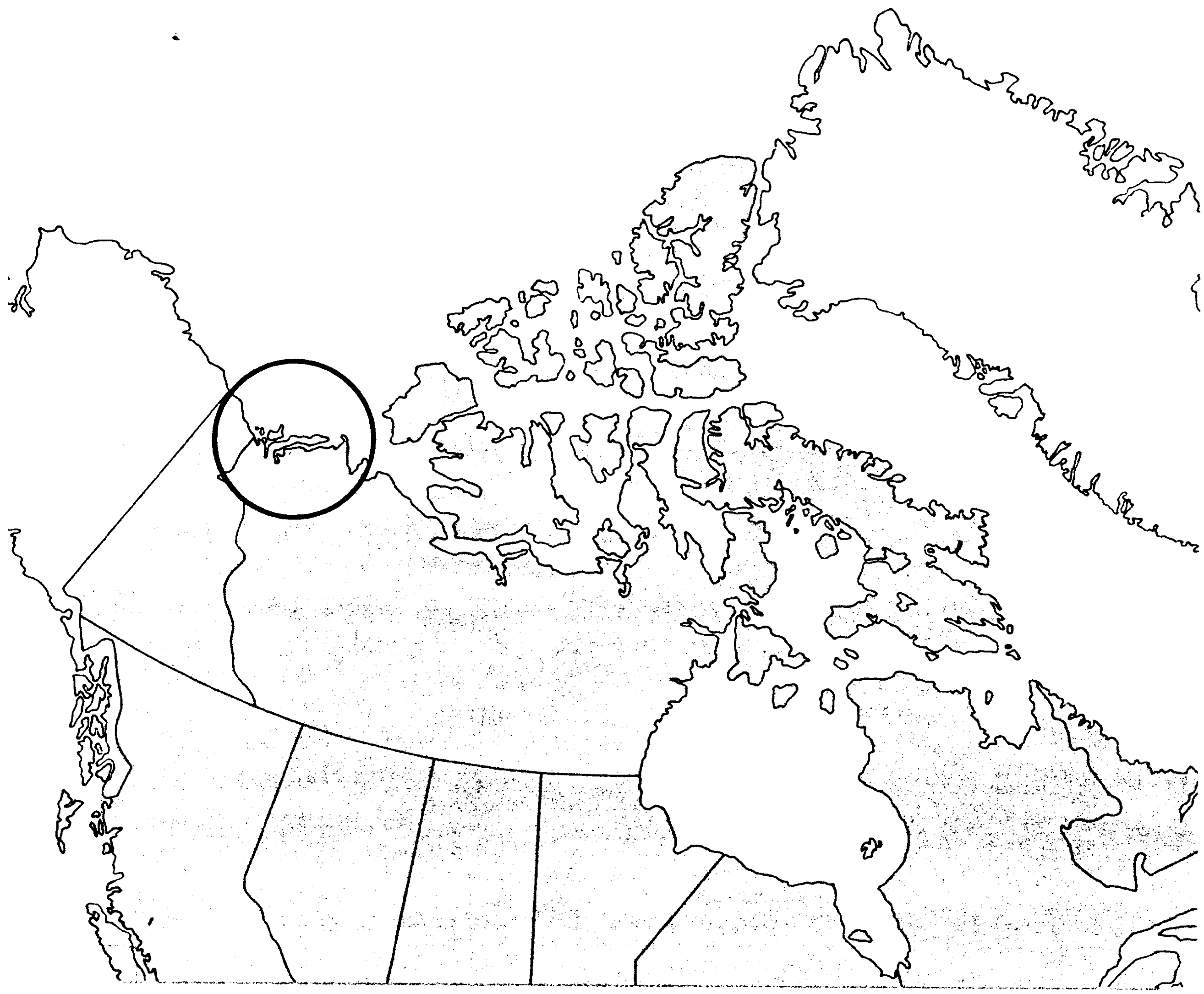
Hydrocarbon Development In The Beaufort Sea - Mackenzie Delta Region



