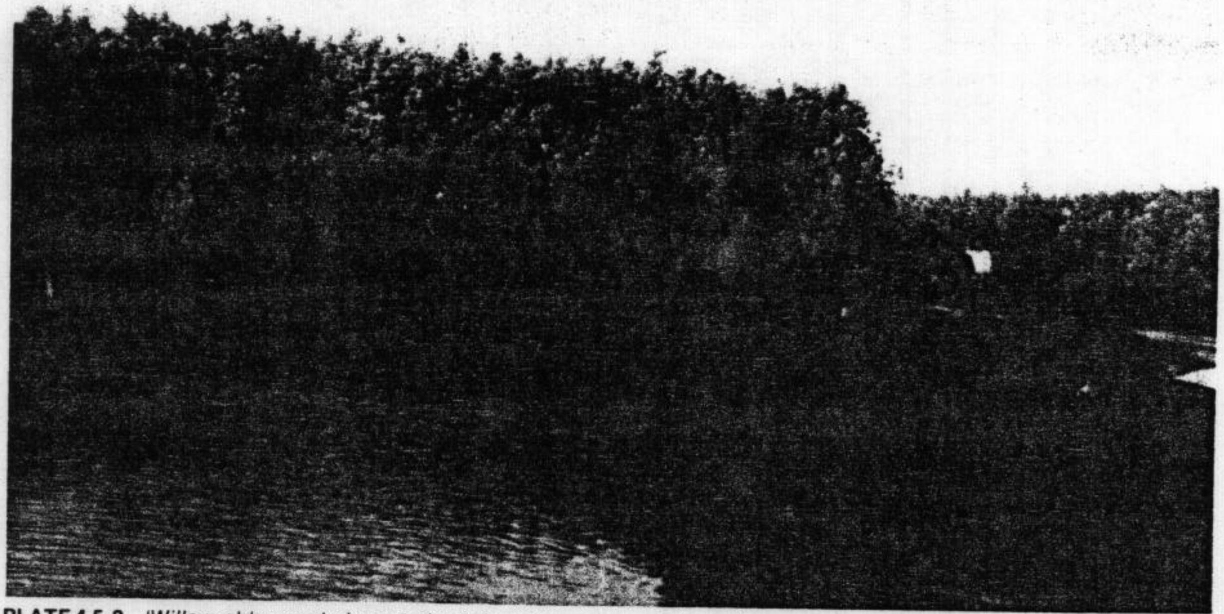

PLATE 4.5-2 *'Willow-alder-poplar' vegetation is found in a zone mainly on the west side of the Mackenzie Delta, inland from the 'sedge-willow' zone. (Courtesy, Hardy Associates, 1978, Ltd.).*

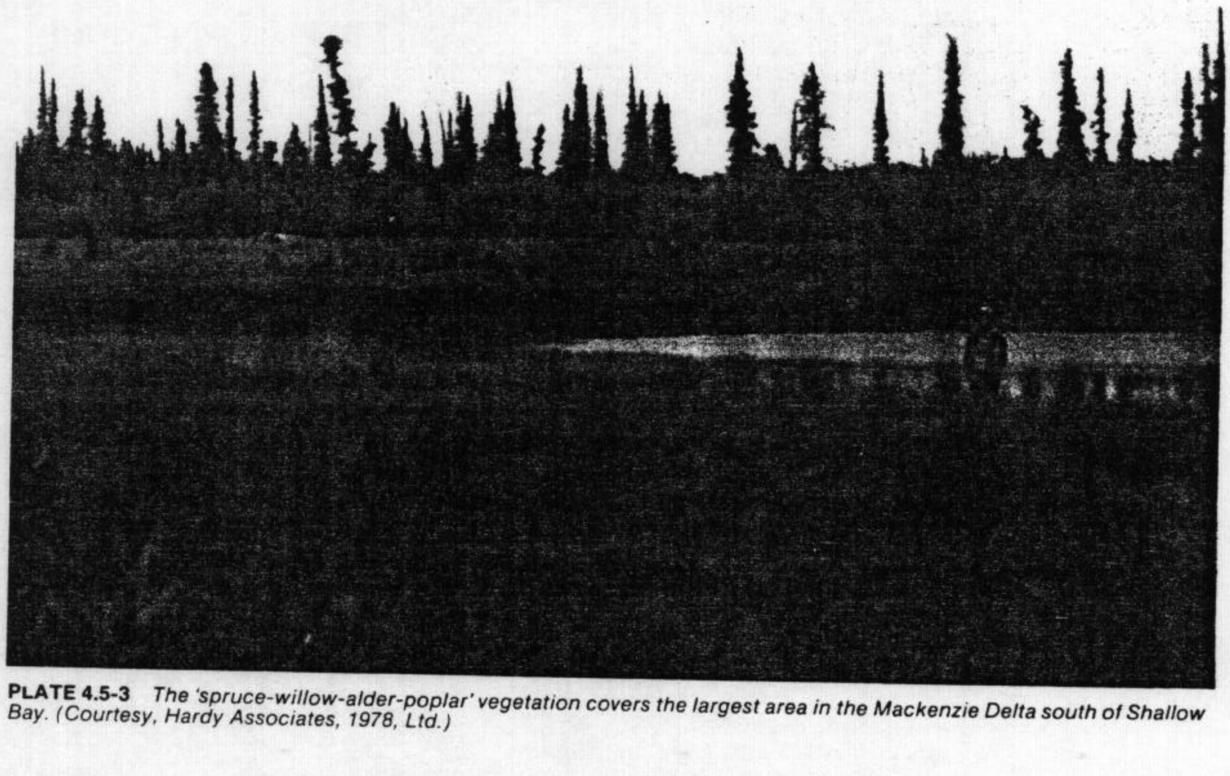

PLATE 4.5-3 *The 'spruce-willow-alder-poplar' vegetation covers the largest area in the Mackenzie Delta south of Shallow Bay. (Courtesy, Hardy Associates, 1978, Ltd.)*

4.5.1.2 Vegetation Communities

The following subsections describe the structure, composition and distribution of the vegetation communities of the Mackenzie Delta. The vegetation classifications used as the basis for these descriptions are those developed by Slaney (1974) and Reid and Calder (1977), although both of these reports dealt primarily with the outer Delta beyond the tree limit. However, Reid and Calder (1977) also discussed some community types found on the inner Delta. Some communities and successional sequences within the inner Delta were also described by Gill (1971a, 1972, 1973a), Lambert (1972c), Hardy Associates (1981) and Cordes (in prep).

The distribution of vegetation communities in the Mackenzie Delta is largely controlled by soil drainage (Slaney, 1974) and vegetation may change markedly with elevational changes of only a few centimetres.

(a) White Spruce/Alder/Feathermoss Forest

This community type was described by Reid and Calder (1977) and is characterized by a closed tree canopy of white spruce and a closed shrub layer of green alder, frequently over a closed carpet of layered feathermoss. Principal dwarf shrubs are lingonberry and alpine bearberry. This community type occurs south of the tree line in the inner Delta, as a narrow band on the well to imperfectly drained silts and silty clay soils which cover the higher levees of the Delta.

According to Hardy Associates (1981), white spruce forests in the Mackenzie Delta are seldom flooded and sedimentation near the root systems is minor. In the southern Delta, white spruce forests are found on surface elevations averaging 7 m above the August water level, while in the northern Delta they are present on soils only 3 m above the water level. On the inner Delta, the white spruce community is considered to be the climax vegetation type although it is subject to channel erosion, thermal erosion, and rarely fires, which return the area to earlier successional stages.

(b) Balsam Poplar Forest

Balsam poplar forests occur to a limited extent on moderately well to imperfectly drained soils of the inner Delta (Reid and Calder, 1977). They are often found along with white spruce forests on high levees along drainage channels. This community is characterized by an open canopy of balsam poplar over a shrub layer dominated by glaucous willow. Dwarf birch and lingonberry may also be present, along with a sparse cover of herbaceous plants. [Gill (1972), Lambert (1972c) and Hardy Associates (1981) described the composition and succession of balsam poplar forests on point bars of the inner Delta.]

(c) Alder Shrub

The 'green alder' community of the Mackenzie Delta forms a dense, almost impenetrable cover 1.5 to 3 m high (Reid and Calder, 1977). Associated shrubs, particularly in older stands, include Alaska willow and lanate willow. Herbaceous cover is sparse but includes common horsetail and alpine bearberry. This community occurs primarily on well drained sand and silty-sand soils of levees. [Lambert (1972c), Forest Management Institute (1975) and Hardy Associates (1981) also described an alder association which forms a band just above the level of annual flooding along Delta channels.]

(d) Willow-Herb

The 'willow-herb' community described by Slaney (1974) occurs on levees where maximum siltation from the Mackenzie River occurs. In these areas, willows may attain heights of 1.8 to 3 m. [An 'Alaska willow/horsetail' community described by Reid and Calder (1977) and the 'willow/horsetail' community described by Hardy Associates (1981) are apparently similar. This community occurs primarily on low, recently formed levees, but occasionally on the crests of higher, well drained levees. It is composed of Alaska willow, to 3 m tall, with a closed herb layer of common horsetail. Alder is also frequently present.]

(e) Willow-Sedge

This vegetation type, described by Slaney (1974), is dominated by low willows less than 0.5 m high, and sedges, with mosses being of secondary importance. It occurs on recent alluvial deposits which are subject to frequent flooding, but where siltation is relatively minor. [A similar 'willow-sedge' community is described by Reid and Calder (1977) and Hardy Associates (1981).] The community is characterized by an open canopy of willows, a closed cover of sedges and frequent horsetail. Alaska willow is also occasionally present. This vegetation association occurs on imperfectly to poorly drained soils, on levee backslopes and Delta plains.

(f) Sedge-Herb

The 'sedge-herb' community (Slaney, 1974) is dominated by aquatic sedges, cottongrass and horsetail and occurs on recent alluvial deposits which are covered with shallow water throughout the summer. Its soils are relatively fertile as a result of the seasonal deposition of silt, and have active layers down to permafrost, ranging in depth from 25 to 61 cm. [The 'horsetail meadow' community described by Reid and Calder (1977) is similar to that described above (Slaney, 1974).

(g) Meadow

The 'meadow' community described by Slaney (1974), is found on poorly drained areas, and has a diverse vegetation cover of sedges, heaths and mosses. Common species are sedges, crowberry and blueberry. Reid and Calder (1977) later identified three community types which may occur within the meadow unit of Slaney (1974). The 'sedge-cottongrass meadow' is dominated by aquatic sedge and cottongrass, and occurs on poorly to very poorly drained mineral soils and shallow organic soils on levee foreslopes, point bars, meander scrolls, abandoned channels and delta plains. The 'pendent grass-hair grass meadow' is dominated by grasses. Associated species often include aquatic sedge, cottongrass and horsetail. This meadow community can exist on poorly to very poorly drained silty soils of point bars and delta plains. The third meadow community is the 'sedge fen' which is dominated by aquatic sedge. Scattered trees and shrubs may be present in this plant association and include tamarack, black spruce, shrub birch, lingonberry and sweet gale. Fens occur on poorly to very poorly drained sedge peat of variable thickness.

[The Forest Management Institute (1975) also described two vegetation types which can be included with this meadow unit. The 'Monocotyledon Wetland-Flat Polygon' type is dominated by sedges and cottongrass with a substantial cover of low shrubs, while the 'Monocotyledon Wetlands-Alluvial Fan' type is dominated by sedges and cottongrass with a small cover of low shrubs. Lambert (1972c) and Gill (1973a) described a horsetail association which may be broadly included in the meadow unit.]

(h) Dwarf Shrub-Heath

The 'dwarf shrub-heath' community grows on most upland tundra areas east of the Delta (Slaney, 1974). It is the dominant community on moraine and glaciofluvial landforms. Within the Mackenzie Delta, it is much less common but nevertheless occurs locally on medium to fine textured, well to imperfectly drained soils. Heaths, dwarf birch, willow and moss are the most prevalent plants. Soil hummocks are common and have active layers ranging in depth from 30 to 45 cm.

Reid and Calder (1977) describe three vegetation associations which may be included within the 'dwarf shrub-heath' community. The first is the 'dwarf birch-Labrador tea/feathermoss' association common in the Mackenzie Delta. Its open stratum is shared by dwarf birch, and Labrador tea and it has a ground cover of layered feathermoss. Green alder and lingonberry are important associated shrubs, while the herbaceous layer includes baked-apple berry and sedges. This community occurs on imperfectly drained soils of raised ridges around ice wedge polygons in the Delta plains.

(i) Cottongrass Tussock

The 'cottongrass tussock' community is more prevalent on the Pleistocene delta of Richards Island than on the recent alluvial deposits of the Mackenzie Delta (Slaney, 1974). However, it occurs locally in imperfectly drained areas, and at these sites cottongrass tussocks are the dominant vegetation.