ENVIRONMENTAL IMPACT STATEMENT
1982

VOLUME 3B NORTHWEST PASSAGE SETTING

ENVIRONMENTAL IMPACT STATEMENT

FOR

HYDROCARBON DEVELOPMENT

IN THE

BEAUFORT SEA - MACKENZIE DELTA REGION

VOLUME 3B
NORTHWEST PASSAGE 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 3B of the Environmental Impact Statement provides the environmental setting for the marine shipping corridor which lies to the east of the Beaufort Sea. The region extends from approximately Banks Island through Viscount Melville Sound, Lancaster Sound, Baffin Bay and Davis Strait, to 60° north latitude in the Labrador Sea (Figure 1). Emphasis has been placed on those subjects deemed to be most relevant for the purposes of assessing possible impacts of shipping operations on the environment (Volume 4) and for addressing associated socio-economic issues (Volume 5). The information has also been used to evaluate the potential impacts of hypothetical major oil spills originating from ships (Volume 6), and to identify 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 detail to permit a satisfactory evaluation to be completed. For information on the Beaufort Sea portion of the eastern shipping corridor and the western corridor, the reader is referred to Volume 3A. Additional information is provided in various supporting documents to the Environmental Impact Statement, as well as the literature cited in the text.

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

LGL Limited -
- Marine Birds
- Mammals
- Fish
- Lower Trophic Levels
- Resource Use
- Special Areas

D.F. Dickens Engineering Consulting -
- Ice

Meteorological and Environmental Planning Ltd (MEP) -
- Surface Weather and Wind Waves

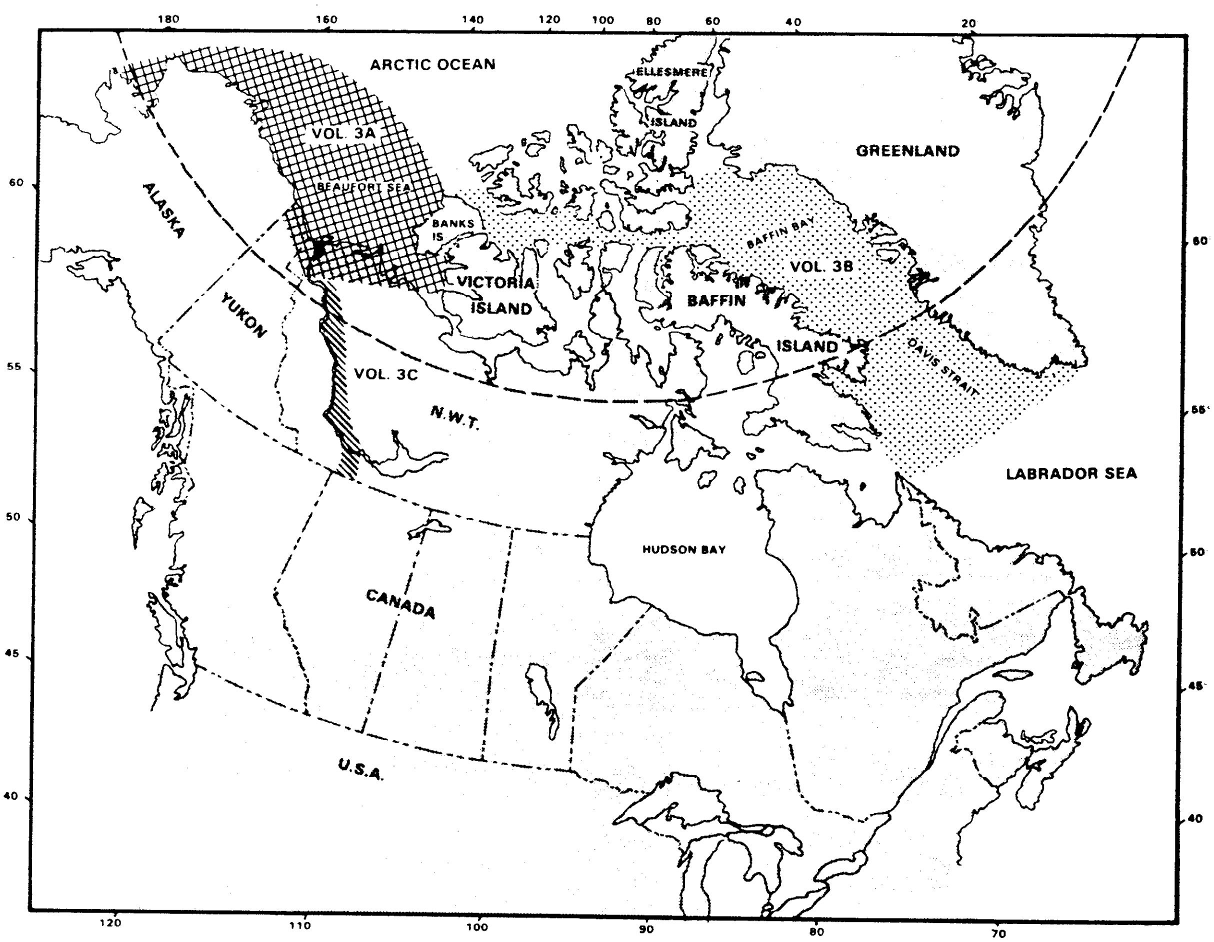

FIGURE 1 *Approximate boundaries of the three geographic regions described in the Environmental Setting, Volumes 3A, 3B and 3C.*

Arctic Sciences Limited -
Water Masses and Their Movements

Woodward-Clyde Consultants -
The Shores

ESL Environmental Sciences Limited -
General Editing

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 marine shipping corridor through the Northwest Passage (Figure 1-1). The information presented here and in Chapter 2 forms part of the background for assessing the potential impacts of commercial shipping and associated activities in the region (Volume 4).

Separate sections review ice conditions, surface weather and wind waves, water masses and their movements, bathymetry and the shore zone character of the region. For information on the Beaufort Sea portion of the eastern shipping corridor and the western corridor, the reader is referred to Volume 3A. 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

Marked regional differences in ice conditions occur within the proposed eastern tanker corridor through the Northwest Passage as a result of oceanographic factors and geography. Due to these differences, ice conditions are described separately from west to east for Prince of Wales Strait, Viscount Melville Sound, Barrow Strait, Lancaster Sound, Baffin Bay and Davis Strait. This is the principal or preferred tanker route from the Beaufort Sea. There are two secondary branches to the preferred route. One branch could route tankers around the west side of Banks Island and through M'Clure Strait instead of through Amundsen Gulf and Prince of Wales Strait. The other could route tankers through Prince Regent Inlet, Fury and Hecla Strait and Foxe Basin, bypassing Lancaster Sound and northern Baffin Bay (see Section 1.4 regarding bathymetric constraints on this branch). Ice conditions for these optional branches are also described.