(j) Medium Willow

The 'medium willow' community occurs on steep slopes, particularly on slump scars of lake banks, and in stream beds (Slaney, 1974). On steep slopes, it is dominated by lanate willow, birch and alder, with ericaceous shrubs, mosses and lichens being present in the undergrowth. Shrubs may be over 1.5 m tall at these sites. In depressions, the canopy of the 'medium willow' community is dominated by glaucous willow, while the undergrowth is dominated by sedges. [The 'high shrub-eroded plant' association described by the Forest Management Institute (1975) is comparable to the 'medium willow' unit on steep slopes, but occurs on steep slopes subject to constant erosion.]

(k) Patterned Ground

Slaney (1974) described and mapped a 'patterned ground' unit which consisted of vegetation on low and high centred polygons. Low centred polygons are common in areas of poor drainage, and are vegetated by sedge, cottongrass and drepanocladus mosses. High centred polygons have vegetation similar to the 'dwarf shrub-heath' community described earlier.

(l) Aquatic Vegetation

Much of the Mackenzie Delta is covered by channels, lakes and ponds. The channel lakes support very little submergent or emergent aquatic vegetation, but shoreline vegetation includes aquatic sedge, cottongrass, marsh marigold and horsetails (Slaney, 1974). Floodplain lakes support a varied and often vigorous aquatic community. Dominant submergent species include pondweed, hornwort, water starwort and water milfoil, while mare's tail and buckbean are the major emergent forms. Saline lakes near the coast may also contain tundra grass and maritime sedge. On the other hand, the river channels are turbid and support little aquatic vascular vegetation.

4.5.1.3 Vegetation Distribution on Landforms

The Mackenzie Delta is a large flat plain of modern alluvial sediments. Landforms are all alluvial related features including delta plains, abandoned channels and meander scars, point bars and levees. Vegetation communities on these landforms differ with slight changes in elevation, resulting from major changes in soil moisture.

For purposes of vegetation description, the Mackenzie Delta can be subdivided into an inner Delta which is south of the tree line, and an outer Delta north of the tree line (Figure 4.5-1). The predominant vegetation types on principal landforms in each of these areas are listed in Table 4.5-3.

TABLE 4.5-3

PREDOMINANT VEGETATION TYPES ON PRINCIPAL LANDFORMS OF THE MACKENZIE DELTA. ALL LANDFORMS ARE ALLUVIAL.

Landform	Soil Drainage	Predominant Vegetation
Outer Delta		
Point Bars	well to imperfect	alder shrub willow-herb willow-sedge sedge-herb
	poor	meadow
Delta Plains	well	willow-herb dwarf shrub heath
	imperfect to poor	willow-herb willow-sedge meadow
Inner Delta		
Point Bars	well	alder shrub balsam poplar white spruce-alder feathermoss
	imperfect to poor	willow-herb meadow
Delta Plains	well	white spruce-alder feathermoss
	imperfect to poor	willow-herb willow-sedge meadow

(a) Inner Delta

The southern part of the inner Delta has many old floodplains which are located 9 m or more above the mean summer low water level. Levees are poorly developed and channels are relatively stable. However, in northern portions of the inner Delta, levees are more common and their height decreases to only 3 to 6 m above the mean low water level (Mackay, 1963). Channels tend to meander more in this region and new land is constantly being formed by silt deposition.

Within the inner Delta, point bars support a sequence of vegetation types reflecting differences in the age of deposits, frequency of flooding and soil drainage. The zone nearest the waters edge, where sedimentation rates are highest, remains unvegetated. Slightly higher areas, including low, recently formed levees which are flooded annually, have a 'willow-herb' community. Higher levees which are intermittently flooded support 'alder scrub' vegetation. Alder appears first above the level of annual flooding, followed by balsam poplar forest above the alder scrub. The highest, rarely flooded levees where sedimentation is minor, are covered by 'white spruce/alder/-feathermoss' forest. In the south, these forests occur on surfaces 7 m or more above the summer water level, but towards the north, they may be found on surfaces only 3 m above the summer water level (Hardy Associates, 1981). Depressions and swales which are poorly to very poorly drained are covered by meadows of variable composition.

The relatively flat Delta plains within the inner Delta support a variety of vegetation types which are distributed according to soil drainage. Well drained, high alluvial plains generally support a 'white spruce-/alder/feathermoss' forest community which occurs mostly in the form of ribbons along channels. Extensive areas of imperfectly to poorly drained mineral soils are dominated by 'willow-sedge' vegetation with local areas of meadow vegetation. In addition, a large portion of the Delta is covered by lakes and ponds with aquatic vegetation.

(b) Outer Delta

The outer Mackenzie Delta, beyond the tree limit, is comprised of three major terrain types: levees, point bars and backswamps (Reid and Calder, 1977). Backswamps include the Delta plains, abandoned channels and lakes. The summits of high, well drained levees are covered with 'alder scrub,' while lower levees support 'willow-herb' and 'willow-sedge' communities. Meadow vegetation, consisting primarily of sedges and horsetails, grows at the base of levees.

The vegetation of point bars is controlled by the age of the soil deposits, frequency of flooding and soil drainage. Raised, well drained soils are vegetated primarily by 'alder shrub,' with lower, more frequently flooded sites having 'willow-herb' and 'willow-sedge' vegetation. Areas subject to frequent flooding and high rates of deposition support a 'sedge-herb' community which is dominated primarily by horsetails. Meadow vegetation dominated by sedges and grasses occurs on poorly to very poorly drained soils in depressions, which are not subject to high rates of sedimentation.

The Delta plains, which encompass much of the outer Mackenzie Delta, have mainly sedge and cottongrass meadows, supplemented by 'willow-sedge' and 'willow-herb' communities. Abandoned, infilled channels of the Delta are also covered by meadows of sedges and cottongrass, whereas ice wedge polygon areas have a 'dwarf shrub-heath' vegetation. Lake margins throughout the outer Mackenzie Delta support meadows and 'willow-sedge' vegetation.

4.5.2 YUKON COASTAL PLAIN AND MOUNTAINS

4.5.2.1 Regional Description

The Yukon Coastal Plain and Mountains region lies west of the Mackenzie Delta and includes the Yukon Coastal Plain and portions of the Peel Plain, Richardson Mountains, Porcupine Plateau, and British Mountains. With the exception of the Fort McPherson area and the upper Firth River valley, this region lies north of tree line (Figure 4.5-1).

Oswald and Senyk (1977) include the Yukon Territory portion of this vegetation region within the 'Northern Mountains and Coastal Plain' ecoregion. Most of the terrain is devoid of trees, but open stands of black spruce, white spruce and balsam poplar occur in protected valleys, particularly along the Firth River. However, the most prevalent vegetation type is sedge and cottongrass tussock tundra. Surfaces are nearly always hummocky. In addition to sedges and cottongrass, shrub birch, willow and alder are common on warmer sites, while ericaceous shrubs, prostrate willows, forbs and mosses occur in cooler areas. Lichens are also prevalent throughout the Yukon Coastal Plain.

Wiken *et al.* (1981a) delineates the area into two ecoregions, the 'Northern Coastal Plain' ecoregion and the 'Northern Mountains' ecoregion. The first is a low relief plain which rises gently from the coast to an elevation of about 150 m above sea level. Vegetation cover is vigorous and nearly continuous, and includes a mixture of cottongrass tussocks and low shrubs (Plate 4.5-4), except on wetlands which have mainly sedges and mosses. The 'Northern Mountains' ecoregion includes the hilly and mountainous terrain which lies inland from the coastal plain. Vegetation cover is sparse and discontinuous at higher elevations, but vigorous and nearly continuous in valley bottoms and at lower elevations. High elevation vegetation is composed primarily of dwarf shrubs, forbs and lichens, while low elevation vegetation includes a mixture of sedge tussocks and low to medium shrubs (Plate 4.5-5). Each of these ecoregions is further subdivided in ecodistricts (Wiken *et al.*, 1981b).

Welsh and Rigby (1971) also provide a brief description of vegetation in the northern Yukon, and report that tussock tundra covers more land surface than any other community type, although it varies in composition with moisture content of the soil.

Forests of this region are included in two sections of the Boreal Forest (Rowe, 1972) (Figure 4.5-2). In the

PLATE 4.5-4 *Sedge-cottongrass-low shrub tundra is typical on the Yukon Coastal Plain. (Courtesy, Hardy Associates, 1978, Ltd.)*

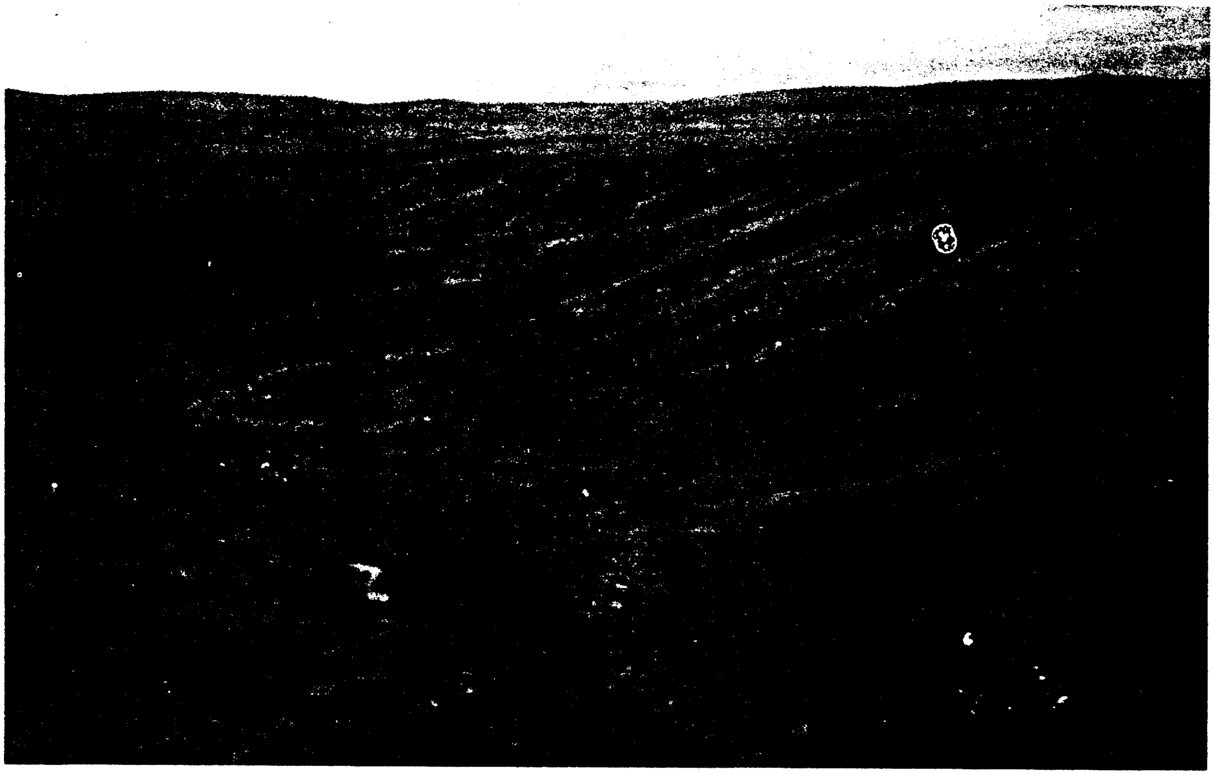

PLATE 4.5-5 *Sedge tussocks, low to medium willow and dwarf birch are common at lower elevations in the foothills and mountains. (Courtesy, Hardy Associates, 1978, Ltd.)*

vicinity of Fort McPherson, the forests lie within the Lower Mackenzie Section. In the upper Firth River valley, forests are included within the 'Alpine Forest-Tundra' section which is characterized by open park-like stands of stunted white spruce alternating with patches of grassy or shrubby vegetation on rocky barren ground (Rowe, 1972). Subalpine fir occurs on north and east-facing slopes in the transition to alpine tundra, but black spruce is common at lower elevations.

4.5.2.2 Vegetation Communities

There are few descriptions of vegetation communities in the Yukon Coastal Plain and Mountains region. A Canadian Arctic Gas Study report by Hettinger *et al.* (1973) discusses the area in greatest detail, and is used as the basis of the present community descriptions. Other vegetation descriptions covering portions of the Yukon Coastal Plain are provided in Reid and Calder (1977), Forest Management Institute (1975), Hardy Associates (1979c), and Drew and Shanks (1965). Hettinger *et al.* (1973) describe twelve major vegetation classes (formations) and twenty-six community types found in this region.

(a) Ephemeral Herb Desert

The 'ephemeral herb desert' vegetation class of the Arctic Coastal Plain and British Mountains is described by Hettinger *et al.* (1973). On the Arctic Coastal Plain it occurs on sand dunes over alluvial fan deposits along the coast. The vegetation is composed of glaucous willow, below which is a heavy cover of milkvetch, mountain avens and locoweed forming closed mats as the soils become stabilized.