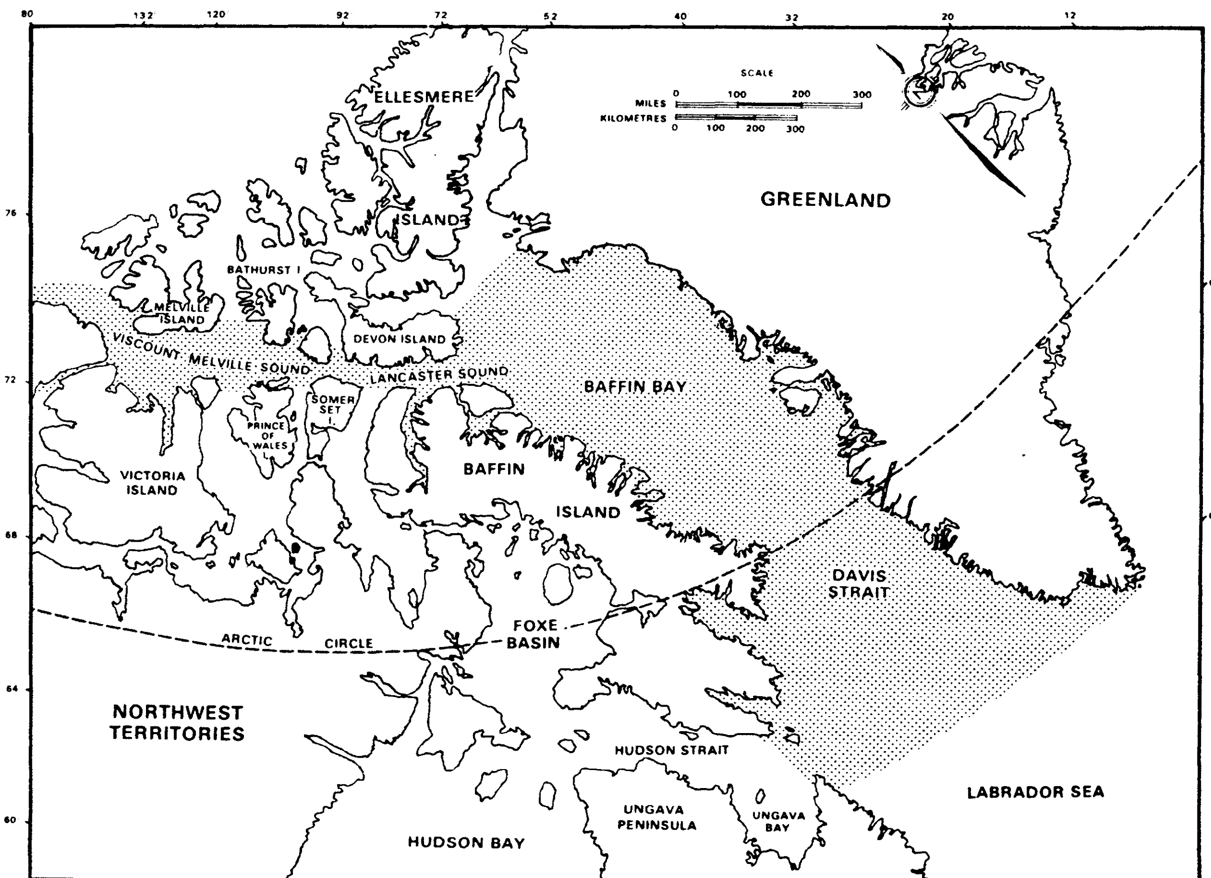

FIGURE 1-1 *Approximate boundaries of the Northwest Passage region described in Volume 3B.*

A summary of ice conditions along the preferred route is shown in Figure 1.1-1.

1.1.1 PRINCE OF WALES STRAIT

In winter, Prince of Wales Strait is expected to have mostly landfast first year ice, with multi-year ice concentrations ranging from 4/10ths in the area north of the Princess Royal Islands to less than 1/10 in the southern portion of the Strait. There is a 30% probability of encountering winter multi-year ice concentrations of 6/10ths in the northern strait, compared to a less than 5% chance of similar conditions to the south. Prince of Wales Strait does not contain any old ice indigenous to the area in the winter. There have been no studies of ice surface roughness in the strait, although aerial photographs show a relatively featureless flat ice cover in the south, progressing to ice with about 1 ridge/km in the nôrthern Prince of Wales Strait.

A maximum winter first year ice thickness of 200 to 210 cm can be expected in these waters due to its early stabilization in the confines of the narrow channel in the fall. This is about 30 cm thicker than typical ice in the Beaufort Sea transition zone (Hoare, 1980).

Prince of Wales Strait breaks up from south to north beginning in mid July. Starting in August and becoming worse in September, old ice from Viscount Melville Sound can temporarily clog Prince of Wales Strait with floes up to 15 km in diameter (Dickins, 1978).