In the British Mountains, this vegetation class occurs on steep scree slopes of loose rocks, where it is a sparse community composed of mountain avens, saxifrage, fireweed and false asphodel. Plant cover increases where mineral soil has accumulated, but since most of the soils are continually moving, few plants become established.

(b) Seasonal Grass and Herb Steppe

This vegetation class is found in the Richardson Mountains on scree slopes which are partially stabilized and have some soil. The vegetation is an open community of bluegrass, minuarta and douglasia. Plant cover occurs in strips aligned up and downslope, which results from the slippage of the substrate materials.

(c) Open Evergreen Microphyllous Dwarf Shrub

This is a very common vegetation class within the

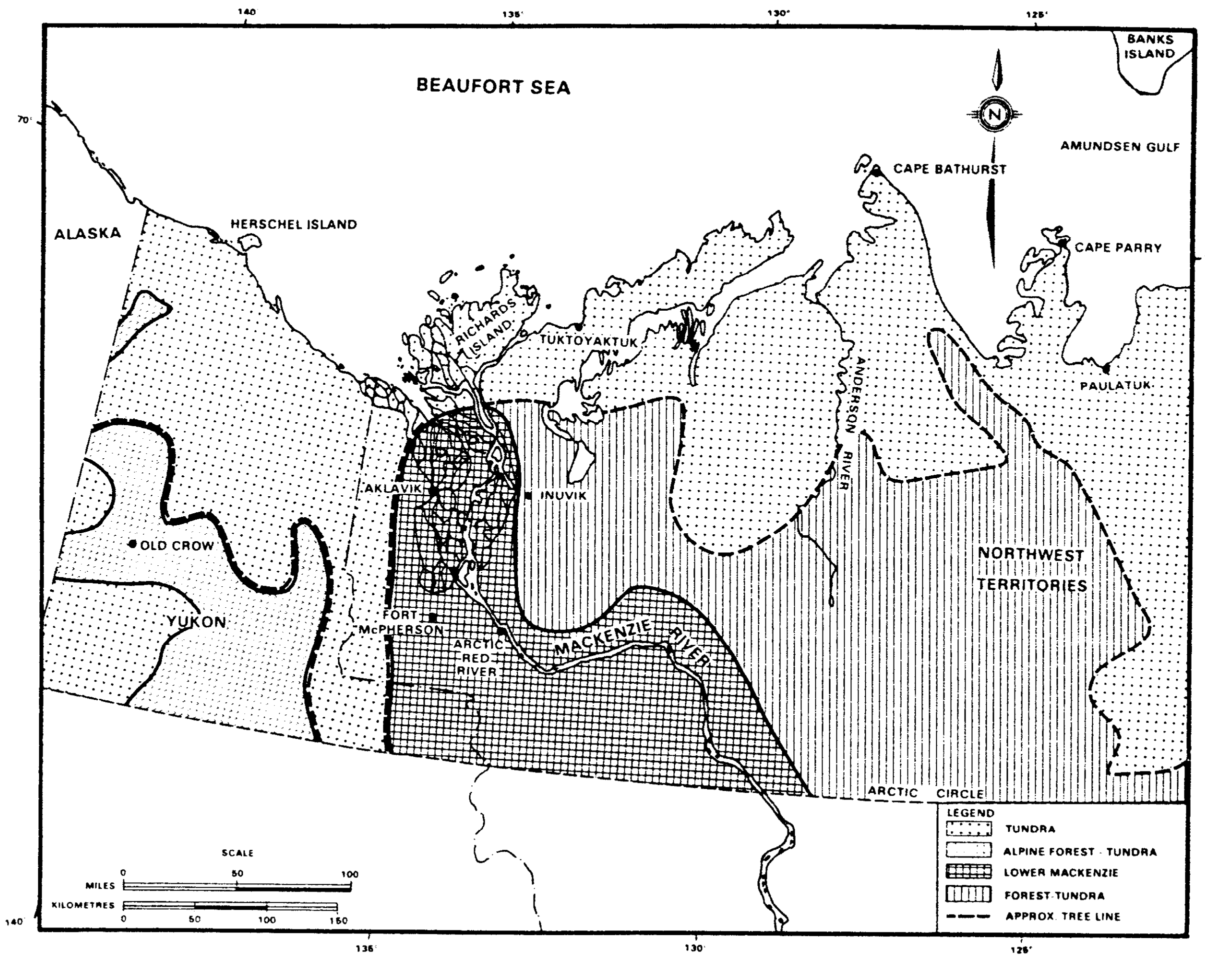

FIGURE 4.5-2 *Forest sections of the Beaufort onshore region (after Rowe, 1972).*

Yukon coastal region, and is found in the Yukon Coastal Plain and Plateau, Richardson Mountains and British Mountains. Five vegetation community types are included within the class (Hettinger *et al.*, 1973). These are the 'mountain avens,' the 'mountain avens-dwarf willow,' the 'dwarf-willow,' the 'sedge-dwarf willow,' and the 'dwarf willow-moss' communities.

The 'mountain avens' community occurs on steep gravel slopes, rock outcrop ridges and plateaus of mountain summits in the British Mountains. It is composed of mountain avens, Lapland cassiope, moss campion and lichens. The extensiveness of the ground cover varies with slope exposure, and is high only in small islands and depressions where soil materials have been deposited.

A 'mountain avens-dwarf willow' community occurs on the undulating solifluction slopes which are prevalent in the British Mountains, and is also common on ridge tops and slopes of foothills bordering the Arctic Coastal Plain. Its dominant plant species include dwarf willow, mountain avens, lupine, lichens and dicranum mosses. Moss cover is greatest in poorly drained areas of solifluction lobes, while dwarf shrubs and lichens are dominant on the drier solifluction lobes, gravel slopes, ridges and other well drained areas. Plant cover is generally sparse on gravel ridges and slopes, but closes in on the wetter areas associated with solifluction lobes.

The 'dwarf willow' community occurs on high rocky ridges and slopes of the Richardson Mountains. Its vegetation cover is open and composed of dwarf willow, spike moss and lichens. This vegetation association also occurs on well drained solifluction slopes in the Richardson Mountains, where it includes Lapland cassiope and occassionally alpine blueberry.

The 'sedge-dwarf willow' community is found on low centre ice wedge polygon terrain of the Arctic Coastal Plain. Sedges and sphagnum and aulocomnium mosses occupy the lower depressions of the polygons, while clumps of dwarf willows occur on the drier ridges of the polygon edges. Soils are usually poorly drained and have a thick, 25 to 30 cm, accumulation of organic materials.

The 'dwarf willow-moss' community occurs on high centre polygons and many silty, rolling hills of the Arctic Coastal Plain. It is comprised of scattered dwarf willow with a closed ground cover of various mosses. The mosses are most prevalent in depressions where soils are imperfectly drained.

(d) Seasonal Orthophyll Meadow

The seasonal orthophyll meadow vegetation class of the Arctic Coastal Plain and the Richardson and British mountains is found in poorly drained depressions and on slopes and terraces. This vegetation class is dominated by sedges. Five community types within this vegetation class are described by Hettinger *et al.* (1973); they are the 'sedge,' 'sedge-mountain avens,' 'cottongrass,' 'cottongrass-sedge' and 'trisetum' communities.

On the Yukon Coastal Plain, the 'sedge' community occurs in poorly drained depressions and flats where surface water may be present throughout the growing season. Many of these places are former lake beds. This community is composed of sedges and sphagnum moss. Soils contain thick peat accumulations.

The 'sedge-mountain avens' community occurs on sites similar to those occupied by the 'sedge' community. The dominant plant species are aquatic sedge and mountain avens. On the drier sites, such as gently sloping drainage channels, dwarf willow and dwarf birch are common.

The 'cottongrass' community covers large areas of the rolling hills at the lower elevations of the Richardson Mountains. It is dominated by cottongrass tussocks. Important associated species include false asphodel, a variety of mosses (especially layered feathermoss) and lichens. The mineral soils associated with this community have a moderately thick surface horizon of organic materials.

The 'cottongrass-sedge' community occurs on poorly drained sites of the Richardson Mountains and Yukon Coastal Plain. It is found below late melting snowbanks, which supply water to these sites throughout the growing season. The vegetation is composed of sedges, cottongrass and sphagnum mosses. On the drier hummocks, shrub birch, baked-apple berry and polytrichum moss are found. Soils associated with this community have a moderately thick, 25 to 30 cm, fibric layer of organic materials over a thin gleyed mineral horizon.

The 'trisetum' community grows on gentle, rocky, south-facing slopes of the Richardson Mountains. This community is composed of trisetum grass and minuarta over a closed ground cover of lichens. Soils associated with this community are well drained and have a thin layer of organic materials.

[Drew and Shanks (1965) describe three landscape types of the upper Firth River Basin of the British Mountains which have vegetation which could be included within the seasonal orthophyll meadow vegetation class. These landscape types are 'sedge meadow terrace,' 'calcareous bog meadow and strangmoor,' and 'noncalcareous bog meadow and strangmoor.' The three 'monocotyledon wetlands' community types described by the Forest Management Institute (1975) are included in the seasonal orthophyll meadow vegetation class.]

(e) Seasonal Short Grass Meadow

The 'seasonal short grass meadow' vegetation class of the British Mountains includes one community type described by Hettinger *et al.* (1973). This is the 'dwarf willow-horsetail-moss' community, common on the gently rolling hills of the British Mountains, which has a "grassy" appearance due to abundant sedges. Its vegetation cover is closed and dominated by dwarf willow, common horsetail, sedge, mountain avens and a closed cover of moss, especially tomenthypnum moss. Soils associated with this community are poorly drained.

(f) Deciduous Shrub Savanna

The 'deciduous shrub savanna' vegetation class of the British Mountains has an open cover of medium sized, 0.5 to 1.5 m tall, shrubs over a closed ground cover of dwarf shrubs and herbaceous species. This single community, described by Hettinger *et al.* (1973), occurs on high terraces within alluvial meander plains and is dominated by glaucous and dwarf willows, larkspur and mountain sorrel. Soils associated with this community are continually moist but well aerated.

(g) Deciduous Orthophyll Shrub

This vegetation class features a closed cover of deciduous orthophyll shrubs such as willows, dwarf birch and alder, in which either low or tall shrubs may be dominant. It occurs on alluvial terraces and hills of the Yukon Coastal Plain and on terraces and colluvial slopes of the Richardson and British mountains. Hettinger *et al.* (1973) describe three community types within the deciduous orthophyll shrub vegetation class. These are the 'dwarf birch,' the 'willow' anmd the 'green alder-willow' communities.

The 'dwarf birch' community is found at elevations from 1,067 to 1,280 m high in the Richardson Mountains, on colluvial slopes below rock outcrops and cliffs. On the Yukon Coastal Plain, this community occurs on the tops of moraine hills. It is composed of dwarf willow, shrub birch, alpine blueberry and numerous lichens. Where steep solifluction terraces occur on silt-mantled terrain, the dominant species of this community include Lapland cassiope, dwarf birch, and various lichen species.

The 'willow' community is composed of tall, generally over 2 m high, glaucous willow and herbaceous species, including bistort and arnica. It grows on high alluvial terraces in the Richardson Mountains, but since it is restricted to valley streams, the total area covered by this community is not extensive.

The 'green alder-willow' community occurs on alluvial terraces of the Yukon Coastal Plain. It has a closed cover of tall shrubs, including green alder and willow, and a closed cover of herbaceous species, including polar grass and coltsfoot beneath the shrubs. Soils associated with this community are well drained and have little horizon development over the cobbly parent materials encountered about 40 cm below the surface. On these alluvial terraces, spring flooding results in the deposition of silt.

(h) Open Deciduous Orthophyll Shrub

This vegetation class is characterized by scattered deciduous shrubs such as dwarf birch, willows and lingonberry. It occurs primarily along drainageways and on solifluction terraces of the Richardson Mountains and Arctic Coastal Plain. Hettinger *et al.* (1973) identify two community types within this vegetation class, these being the 'dwarf birch' and the 'willow' communities.

The 'dwarf birch' community has widely spaced dwarf shrubs, including dwarf birch and lingonberry, which are usually found on relatively dry microsites such as low mounds. Beneath the shrubs and on wetter microsites, the dominant species in the closed ground cover are layered feathermoss, polytrichum moss and sphagnum moss. This community is found on imperfectly drained solifluction terraces on silt-mantled colluvial slopes of the Richardson Mountains. It may also cover a large proportion of the Yukon Coastal Plain (Forest Management Institute, 1975).

The 'willow' community occurs along drainage channels in foothills bordering the Yukon Coastal Plain, while further north it is scattered on alluvial fans. Its vegetation is composed of an open cover of several willow species, with an undergrowth of groundsel and moss.

(i) Evergreen Orthophyll Short Tussock Grass

Large areas of the Yukon Coastal Plain and high plateaus on its borders are covered by this vegetation class, which features cottongrass tussocks. The composition of this vegetation class varies with the moisture regime of the area. On some relatively dry sites the predominant species are willows rather than cottongrass. Two community types within this vegetation class are identified by Hettinger *et al.* (1973), the 'cottongrass-mountain avens-dwarf willow' and the 'cottongrass' communities

The 'cottongrass-mountain avens-dwarf willow' community covers large areas on the high plateaus which border the Yukon Coastal Plain. Scattered cottongrass tussocks appear to be the dominant component of this community, although dwarf willow species may provide a greater cover in some areas, especially on the drier sites. Other species included within this community type are mountain avens and sphaghum moss, polytrichum moss and layered feathermoss. [A similar community, 'low shrub-sedge upland,' is described by the Forest Management Institute (1975].

The 'cottongrass' community covers much of the Yukon Coastal Plain and is usually described as tussock tundra. Cottongrasses dominate the appearance of this community, but tomenthypnum and aulacomnium mosses usually provide greater ground cover. Other species included within this community are dwarf willow and mountain avens. These species are most abundant on drier sites. Gleyed soils are usually associated with this community type. [A similar community, 'Monocotyledon Variable,' is described by the Forest Management Institute (1975).]

(j) Closed Deciduous Scrub with Scattered Trees

This vegetation class is dominated by low shrubs but has scattered coniferous trees. A single community called the 'Labrador tea' community is described for the Richardson Mountains by Hettinger *et al.* (1973).

In the Richardson Mountains, the 'Labrador tea' community dominates the vegetation on many lower slopes of interior valleys. This community is primarily composed of low shrubs, including Labrador tea, lingonberry, alpine blueberry and alpine bearberry. A dense cover of cetraria lichens is found beneath the shrubs, and white spruce trees are widely scattered throughout the community. Soils associated with this community are imperfectly drained and receive subsurface drainage from higher slopes. [Drew and Shanks (1965) describe a solifluction slope with a scattered spruce vegetation similar to that described above.]

(k) Open Evergreen Sclerophyll and Deciduous Forest

This vegetation community has an open cover of evergreen and, occasionally, deciduous trees. Hettinger *et al.* (1973) describe one community type within this vegetation class called the 'black spruce-tamarack and cloudberry-sphagnum' community, which covers much of the northern Peel Plain and Peel Plateau. On the Yukon Coastal Plain it is found only near Fort McPherson. The open tree layer is composed of black spruce and tamarack. The closed shrub layer beneath the trees is composed of Labrador tea, lingonberry and cloudberry, and there is a dense ground cover of sphagnum moss. [A similar open black spruce vegetation is described by Reid and Calder (1977) and the Forest Management Institute (1974, 1975).]

(l) Closed Evergreen Forest

Within the Yukon Coastal Plain area, the closed evergreen forest vegetation class occurs only near Fort McPherson and in the Firth River valley near the Yukon-Alaska border (Reid and Calder, 1977; Forest Management Institute, 1974). Hettinger *et al.* (1973) identify two community types within this vegetation class.

The 'white spruce and alder-prickly rose' community is found near Fort McPherson on river terraces along the Peel River and Stoney Creek. This is a community of mature white spruce with an undergrowth of green alder, prickly rose, layered feathermoss, common horsetail and mustard. Soils associated with this community usually contain alluvial sands, cobbles, or both, on top of which is a thin (5 cm) layer of organic materials.

Similar closed-canopy white spruce forests grow on stream terraces in the upper Firth River Basin (Drew and Shanks, 1965). The canopy includes white spruce trees up to 15 m tall. The understory consists of willows up to 8 m tall, and balsam poplar up to 11 m tall. The ground cover is composed of layered feathermoss and a variety of dwarf shrubs and herbaceous species.

Hettinger *et al.* (1973) describe a second closed white spruce forest community type, 'white spruce and willow-thoroughwax,' which is found on eroding valley slopes and ravines. The undergrowth is composed of glaucous willow, thoroughwax and mosses. [This community type may be included within the 'Pioneer Steep Slope Mixtures' community type which occurs on valley sideslopes of Peel River tributaries near Fort McPherson (Forest Management Institute, 1974, 1974).]

4.5.2.3 Vegetation Distribution on Principal Landforms

The following information about the distribution of vegetation classes and community types on principal landforms in the Yukon coastal area is derived either directly from descriptions by Hettinger *et al.* (1973) or indirectly from a comparison of vegetation distributions mapped by the Forest Management Institute (1975) with surficial geology information of the area. Six land-form types and their associated vegetation classes and community types are described for the Yukon Coastal Plain and Mountains region. Predominant vegetation types on principal landforms are listed in Table 4.5-4.

TABLE 4.5-4

PREDOMINANT VEGETATION TYPES ON PRINCIPAL LANDFORMS OF THE YUKON COASTAL PLAIN AND MOUNTAINS REGION

Landform	Soil Drainage	Predominant Vegetation
Coastal Plain		
Moraine	well	deciduous orthophyll shrub evergreen orthophyll short tussock grass
	imperfect	open evergreen microphyllous dwarf shrub
	poor	seasonal orthophyll meadow open evergreen microphyllous dwarf shrub
Alluvial	well to imperfect	deciduous orthophyll shrub
	poor	seasonal orthophyll meadow
Glaciofluvial	well	ephemeral herb desert
	imperfect to poor	seasonal orthophyll meadow
Glaciomarine	imperfect	deciduous orthophyll shrub
	poor	seasonal orthophyll meadow
Organic	poor	seasonal orthophyll meadow
Mountains		
Bedrock	well	open evergreen microphyllous dwarf shrub
	imperfect to poor	seasonal orthophyll meadow
Colluvial	rapid	ephemeral herb steppe desert
	well to imperfect	seasonal grass and herb steppe open evergreen microphyllous dwarf shrub evergreen orthophyll short tussock grass open deciduous orthophyll shrub
	poor	open evergreen microphyllous dwarf shrub season orthophyll meadow
Alluvial	well to imperfect	deciduous shrub savanna deciduous orthophyll shrub
	poor	seasonal orthophyll meadow

(a) Bedrock - Colluvial

Bedrock exposures and colluvium are the most extensive surficial materials in the Yukon Coastal Plain and Mountains region. The bedrock - colluvial landform covers the British and Richardson mountains. Deposition of colluvial materials in this region may be the result of weathering of local bedrock or glaciation.

Bedrock outcrop ridges are vegetated by 'open evergreen microphyllous dwarf shrub' vegetation including the 'moutain avens' and 'dwarf willow' types. Scree slopes of unstable coarse materials have 'ephemeral herb steppe desert' vegetation, while 'seasonal grass and herb steppe' is commonly present on scree slopes which are partly stabilized. 'Seasonal orthophyll meadow' is common on more stabilized, south-facing rocky slopes and on poorly drained bedrock terrain.

Colluvial slopes composed of finer materials are extensive and support a variety of vegetation types according to their drainage, elevation, frost activity and slope. Well drained materials support an 'open evergreen microphyllous dwarf shrub' vegetation. Imperfectly drained materials commonly support 'open evergreen microphyllous dwarf shrubs' and 'evergreen orthophyll short tussock grass.' The imperfectly drained materials associated with solifluction terraces support 'open deciduous orthophyll shrub' vegetation. Poorly drained colluvial materials are commonly vegetated by 'open evergreen microphyllous dwarf shrub' and 'seasonal orthyophyll meadows.'

(b) Till

Till landforms include ground moraines and hummocky moraines, which, within the Yukon Coastal Plain and Mountains region, are found primarily on the Arctic Coastal Plain. Well drained to imperfectly drained till in this region usually has 'deciduous orthophyll shrub' vegetation or 'evergreen orthophyll short tussock grass' vegetation, commonly called tussock tundra. Imperfectly drained till materials may be vegetated by 'open evergreen microphyllous dwarf shrub.' Poorly drained depressions and low lying areas are covered by 'seasonal orthophyll meadows' and 'open evergreen microphyllous dwarf shrub.' Till plains in the Fort McPherson area have an open 'evergreen sclerophyll and deciduous' forest.

(c) Alluvial

Alluvial landforms, including terraces, plains, deltas and fans, are common on the coastal plains near the mouths of principal rivers. Alluvial terraces on the coastal plains support mainly 'deciduous orthophyll shrub' and 'open deciduous orthophyll shrub.' Alluvial terraces at higher elevations have a 'deciduous shrub savanna' and 'deciduous orthophyll shrub' vegetation. However, on the coastal plains these fans are vegetated primarily by 'open deciduous orthophyll shrub' and 'seasonal orthophyll meadows.'

(d) Glaciofluvial

Glaciofluvial landforms occur locally near the coast. Their predominant vegetation is the 'seasonal orthophyll meadow,' although small areas of 'ephemeral herb desert' vegetation may also be present.

(e) Glaciomarine

Glaciomarine landforms in the Yukon Coastal Plain and Mountains region include isolated plains and deltas along the coast. Near King Point and Sabine Point, the vegetation is primarily 'seasonal orthophyll meadow,' but 'deciduous orthophyll shrub' vegetation is also found.

(f) Organic Terrain

Organic terrain is uncommon in the Yukon Coastal Plain region, but where it exists its vegetation is probably the 'seasonal orthophyll meadow.'

4.5.3 ANDERSON PLAIN - TUKTOYAKTUK PENINSULA

4.5.3.1 Regional Description

Most of the Anderson Plain - Tuktoyaktuk Peninsula region lies north of the tree line (Figure 4.5-1). Patches of stunted trees are found within a matrix of tundra communities south of Eskimo Lakes and in the Anderson and Horton river valleys. The remainder of the vegetation of this region is tundra, with abundant low shrubs and, in some areas, tall shrubs. Tussock tundra covers much less of this region than it does in the Yukon Coastal Plain and Mountains region (Section 4.5.2).

The subarctic forests of the Tuktoyaktuk Peninsula -Anderson Plain region are included in the Forest-Tundra Section (Rowe, 1972). This section forms a transition from forest to Arctic tundra and has patches of stunted trees along shores of lakes and rivers, with tundra vegetation on the uplands.

Zoltai *et al.* (1979) divide the region east of the Kugaluk River into two ecoregions: the Low Arctic ecoregion characterized by tundra communities of shrubs, herbaceous plants, mosses and lichens, and the High Subarctic ecoregion characterized by open canopied white spruce forest. The Low Arctic ecoregion is separated into three ecodistricts: the Cape Parry, Hornaday River and Mason ecodistricts. The first includes the northern half of the Parry Peninsula where environmental conditions are not favorable for plant growth, and vegetation cover is generally less than 25% (Zoltai *et al.*, 1979, Hardy Associates, 1979a). The Hornaday ecodistrict includes the southern half of the Parry Peninsula and coastal areas around Darnley Bay. Here vegetation covers 80 to 100% of the soil surface and is composed of tall and low shrubs, sedges and lichens. The Mason ecodistrict lies north of the tree line and west of Parry Peninsula, and is characterized by a complete plant cover composed of tall and low shrubs, sedges and mosses. The High Subarctic ecoregion includes only the Anderson ecodistrict, in the area of direct interest to this report. Its vegetation is typically open canopied white spruce-shrub-lichen woodlands, with large areas of fire-induced tundra west of the Anderson River.

4.5.3.2 Vegetation Communities

Vegetation community descriptions for the Anderson Plain-Tuktoyaktuk Peninsula region are incomplete. For the Horton-Anderson rivers area, Zoltai *et al.* (1979) briefly describe general vegetation types encountered in a natural resource survey. These descriptions are supplemented by landform-vegetation maps which show landscape relief and surficial materials, vegetation types and vegetation cover. The major vegetation types of the Tuktoyaktuk Peninsula and the region south of Eskimo Lakes have been described by the Forest Management Institute (1975). The vegetation of smaller areas within the Anderson Plain - Tuktoyaktuk Peninsula region is described in greater detail by Corns (1974) and Hardy Associates (1979a, 1979b). The vegetation classification of Zoltai *et al.* (1979) is used as the basis for the vegetation community descriptions in the following sections, since it applies to a large portion of the region. This classification includes eight major types and seven community subtypes. The following headings refer to the eight major types of vegetation communities found in this region.

(a) Dwarf Shrubs-Herbs-Lichens

This community includes mainly mountain avens, a dwarf shrub which grows up to 15 cm tall, but also includes other medium height shrubs such as dwarf willow and, in southern areas, shrub birch. Lower and taller shrubs are usually not present. Lichens, clumps of grasses or sedges, and forbs (broad-leaved herbaceous plants) may be present. This community exists on well drained upland sites, especially in northern portions of the region. It is the principal community found on the northern Parry Peninsula. Zoltai *et al.* (1979) described two subtypes within the community type. The 'Dryas' subtype is characterized by mats of mountain avens, but includes certain lichens and forbs, such as lousewort and saxifrage, scattered among the mountain avens mats. Small clumps of sedges may also be present. The 'ericaceous' subtype features dwarf ericaceous shrubs such as lingonberry, Labrador tea, alpine bearberry, and mountain avens. It may also include shrub birch, willow, forbs and lichens.