Some old floes continue to move south into the strait after new ice has started to form in the northerly sections in late September. This drift of old ice gradually decreases until the expected winter ice composition in the strait is reached in mid October. The earlier solidification of the northern strait (by up to two weeks) effectively prevents the drift of much old winter ice into the southerly two-thirds of the strait.

1.1.2 VISCOUNT MELVILLE SOUND

Viscount Melville Sound has consistently higher multi-year ice concentrations and less open water than any other water body along the main eastern tanker route. The western end of the sound has the most severe winter ice conditions along the entire route. Summer ice concentrations in these waters rarely drop below 6/10ths, and then only for several weeks. Multi-year ice is heaviest along the most southerly 30 km of the sound, with old floes averaging about 5 km in diameter and some as large as 40 km in diameter. Between 1960 and 1977, there was considerable summer open water in the western part of Viscount Melville Sound in only three years (1962, 1963, 1971). In spite of this heavy ice pack, there is still some movement of the ice well into November, and refrozen leads of thin ice have been observed on satellite imagery as early as May (Dickins, 1978). Even in a poor ice year such as 1974, distinct east-west leads have been observed about 10 km apart between Victoria and Melville islands in late September. If such leads remained through freeze-up, transits through areas of high concentrations of old ice would be easier for icebreaking vessels.

The winter ice cover in the sound generally does not move from mid November until late July. Consequently, first year ridges are formed early in the growth cycle. An overflight in 1978 indicated 1.5 ridges/km in northern Viscount Melville Sound (INTERA, 1978). During the same year, an east-west ice traverse between Resolute and Bridport Inlet documented first year ridge frequencies of less than 0.2 ridges/km. Mean ridge height was 1.9 m and mean keel depth of these ridges was 6.3 m with a maximum keel depth of 10.3 m. For these first year ridges, the ice was consolidated to a depth of only 4 m leaving the remaining 70% of the submerged ice in the form of unconsolidated blocks. In addition, ice roughness generally decreased moving west from Barrow Strait (Edwards *et al.*, 1978).

An April 1979 north-south traverse between Melville Island and Victoria Island showed two distinct ice zones (Markham, 1980). The southern most stretch of 65 km was composed primarily of very distorted multi-year ice. Typical horizontal ridge keel spacings were in the range from 30 to 50 m, with most keels varying in depth from 2.5 to 5 m. Ice thickness was greater than 3 m in 51% of the areas examined. Ice less than 2 m thick (assumed to be first year ice) covered only 9% of this southern section. The northerly 60 km of the traverse was over mainly second year ice, with only 5% of it being thicker than 3 m (Markham, 1980).

The only known multi-year floe size data were extrapolated from an October photo-mosaic of Southern Viscount Melville Sound (NORCOR, 1977). At this time, the ice concentration was 6/10ths, consisting of old ice. Thirty-five percent of the 1,020 floes examined were less than one shiplength in diameter. However, over half the old ice present was in the form of 10 floes with a diameter greater than 5 km (NORCOR, 1977).

Break-up in Viscount Melville Sound begins in early August within 20 km of the northern shore. Ice in the western end starts to fracture about two weeks later, and break-up progresses to the centre of the sound by mid September. During the short summer, old ice tends to drift south east through the sound at a speed of about 6 km/day (Marko, 1977). Ice concentrations decrease below 5/10ths for short periods, but