[In other studies of the Anderson Plain - Tuktoyaktuk Peninsula region, 'dwarf shrub' communities have been found, primarily in northern coastal portions of the region (Forest Management Institute, 1975; Hardy Associates, 1979a, 1979c).]

(b) Sedges- Low Shrubs

This vegetation type is characterized by low, up to 50 cm high shrubs and sedges, and includes subtypes which occur on both uplands and lowlands (Plate 4.5-6). The 'birch-willow' subtype includes mainly low shrubs, while sedges are the major component of the 'cottongrass-willow' and 'sedge-willow' subtypes. The 'birch-willow' subtype occurs on upland sites, and is composed of low shrubs, including shrub birch, willows and Labrador tea, and dwarf shrubs such as mountain avens, alpine bearberry, and lingonberry. Its ground cover is predominantly mosses, lichens and, occasionally, a few forbs. [A low 'shrub-heath' community described by Corns (1974) is generally similar to the 'birch-willow' community subtype and is the most extensive type found on the Tuktoyaktuk Peninsula. The Forest Management Institute (1975) also reports that low shrub-dominated vegetation types are extensive east of the Mackenzie Delta and on the Tuktoyaktuk Peninsula, and describes two 'low shrub upland' vegetation types.]

The 'cottongrass-willow' subtype described by Zoltai *et al.* (1979) is composed primarily of cottongrass and sedge, and includes scattered low shrubs (primarily glaucous willow and mosses, but rarely includes forbs and lichens. It usually occurs on imperfectly to poorly drained slopes. [Corns (1974) describes a 'herb-low shrub-heath' vegetation type for the Tuktoyaktuk Peninsula which is generally similar to the 'cottongrass-willow' subtype.]

The 'sedge-willow' subtype described by Zoltai *et al.* (1979) for the Anderson Plain - Tuktoyaktuk Peninsula region exists on poorly drained mineral or organic soils where the landscape is level or gently sloping (Plate 4.5-6). It features wet meadow vegetation composed of aquatic sedges *(Carex glauca and S. alaxensis)* in low, very wet areas, and willows on small mounds and raised polygon edges. Wetland drepanocladus mosses are common. [Similar wetland 'sedge-willow' vegetation types are described for this region by the Forest Management Institute (1975), Corns (1974), and Hardy Associates (1979a, 1979b). Corns (1974) reports that they cover 61% of the land surface on Atkinson Point, but are not common in other areas of this region, covering only 1% of the land in the Caribou Hills and Eskimo Lakes area, and 2% of the land near Tuktoyaktuk.]

(c) High Shrubs-Sedges-Mosses

This vegetation type has tall shrubs, up to 2 m high, which are either scattered or form a closed canopy. This vegetation type covers large areas in the western portion of the Horton-Anderson rivers area (Figure 4.5-2) and includes two subtypes (Zoltai *et al.*, 1979).

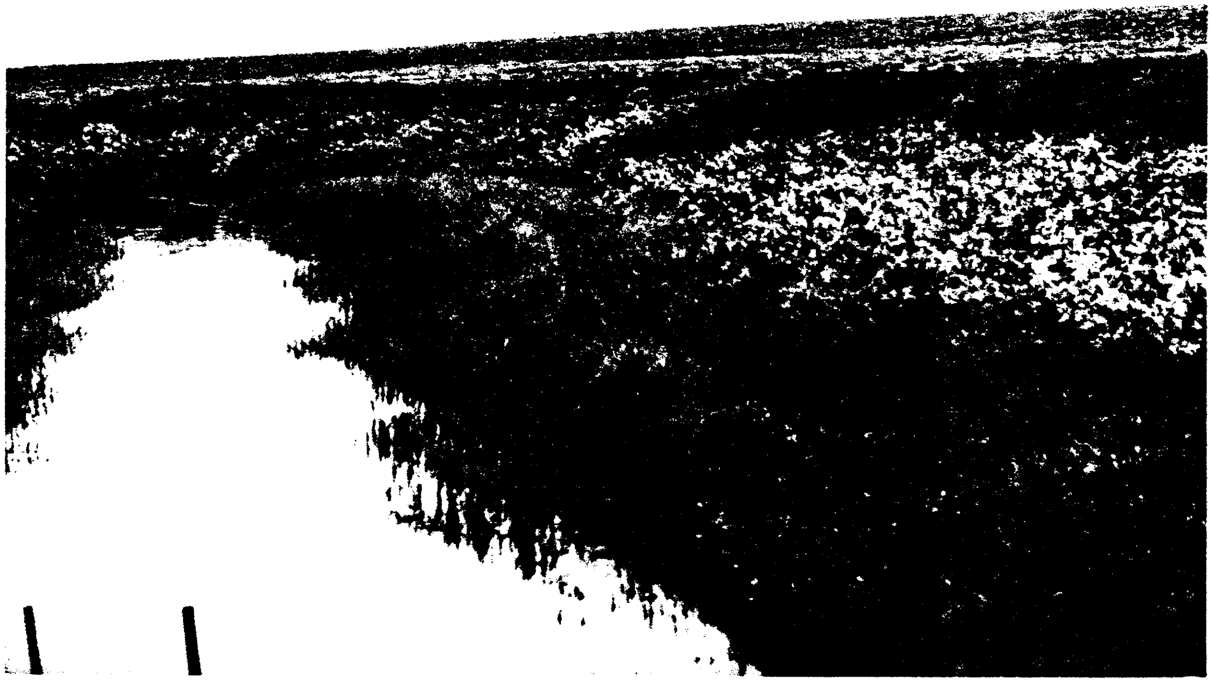

PLATE 4.5-6 *On the Tuktoyaktuk Peninsula, a 'low shrub-herb-moss-lichen' community dominates, particularly on higher ground. In poorly drained areas such as beside this creek on the peninsula, 'sedge-willow' vegetation is typical.*

The 'birch-alder' subtype is usually associated with well to imperfectly drained soils. It is composed primarily of shrub birch, green alder and, to a lesser extent, willows, and includes low and dwarf shrubs such as lingonberry, alpine blueberry, alpine bearberry and Labrador tea. The ground cover is mainly composed of ground-dwelling lichens, and may include forbs such as wintergreen, coltsfoot and Arctic lupine. [The medium 'shrub-heath' (birch-alder-heath) vegetation type described by Corns (1974) is similar to the 'birch-alder' subtype, and is estimated to cover 26% of the land in the Eskimo Lakes area.]

The 'willow subtype' has tall willow shrubs (greater than 1.5 m tall), which occur in closed stands or as scattered clumps (Zoltai *et al.,* 1979). This community subtype is associated primarily with alluvial sites along stream courses and poorly drained lowlands, and is composed primarily of willows. On alluvial soils, horsetails provide the undergrowth, while sedges and mosses form the major undergrowth on wet lowlands. [Corns (1974) describes several tall 'shrub-herb' vegetation types of communities associated with alluvial soils east of the Mackenzie Delta. Three of these vegetation types occur along streams. The two found nearest to streams are composed primarily of willows, while the type found furthest from the streams, where flooding is less frequent, is composed of alder.]

(d) Sedge-Shrubs-Scattered Trees

This vegetation type, described by Zoltai *et al.* (1979), occurs at the tree line within the transition zone between open spruce-lichen woodland and birch-alder tundra. It is similar in composition to the 'high shrub-sedge-moss' type but also includes scattered individuals or clumps of white spruce.

(e) Open Spruce-Lichen

This vegetation type is very common in southwestern portions of the Anderson Plain region (Zoltai *et al.,*1979). It is composed of open-canopied white spruce forests, in which trees are generally 5 m or more apart and are less than 10 m tall. Shrubs may be present between the trees, but herbaceous vegetation is sparse and the dominant ground cover is lichens. Aspen and balsam poplar may occur on steep south or west-facing slopes.

(f) Open Spruce-Shrubs

A more prominent shrub layer distinguishes this type from the 'open spruce-lichen' type. The increased shade results in a marked reduction in lichen cover and an increase in moss cover.

(g) Spruce-Moss

The 'spruce-moss' vegetation type, described by Zoltai *et al.* (1979), is characterized by closed canopy forests composed primarily of white spruce trees which are closely spaced and up to 20 m tall. The ground cover is a continuous layer of feathermosses. This vegetation type is found only in small patches in the southwestern part of the Anderson Plain region. [The Forest Management Institute (1974) describes an 'upland spruce-feathermoss' vegetation type which is generally similar to the 'spruce-moss' vegetation type.]

(h) Open Black Spruce-Moss

The 'open black spruce-moss' vegetation type is characterized by open black spruce woodlands with a dense ground cover of mosses, principally sphagnum and feathermosses, and a layer of low shrubs, including Labrador tea and ericacious shrubs. This vegetation includes the 'black spruce/sphagnum' and 'black spruce/lichen' vegetation types, the 'moss-variable' and the 'lichen-variable' vegetation types, described by the Forest Management Institute (1974, 1975), and the evergreen narrow sclerophyll forest' vegetation 'open type described by Reid and Calder (1977). Similar subarctic black spruce forests on hummocky permafrost terrain exist in the vicinity of Inuvik (Zoltai *et al.*, 1975).

4.5.3.3 Vegetation Distribution on Principal Landforms

The following information regarding distribution of vegetation types on principal landforms is drawn from landform-vegetation maps of the Anderson Plain area (Zoltai *et al.*, 1979), and from surficial geology and vegetation maps (Forest Management Institute, 1975) of the Tuktoyaktuk Peninsula and area south of Eskimo Lakes.

Incomplete vegetation descriptions and maps, the lack of a uniform vegetation classification and the lack of agreement on the classification of surficial materials of the Anderson Plain-Tuktoyaktuk Peninsula area, makes conclusions regarding the predominant vegetation types on principal landforms in this area tentative.

The expected main vegetation types found on principal landforms are listed in Table 4.5-5. Moraines are the principal landforms of the Anderson Plain. North of the tree line, the predominant vegetation on these landforms is the 'sedges-low shrubs' type, especially the 'birch-willow' subtype, although the 'sedge-willow' subtype and 'cottongrass-willow' subtype occur on wet sites. The 'high shrubs-sedges-mosses' type occurs on relatively moist sites, while the 'dwarf shrubs-herbs-lichens' type occurs on some dry upper slopes. South of the tree line, 'open spruce-lichen' vegetation is predominant on moraines.

The 'sedges-low shrubs' type is also predominant on most other landforms north of the tree line. The 'birch-willow' subtype exists on well to imperfectly drained soils, while the 'sedge-willow' and 'cottongrass-willow' subtypes are characteristic of imperfectly to poorly drained soils. The 'high shrubs-sedges-mosses' type occurs on moist colluvial, fluvial and alluvial materials.

South of the tree line, the 'open spruce-lichen' type and 'sedges-low shrubs' type are the predominant vegetation communities on most landforms. Other common types include 'open black spruce-moss' vegetation on imperfectly to poorly drained lacustrine and organic materials, and the 'high shrubs-sedges-mosses' type on moist alluvial and lacustrine materials.

TABLE 4.5-5

PREDOMINANT VEGETATION TYPES OF PRINCIPAL LANDFORMS IN THE ANDERSON PLAIN-TUKTOYAKTUK PENINSULA REGION.

				Landform			
	Moraine	**Bedrock/ Colluvial**	**Fluvial**	**Alluvial**	**Lacustrine**	**Organic**	**Marine**
North of Treeline							
	sedges-low shrubs	high shrubs-sedges-mosses	high shrubs-sedges-mosses	sedges-low shrubs	sedges-low shrubs	sedges-low shrubs	dwarf shrubs-herbs -lichens
	high shrubs-sedges-mosses	dwarf shrubs-herbs-lichens	sedges-low shrubs	high shrubs-sedges-mosses			sedges-low shrubs
	dwarf shrubs-herbs-lichens		dwarf shrubs-herbs-lichens				
South of Treeline							
	open spruce-lichen	open spruce-lichen	open spruce-lichen	sedges-low shrubs	sedges-low shrubs	sedges-low shrubs	
	open spruce-shrubs	sedges-low shrubs	sedges-low shrubs	high shrubs-sedges-mosses	open black spruce-moss	open black spruce-moss	
			spruce-moss		high shrubs-sedges-mosses		

4.6 RESOURCE USE

4.6.1 HUNTING AND TRAPPING

Trapping provides a full-time occupation or an income supplement for a large number of native people from communities in both the Mackenzie Delta and the coastal Beaufort Sea region. These communities are Aklavik, Arctic Red River, Fort McPherson, and Inuvik in the Mackenzie Delta, and Tuktoyaktuk, Paulatuk and Coppermine along the mainland coast adjacent to the Canadian Beaufort Sea. Two other coastal communities in the Canadian Beaufort Sea region are Holman Island on southwestern Victoria Island, and Sachs Harbour on southern Banks Island. People from the latter three communities do not hunt and trap on the lands in the vicinity of the southeastern Beaufort Sea and are consequently not considered in the following discussion. The harvest of offshore waterfowl, seals, whales, Arctic foxes and polar bears is discussed in detail in Section 3.6. Resource Use (marine species).

The total number of active trappers from communities in the Delta and from Tuktoyaktuk and Paulatuk has increased by about 20 percent over the last decade from an estimated 475 in 1970-71 to 568 in 1979-80 (Table 4.6-1). The general movement of people from distant camps to larger settlements has resulted in a decline in the number of men trapping for their primary source of income (Usher, 1976), and an increase in the number of people trapping part-time. Hunting is also considered important to the local economy, but primarily as a source of food rather than income (Bissett, 1974). Nevertheless, some market hunting does occur.

Snowmobiles are the chief mode of winter transport, and their use allows hunters and trappers access to the more distant hinterlands (Usher, 1976). However, ever since the advent of the snowmobile, trapping areas near the communities receive greater harvest pressures than less accessible areas. Part-time trappers are usually wage earners, but they use day-trip traplines (daylines) that can be covered within a day from the community on weekends. Hunting is often opportunistic, particularly during the trapping season, and also is most intensive near communities.

4.6.1.1 Harvest Statistics

The most important furbearers to coastal communities in the Mackenzie Delta and coastal Beaufort region in decreasing economic importance are muskrat, lynx, marten, coloured fox, Arctic fox, mink and wolf (Table 4.6-2). However, this list reflects the proximity of the larger communities to the Mackenzie Delta where muskrat are abundant. For example, the most important species (in decreasing economic importance) in Tuktoyaktuk and Paulatuk are Arctic fox, and coloured fox.

TABLE 4.6-1
ACTIVE TRAPPERS (1967-1980) FROM COMMUNITIES WITHIN THE MACKENZIE DELTA AND ALONG THE BEAUFORT SEA COAST

Community	1967-68[a]	1970-71[a]	1972-73[a]	1973-74[b]	1974-75[b]	1975-76[b]	1976-77[b]	1977-78[b]	1978-79[b]	1979-80[b]
Aklavik	137	142	118	111 (21)	104 (21)	146 (41)	153 (71)	169 (61)	166 (48)	117 (22)
Arctic Red River	26	20	20	28 (4)	21 (5)	20 (9)	30 (10)	26 (11)	31 (16)	31 (13)
Fort McPherson	129	106	103	113 (8)	80 (13)	106 (38)	127 (43)	130 (47)	138 (56)	151 (52)
Inuvik	110	138	110	124 (22)	111 (11)	124 (44)	127 (42)	141 (55)	150 (52)	148 (52)
Paulatuk				30 (19)	24 (4)	26 (7)	29 (14)	17 (3)	27 (14)	34 (19)
Tuktoyaktuk	36	42	64	81 (17)	74 (12)	83 (19)	78 (29)	75 (24)	88 (41)	87 (26)

a = Fur trader's record books, cited in Bissett (1974)
b = Trapper Incentive Program Records.
() = Number of trappers selling trapped furs totalling more than $1,000,000 annually.

The total value of furs harvested for each community (Table 4.6-2) were derived from the Trappers Incentive Program and are based on the records of fur buyers (R. Tingling, pers. comm.).

In general, barren-ground caribou, moose, and bear are the most important big game species hunted by residents in the Mackenzie Delta and coastal Beaufort region (Tables 4.6-3, 4.6-4, 4.6-5). With the exception of Arctic Red River, the importance of caribou far exceeds that of moose and bear in both numbers taken and the amount of meat supplied to the communities. Approximately 50 moose in total are harvested annually by residents in the Mackenzie Delta

TABLE 4.6-2
AVERAGE ANNUAL NUMBER AND VALUE OF FURS EXPORTED FROM COMMUNITIES WITHIN THE MACKENZIE DELTA AND ALONG THE BEAUFORT SEA COAST

Species	Aklavik		Arctic Red River		Fort McPherson	
	Number[a]	Value[b]	Number[a]	Value[b]	Number[a]	Value[b]
Bear, other than Polar Bear	2.75	228.25	0.38	31.54	4.00	332.00
Beaver	2.50	69.70	14.75	411.23	30.38	846.99
Coyote	0	0	0	0	0	0
Fisher	0	0	0	0	0	0
Arctic Fox[c]	55.63	2,160.75	0.38	14.76	4.13	161.00
Coloured Fox[d]	80.88	7,926.45	10.76	1,030.76	25.64	2,374.31
Lynx	82.00	22,564.76	9.63	2,649.98	51.00	14,034.18
Marten	86.50	3,306.90	230.38	8,807.43	421.63	16,118.91
Mink	300.00	11,346.00	28.50	1,077.87	211.75	8,008.39
Muskrat	30,776.00	151,417.92	910.63	4,480.30	18,955.63	93,261.70
Otter	0	0	0	0	0.38	26.69
Squirrel	6.75	10.60	2.00	3.14	67.75	106.37
Weasel	87.25	117.79	10.88	14.69	122.75	165.71
Wolf	16.13	3,254.55	0.38	76.67	1.00	201.77
Wolverine	0.38	75.37	0.13	25.78	0.50	99.17
Total Value		$201,479.04		$18,624.15		$135,737.19
Years of data	8		8		8	

Table 4.6-2 continued on page 4.103

The furbearer harvest data in Table 4.6-2 are taken directly from the Fur Export Tax Returns of the Northwest Territories, and indicate the number of furs exported from the Northwest Territories by each community. The indicated exports from the smaller communities may be considerably lower than the actual harvest since trappers often sell their furs to buyers in larger communities who in turn export the furs. Consequently, the furs are often recorded as taken by the community which exported them. In addition, furs used for domestic purposes or sold within the Northwest Territories are not included in the Fur Export Returns. Therefore, the data in Table 4.6-2 must be considered with caution and are intended primarily to illustrate the relative economic importance of furbearers in different communities. and coastal Beaufort region (P. Latour, pers. comm.). The number of Dall's sheep harvested in the mountains west of the Mackenzie River by residents of Aklavik exceeds the number of bears taken; an average of 16 sheep/year were taken between 1972-73 and 1975-76 (N.W.T. Wildlife Service, unpublished data). The harvest statistics for caribou, moose, Dall's sheep and bear (other than polar bear) are derived from General Hunting Licence Returns. However, holders of General Hunting Licences are not compelled to maintain and submit hunting records, and the reliability of these estimates is unknown (R. Tingling, pers. comm.).

TABLE 4.6-2 (cont'd)
AVERAGE ANNUAL NUMBER AND VALUE OF FURS EXPORTED FROM COMMUNITIES WITHIN THE MACKENZIE DELTA AND ALONG THE BEAUFORT SEA COAST

Species	Inuvik		Paulatuk		Tuktoyaktuk	
	Number[a]	Value[b]	Number[a]	Value[b]	Number[a]	Value[b]
Bear, other than Polar Bear	10.63	882.29	0.14	11.62	3.50	290.50
Beaver	102.50	2,857.70	0	0	1.25	34.85
Coyote	0	0	0	0	0.13	7.74
Fisher	0	0	0	0	0	0
Arctic Fox[c]	879.75	34,167.37	358.57	13,926.36	1,030.26	40,011.20
Coloured Fox[d]	340.14	33,305.94	30.15	2,750.56	206.01	19,056.43
Lynx	167.50	46,092.65	0	0	3.63	998.90
Marten	875.13	33,456.22	1.43	54.67	226.88	8,673.62
Mink	738.50	27,930.00	1.14	43.11	19.13	723.50
Muskrat	35,176.63	173,069.02	211.43	1,040.24	2,092.75	10,296.33
Otter	0.38	26.69	0	0	0.13	9.13
Squirrel	17.13	26.89	0	0	0	0
Weasel	372.75	503.21	3.00	4.05	7.88	10.64
Wolf	24.25	4,892.92	5.14	1,037.10	8.25	1,664.60
Wolverine	5.88	1,166.18	0.14	27.77	0.50	99.17
Total Value		$358,377.08		$18,895.48		$81,876.61
Years of data	8		7		8	

a = The average of available data between 1971-72 and 1978-79 (Fur Export Tax Returns).
b = The values are based on the mean of 1978-79 and 1979-80 average fur prices paid to trappers in the N.W.T.
c = Blue and white fox have been combined although value has been calculated separately for each colour phase and summed for this table.
d = Red, cross, and silver fox have been combined although value has been calculated separately for each colour phase and summed for this table.

TABLE 4.6-3
CARIBOU HARVEST BY COMMUNITIES IN THE MACKENZIE DELTA AND BEAUFORT SEA COASTAL AREA (1964-1979)

Community	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80
Aklavik	774[a]	647[a]	477[a]	996[a]	541[a]	465[d]	427[a]	688[a]	674[b]	1300[d]	917[b]	145[b]	N/R	114[d]	187[d]	147[d]
Arctic Red River	46[a]	67[a]	0[a]	23[a]	31[a]	2[a]	13[a]	2[a]	0[b]	12[b]	0[b]	0[b]	N/R	N/R	97[e]	0[e]
Fort McPherson	492[a]	479[d]	479[d]	1030[a]	757[b]	363[a]	723[d]	696[a]	621[b]	500[d]	757[b]	304[b]	N/R	350[d]	12[d]	168[d]
Inuvik	133[a]	52[a]	72[a]	328[a]	139[b]	150[b]	110[a]	149[a]	195[b]	273[b]	344[b]	134[b]	N/R	140[e]	245[e]	263[e]
Paulatuk	0[c]	1[c]	0[c]	70[c]	150[c]	245[c]	186[c]	194[c]	200[b]	370[b]	267[b]	104[b]	N/R	291[e]	375[e]	230[e]
Tuktoyaktuk	33[c]	87[a]	57[a]	341[a]	186[a]	90[a]	349[a]	115[a]	191[b]	353[b]	271[b]	271[b]	N/R	561[e]	995[e]	1555[e]

a = General Hunting Licence Returns, cited in Bissett (1974)
b = General Hunting Licence Returns, kill statistics
c = Data from Usher (1975), tables
d = Data from Yukon Game Branch
e = Data, P. Latour NWT Wildlife Service, pers. comm.
N/R = no recorded harvest or unknown.

TABLE 4.6-4
MOOSE HARVEST BY COMMUNITIES IN THE MACKENZIE DELTA AND BEAUFORT SEA COASTAL AREA. 1963-1977

Community	1963 -65[c]	1964 -65[a]	1965 -66[a]	1966 -67[a]	1967 -68[a]	1968 -69[a]	1969 -70[a]	1970 -71[a]	1971 -72[a]	1972 -73[b]	1973 -74[b]	1974 -75[b]	1975 -76[b]	1976 -77	1977 -78[b]
Aklavik	24	26	12	32	14	33	61	7	24	9	12	4	12	N/R	5
Arctic Red River	49	20	11	13	17	11	2	N/R	N/R	3	5	0	3	N/R	N/R
Fort McPherson	150	35	14	35	43	16	31	22	14	4	8	18	12	N/R	20
Inuvik	27	21	15	21	35	13	22	40	19	12	24	10	15	N/R	5
Paulatuk	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	0	0	0	0	N/R	0
Tuktoyaktuk	2	12	7	3	35	17	10	22	11	7	6	0	0	N/R	3

a = General Hunting Licence Returns, cited in Bissett (1974)
b = General Hunting Licence Returns, kill statistics
c = General Hunting Licence Statistics cited in Dickinson and Herman (1979).
N/R = no recorded harvest or unknown.