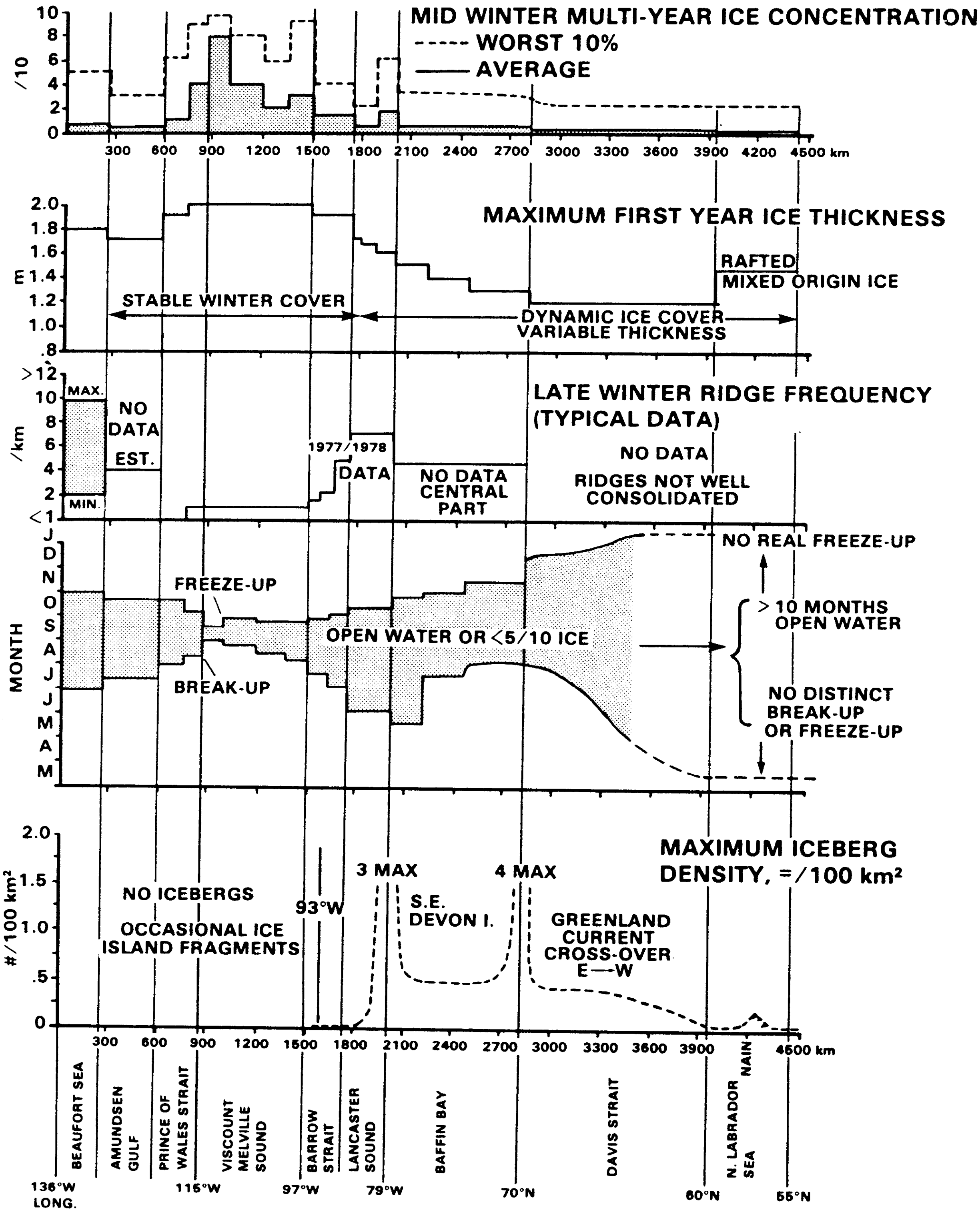

FIGURE 1.1-1 *Ice conditions from the Beaufort Sea through to the North Labrador Sea (Source: Dickins 1978). The worst ice conditions are experienced in Viscount Melville Sound and the northern exit of Prince of Wales Strait.*

large daily changes in concentration are common depending on local winds. In some years in September, a band of open water about 20 km wide may extend westward along the Melville Island shore past Bridport Inlet (Plates 1.1-1 and 1.1-2). At this time,