TABLE 4.6-5
GRIZZLY &/OR BLACK BEAR HARVEST BY COMMUNITIES IN THE MACKENZIE DELTA AND BEAUFORT SEA COASTAL AREA. 1964 - 1979

Community	1964 -65	1965 -66	1966 -67	1967 -68	1968 -69	1969 -70	1970 -71	1971 -72	1972 -73	1973 -74	1974 -75	1975 -76	1976 -77	1977 -78	1978 -79	1979 -80
Aklavik	9[a]	14[a]	3[a]	3[a]	1[a]	11[a]	3[a]	8[a]	9[b]	7[b]	9[b]	4[b]	3[c]	3[c]	6[c]	2[c]
Arctic Red River	19[a]	7[a]	7[a]	2[a]	5[a]	3[a]	2[a]	0[a]	1[b]	4[c]	3[c]	4[c]	2[c]	18[c]	1[c]	4[c]
Fort McPherson	2[a]	5[a]	6[a]	6[a]	8[a]	6[a]	4[b]	6[a]	6[a]	13[a]	1[b]	3[b]	11[c]	4[b]	1[c]	1[c]
Inuvik	3[a]	3[a]	2[a]	4[a]	0[a]	1[a]	1[a]	5[a]	9[a]	12[c]	13[c]	7[c]	7[c]	22[c]	16[c]	n/r
Paulatuk	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[b]	0[b]	0[c]	0[b]	1[c]	0[c]	0[c]	0[c]
Tuktoyaktuk	0[a]	0[a]	1[a]	0[a]	0[a]	0[a]	1[a]	2[a]	7[b]	11[b]	3[c]	4[b]	6[c]	10[b]	2[c]	1[c]

a = data taken from Bisset (1974), derived from General Hunting Licence Returns
b = data from kill statistics derived from General Hunting Licence Returns.
c = Data from Fur Export Tax returns (FETR) or Trader Fur Record Books (TFRB)
n/r = no records available

4.6.1.2 Hunting and Trapping Areas

Hunting and trapping areas utilized by residents of Aklavik, Inuvik, Arctic Red River, Fort McPherson, Tuktoyaktuk and Paulatuk are indicated on Figure 4.6-1. The numbered divisions (areas) on the figure are based primarily on the Northern Land Use Information Series (Environment Canada, 1972, 1976; Fisheries and Environment Canada, 1977a), and indicate areas with similar patterns and intensity of hunter and trapper use. In addition, supplemental information was obtained from DIAND/MPS (1973), Bissett (1974) and Freeman (1976).

During fall and winter, residents of Aklavik may hunt caribou along the valleys of the Malcolm and Firth rivers and Joe Creek in Area 1. Historically, caribou were hunted mainly in summer throughout this area in the aforementioned valleys, the west side of the Richardson Mountains and the north slopes of the British and Barn mountains. Sheep are taken in mountainous areas along Joe Creek, while moose are hunted on the flats of the Firth River.

The northern Yukon coast and Herschel Island (Area 2) is a hunting and trapping area for residents of Aklavik and Inuvik. Caribou are hunted along the coast and on Herschel Island mainly during summer, but are also taken during fall and winter. Moose are hunted along the Babbage River. During fall, winter and spring, residents of Aklavik hunt caribou and Dall's sheep in the Richardson Mountains. In summer, caribou are also hunted along the coast and near Coal Mine Lake (primarily north of Rat River), although some animals are taken as far south as Stoney Creek by residents of Fort McPherson (Area

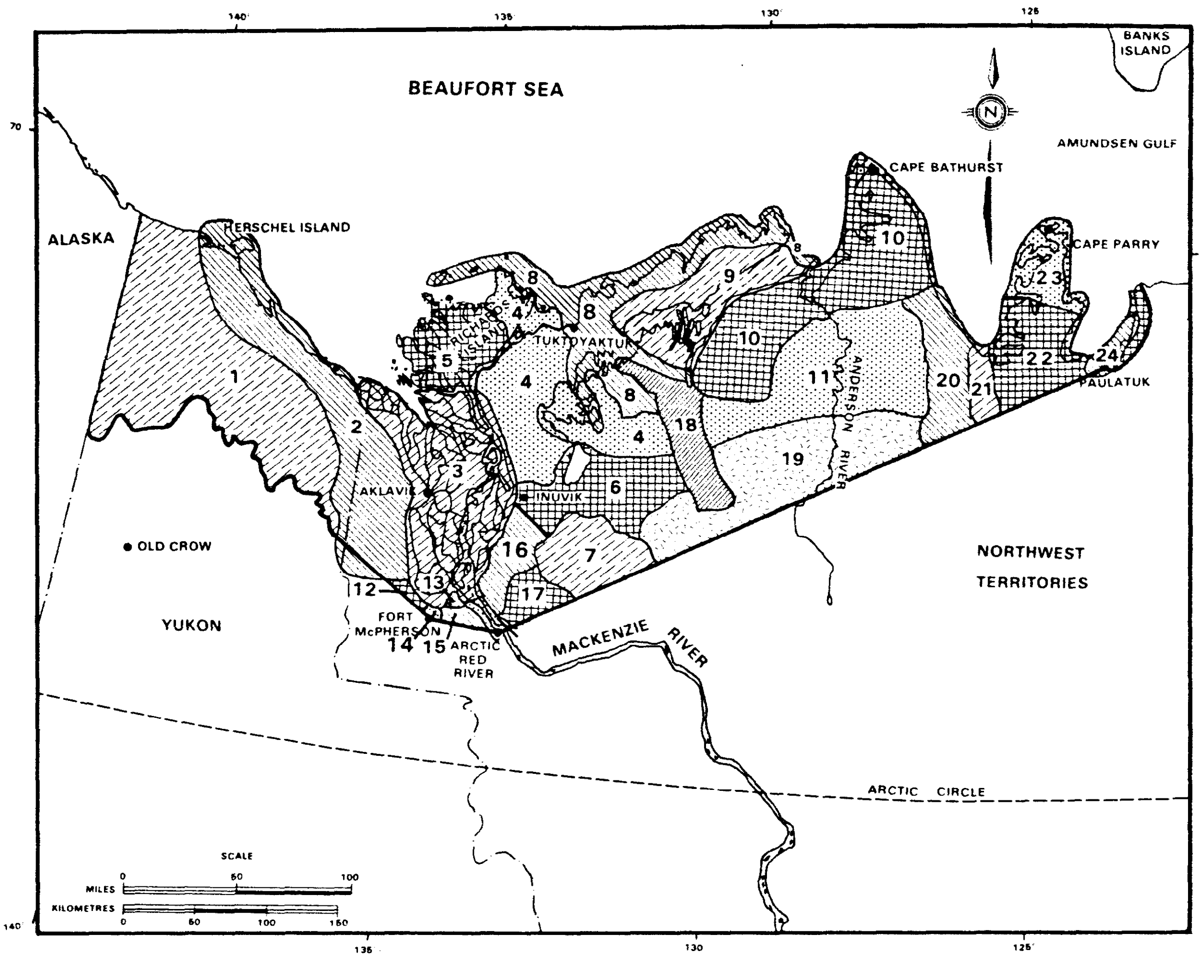

FIGURE 4.6-1 *Hunting and trapping areas used by residents of communities in the onshore Beaufort region.*

12). Arctic for are trapped along the Arctic coast and on Herschel Island, and coloured fox are trapped in the Richardson Mountains. Big Fish River and Cache Creek are important trapline routes for coloured fox, and the former is also trapped for wolverine. Lynx are occasionally trapped in the uplands between the mountains and the Mackenzie Delta.

The Mackenzie Delta (Area 3) is the most heavily trapped area in the Beaufort Sea region, and the majority of muskrat taken by Aklavik, Inuvik, Fort McPherson and Arctic Red River trappers are hunted and trapped there between April and June. Mink, beaver, lynx, and coloured fox are also trapped on the Delta during the winter trapping season (November to March). In addition, moose are hunted on the Delta, particularly in years when caribou are scarce in the mountains.

In Area 4, trappers from Tuktoyaktuk take muskrat during late winter in the vicinity of Parsons and Noell lakes. In addition, moose and Arctic fox are taken occasionally in this area. A few residents of Aklavik trap Arctic fox on Richards Island (Area 5), and occasionally muskrat (spring) and moose (fall).

Area 6 is visited by hunters from Inuvik and Aklavik during the winter. Barren-ground caribou, grizzly bear and moose are the main species hunted, while Arctic fox, marten, mink and wolverine are sometimes trapped. The large area north of and including Travaillant Lake (Area 7) is considered to be one of the best marten trapping areas in the north. In the past it was used annually by as many as 6 men from each of Arctic Red River and Fort McPherson, and by several trappers from Aklavik and Inuvik, but regular use has declined. Mink, lynx, coloured fox, beaver and wolverine may be trapped and moose and barren-ground caribou are hunted for food.

Travel routes through the Eskimo Lakes area (Area 8) are generally used by Tuktoyaktuk residents for trapping coloured fox. The routes also lead to marten trapping areas east of Kugaluk River. Moose are sometimes hunted in the valley of the Miner River. Traplines for Arctic fox are set from Tuktoyaktuk west to Pelly Island, east along the Tuktoyaktuk Peninsula and coast (see Section 3.7), and along the north shore of Liverpool Bay (Area 9).

The coastal area including the Bathurst Peninsula and the area south of Wood and Liverpool bays (Area 10) is an important resource harvesting area for the people of Tuktoyaktuk (Speller, 1975). With the exception of the Mackenzie Reindeer Grazing Reserve where special hunting restrictions apply, caribou are hunted throughout the area in fall and winter, while moose are taken in the lower parts of the Kugaluk, Smoke, Anderson and Mason river valleys. Arctic fox are occasionally trapped along the shores of Liverpool Bay and Wood Bay, and muskrat have been taken in spring between the Kugaluk River and Rufus and Kaglik lakes (Environment Canada, 1976). Hunters based at Cape Bathurst and North Star Harbour trap furbearers and hunt caribou north of the Mason River near the mouth of Horton River. Residents of Tuktoyaktuk also hunt moose and caribou in the Anderson River valley during fall and winter (Area 11). Muskrat and marten have also been taken there. An area east of the Anderson River and in the vicinity of Lac Rendez-vous is used by Tuktoyaktuk residents in most years to trap marten; caribou and moose are taken opportunistically for food.

The upland region between the Peel River and Richardson Mountains (Area 12) is an important hunting and trapping area for many families from Fort McPherson. Migrating caribou are often found during fall, winter and spring. Traplines follow many of the creek valleys, and the main species harvested include lynx, marten, mink, coloured fox, wolf, and wolverine. A small area east of Niendo Lake at the south end of the Mackenzie Delta (Area 13) is irregularly trapped by residents of Aklavik, Inuvik, Arctic Red River and Fort McPherson. Harvests include marten, mink, lynx, and moose in winter. The Peel River and adjacent lowlands (Area 14) are used at various times of the year by most residents of Fort McPherson as a travel corridor. Moose are often hunted there during late summer, and the lowlands east of the Peel River at Shiltee Rock and along the Satah River are particularly important spring hunting and trapping areas for beaver and muskrat. A large lowland area south of Niendo Lake between the Peel and Mackenzie rivers (Area 15) is an important trapping area for residents of Fort McPherson and Arctic Red River. Large numbers of muskrats and beaver are trapped each spring, while lynx, marten, beaver, and wolverine constitute most of the winter catch.

Residents of Aklavik, Inuvik, Arctic Red River and Fort McPherson hunt moose in late summer and black bear in spring along the Mackenzie River lowlands in Area 16. A lowland area along the Rengleng River in Area 17 is used by several trappers from Aklavik, Fort McPherson and Arctic Red River, and most heavily during the spring beaver and muskrat hunt. Winter trapping includes harvests of mink and marten in the Whirl, Attoe, and Pierre lakes area; moose and caribou are often hunted opportunistically by the trappers. The area along and north of the Wolverine River (Area 18) is one of the most productive areas for furbearers and is trapped by the people of Tuktoyaktuk. Marten are the main species trapped, but beaver, mink, muskrat, and wolverine are also taken. Moose are found throughout this area, and are hunted along the traplines.

The Crossley Lakes region (Area 19) was trapped extensively in the past, and is still utilized by a few trappers from Aklavik, Inuvik, and Tuktoyaktuk. Prime trapping areas occur around Hyndman Lake, the confluence of the Anderson and Carnwath rivers and the area east of the Anderson River. Moose are hunted close to the traplines. Hunters from Paulatuk and Tuktoyaktuk have used the lower Horton River valley (Area 20) in past years to hunt caribou and moose. Paulatuk residents have extended trapping to the southwest into much of the Horton River valley and Tadonet Lake area. An outpost camp has been established at Delesse Lake.

The area south and west of Biname Lake (Area 21) is occasionally used by residents of Paulatuk for hunting barren-ground caribou. In addition, some winter trapping also occurs in the area. The southern part of Parry Peninsula and the Melville Hills (Area 22) are the principal areas used by residents of Paulatuk for hunting caribou. Hunting usually occurs in fall and winter, although some caribou stay year-round. Arctic fox are trapped in winter north of the Melville Hills, and wolf and wolverine are trapped or hunted in the area around Biname and Billy lakes. Muskoxen are also occasionally hunted in this area. The northern and eastern parts of Parry Peninsula (Area 23), the Hornaday River delta, Brock River delta and Clapperton Island (Area 24) are easily accessible from Paulatuk and are used regularly for trapping Arctic fox in winter.

4.6.2 FISH RESOURCE USE

This section presents a summary of domestic, commercial, and sport fish harvests along the Beaufort coast, including the Mackenzie Delta and Tuktoyaktuk Peninsula, the coastline east of the Delta to the Hornaday River near Paulatuk, and the coastline west of the Delta to the Firth River near Herschel Island. This section attempts to focus on the inland freshwater fish harvests, while coastal fisheries for marine species, such as Pacific herring, are mentioned separately in Section 3.6.6 of this volume. The inland fishery generally predominates over the coastal fishery, particularly in the Mackenzie Delta. Of the 17 species important to commercial, domestic or sport fishing in the Northwest Territories, 12 are commonly caught in the region (Table 4.6-6). The most common species harvested are humpback (lake) and broad whitefish, Arctic and least ciscos, inconnu, Arctic char, lake trout, northern pike, and burbot.

The quantities of fish harvested in the Beaufort area, particularly by domestic fisheries, have generally been inconsistently documented.

For the purpose of this document, domestic fisheries include "all subsistence fishing by Indians, Inuit, or persons of mixed blood utilizing traditional methods to provide food for himself, his family, or his dogs" (Fisheries and Environment Canada, 1977b). Commercial fishing is defined as "all fishing for the purpose of sale or barter" (Fisheries and Environment Canada, 1977b). This includes fish sold locally and exported through the Freshwater Fish marketing Corporation (FFMC). Sport fishing is classified as recreation and is not food oriented.

4.6.2.1 Mackenzie Delta and Tuktoyaktuk Peninsula

The domestic fisheries of the Mackenzie Delta region include those of the settlements of Inuvik, Aklavik, Fort McPherson, Arctic Red River, and Tuktoyaktuk. Together they represent one of the most important regions for domestic fishing within the Mackenzie Valley (Withler, 1975). Fishing locations vary slightly from year to year, but major sites include areas along river channels in the Delta and near Tuktoyaktuk, as well as Eskimo (Husky) Lakes, Noell Lake, Sitidgi Lake, and Travaillant Lake.

Domestic catches from the Mackenzie Delta and Tuktoyaktuk Peninsula have been estimated by a variety of investigators since 1960 (Withler, 1975; Corkum and McCart, 1981). Estimates prepared by Wolforth (1966), Sinclair *et al.* (1967), Hunt (1972), DIAND/MPS (1973), Hunt (1973), Jessop *et al.* (1974), Usher (1975), and Olesh (1979) suffer from a lack of uniform data gathering methodology. Overall, domestic fishing has declined in the Mackenzie Delta and elsewhere in response to a number of socio-economic changes over the last 20 years (McCart and Den Beste, 1979).

Since 1978, some efforts have been made to improve the quality of data available to estimate domestic harvests in the Mackenzie Delta, including questionnaires sent to fishermen in the area (Corkum and McCart, 1981). These data indicate that the total domestic harvest was in the order of 100,000 kg annually in 1979 and 1980. On the other hand, data from the early 1960's, while somewhat unreliable,

TABLE 4.6-6

LIST OF FRESHWATER FISH SPECIES IMPORTANT IN DOMESTIC, COMMERCIAL AND SPORT FISHERIES IN THE NORTHWEST TERRITORIES (AFTER FISHERIES AND ENVIRONMENT CANADA 1977a)

	Species Name		Fisheries		
Family	Common	Scientific	Domestic/ Commercial	Sport	Present in Beaufort Region
Salmonidae	Rainbow trout	Salmo gairdneri		+	
	Arctic char	Salvelinus alpinus	+	+	+
	Dolly Varden	Salvelinus malma		+	
	Brook trout	Salvelinus fontinalis		+	
	Lake trout	Salvelinus namaycush	+	+	+
	Lake cisco	Coregonus artedii	+	+	
	Arctic cisco	Coregonus autumnalis	+	+	+
	Least cisco	Coregonus sardinella	+	+	+
	Lake (humpback) whitefish	Coregonus clupeaformis	+	+	+
	Broad whitefish	Coregonus nasus	+	+	+
	Round whitefish	Prosopium cylindraceum	+		+
	Inconnu	Stenodus leucichthys	+	+	+
	Arctic grayling	Thymallus arcticus		+	+
Hiodontidae	Goldeye	Hiodon alosoides		+	
Esocidae	Northern pike	Esox lucius	+	+	+
Gadidae	Burbot	Lota lota	+		+
Percidae	Walleye	Stizostedion vitreum	+	+	+
			12	15	12

indicate annual harvests nearly a full order of magnitude greater than this (Wolforth, 1966; Olesh, 1979).

Recent data presented by Corkum and McCart (1981) indicate that broad and humpback whitefish are the dominant species captured, and that they account for a least 50% of the domestic harvests for all areas combined in the lower Mackenzie region. Other major species include Arctic and least cisco, inconnu, pike, and burbot, which together represent over 25% of the fish captures. Minor species, captured in a few locations depending on available habitat, include Arctic grayling, Arctic char, lake trout, chum salmon, longnose sucker, and Pacific herring (Tuktoyaktuk only).

Arctic char are caught only by residents of Aklavik and Inuvik in the western portions of the Delta (Plate 4.6-1). Fishing pressure for other species, while not distributed evenly, does result in some utilization of the entire Delta. Estimates of the domestic harvest for each Mackenzie Delta management area are presented in Corkum and McCart (1981).

Except for the period from 1967 through 1971, commercial fishing has been documented for the Mackenzie Delta since 1955 (Corkum and McCart, 1981). However, these data suffer from the same inconsistencies as do the domestic fishing data. Recent data indicate that commercial fisheries represent relatively minor proportions of fish harvests and often involve small scale efforts to supply local markets. For instance, data from 1979 indicate that in addition to an estimated 100,000 kg harvested for domestic use, approximately 10,000 kg of fish were exported to areas outside the Delta, while approximately 12,000 kg of fish were sold locally (Corkum and McCart, 1981).

The dominant and preferred species for both local and export commercial markets in the Delta area is the broad whitefish. Although humpback whitefish are also harvested, they usually have too many parasites for commercial use (Corkum and McCart, 1981). Other minor species include ciscos (Arctic and least), inconnu, Arctic char, northern pike, and burbot. Locations of commercial fishing sites are similar to those of the domestic fishery, being largely centred around Delta channels where whitefish populations migrate.

Historically there have been several attempts to

PLATE 4.6-1 *In the western portions of the Mackenzie Delta Arctic char are caught by the residents of Aklavik and Inuvik. Here char are being dried for long-term storage and use.*

establish large scale fish export operations in the Delta region, all of which ended in failure (McCart and Den Beste, 1979). While no records are available of local fish sales prior to 1977, these fish were probably included in early estimates of domestic fishing for the area (Corkum and McCart, 1981).

Little information is available concerning the sport fishery in this region. However, one fishing lodge is located on Sitidgi Lake and operates during summer months only. Other areas for sport fishing include the lakes near Inuvik and Tuktoyaktuk. Residents of all communities in the region periodically angle in the Mackenzie mainstem and in accessible tributary streams.

4.6.2.2 Paulatuk and Surrounding Area

East of the Mackenzie Delta a commercial fishery for Arctic char, was until recently, located at the mouth of the Hornaday River east of Paulatuk. This fishery was the last major commercial operation in the Canadian Beaufort region. The Paulatuk operation began in 1968 with a quota of 5,000 lb (2,270 kg), and had been increased to 15,000 lb. (6,800 kg) dressed (R. Barnes, pers. comm.). It supplied markets mainly in Inuvik and provided a major source of income for several families in Paulatuk. However, this fishery was recently closed due to declines in fish stocks (Corkum and McCart, 1981).

Communities east of the Mackenzie Delta, such as Paulatuk and Sachs Harbour, rely less heavily on fish for domestic needs, but, as in other areas, few accurate records exist which document the harvest. Recent data presented by Corkum and McCart (1981) indicate that Arctic char are the most abundant species caught in the Paulatuk domestic fishery, while whitefish and burbot are increasingly important to residents of Sachs Harbour.

Based on data from outfitters in the region, Corkum and McCart (1981) report that sport fishing comprises a very minor component of the total fish capture east of the Mackenzie Delta. Outfitters report harvest estimates totalling approximately 2,000 lb (910 kg) per year from Hazen Lake, Char Lake, Hornaday River, Sitidgi Lake and Husky Lake. Some incidental sport fishing occurs in the vicinity of Paulatuk and other communities in the region (Corkum and McCart, 1981).

4.6.2.3 Yukon Coast

Domestic fishing along the Yukon coast and on Herschel Island from 1971 to 1973 was estimated by Steigenberger *et al.* (1974). These data indicated that 1,000 to 3,000 Arctic char, ciscos, broad whitefish, and inconnu were taken annually in the most important coastal domestic fisheries. More recent data (1978-1980) suggest that 700 to 1,500 kg of char, ciscos, and white fish are taken annually from Shingle Point (R. Barnes, pers. comm.). Delta communities also report that utilization from this region is limited to incidental harvests during hunting and whaling trips. Arctic char have been harvested from the Firth River drainage and Nunaluk Lagoon in past years (Griffiths *et al.*, 1975), but these areas have not been utilized recently.

The Department of Northern Affairs and National Resources initiated a fishery at Shingle Point on the Yukon coast in 1960. A total of 8,200 kg of unspecified fish were harvested in 1960, and an additional 5,500 kg were harvested in 1961 before closure of the fishery for economic reasons. No other commercial fishing has been conducted in this region to date.

No data were available on sport fishing in this area. Residents of Inuvik and Aklavik report that sport fishing has been conducted for Arctic char in several Yukon streams by hunting parties and by a few fly-in fishermen landing float planes on lakes in the area to fish in nearby streams (Plate 4.6-2).

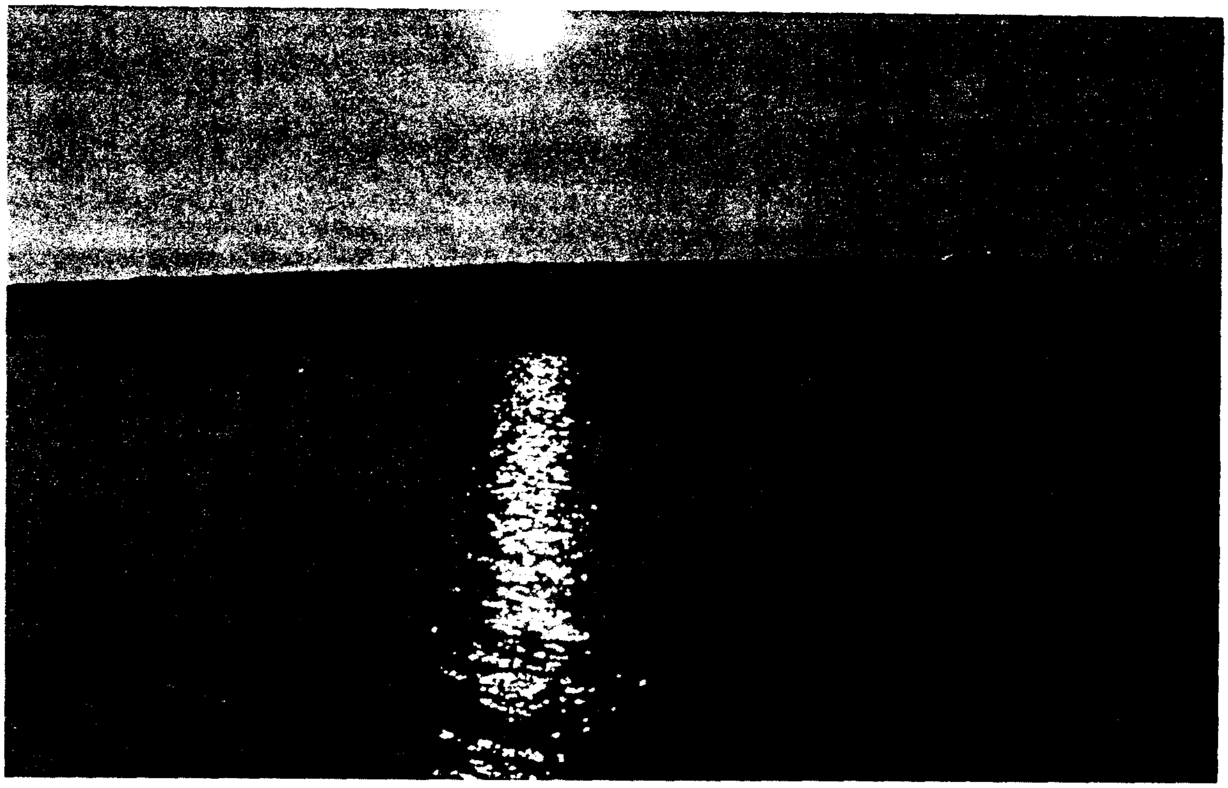

PLATE 4.6-2 *Sport fishing has been conducted in the lakes and streams of the Yukon North Slope by a few fly-in fishermen. (Courtesy, Aquatic Environments Limited).*

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