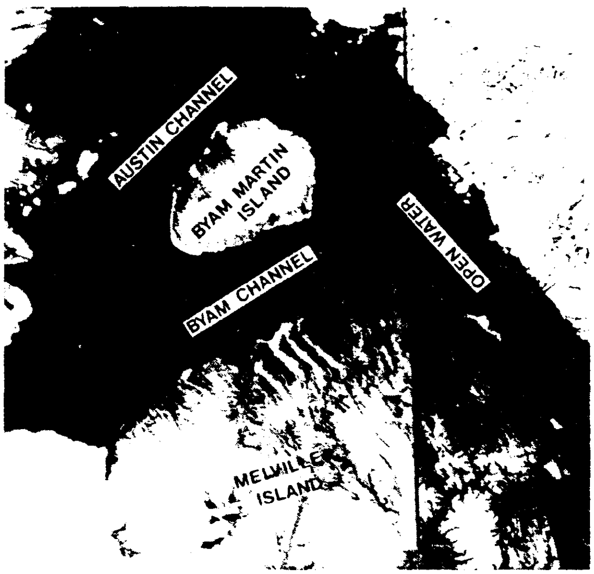

PLATE 1.1-1 *Open water in northern Viscount Melville Sound shown in a LANDSAT photograph, 30 August 1976 (Courtesy: John Marko).*

the channels to the north can open sufficiently to allow a stream of old ice to move south through Byam Martin Channel into the northern reaches of the sound. However, such an influx of significant quantities of old ice into the sound from the Sverdrup Basin is a spasmodic event. Such an influx did occur in September 1962 when the ice island T3 and multi-year floes moved south to create a partial block that winter along the northerly shipping route (see Figure 1.1-2). Again in September 1977, a large multi-year plug in Byam Martin Channel broke free, allowing many old floes to congest Viscount Melville Sound. Normally in September, multi-year ice from the north drifts south. Then driven further south by prevailing winds in early October, a 10 to 20 km wide band of predominantly first year ice is allowed to form south of Melville Island stretching as far west as Bridport Inlet (Plate 1.1-3).

Ice conditions in Viscount Melville Sound from June to October have been evaluated along four routes connecting Prince of Wales Strait and Barrow Strait, using a criterion of minimum old ice encounter between 1972 and 1980 (Figure 1.1-2). Of the fifty occasions examined, a northerly route would have been chosen 58% of the time, central Viscount Melville Sound 24% of the time, and the direct shortest route 18% of the time (Plate 1.1-4). A southerly route offered definite advantages only once, during the winter of 1980-81. Table 1.1-1 shows that conditions generally improve from west to east along the northerly route. A shift to an arbitrary central track would increase average multi-year ice concentrations to over 6/10ths along the entire Viscount Melville Sound route.

1.1.3 BARROW STRAIT

In Barrow Strait there is a transition of ice types, from the relatively static older winter sheet in Viscount Melville Sound to the dynamic first year ice of Lancaster Sound. There is a mid winter demarcation between landfast and moving ice which most often falls at 90° W longitude, between Maxwell Bay on Devon Island and Prince Leopold Island (place-names are shown in Figure 1.1-2). However, there can be wide fluctuations in the position of the land-fast ice edge, ranging from 95°W near Resolute in 1964, 1974 and 1976, to about 82°W off Navy Board Inlet in 1970, 1978 and 1979 (Sowden, 1980). Figure 1.1-3 shows break-up and freeze-up ice conditions observed in Barrow Strait and Lancaster Sound during 1975 and 1976. There are two distinct ice zones in Barrow Strait. Between Resolute and Maxwell Bay, ice is only slightly more severe than in the west end of Lancaster Sound. Normally continuous ice covers Barrow Strait from late November until early July. The eastern end of Barrow Strait acts as a winter source of new ice which subsequently drifts into Lancaster Sound and Baffin Bay. West of Resolute, conditions are more severe. The small islands such as Young, Lowther and Griffith tend to stabilize the ice, and lead to a relatively early consolidation usually in October, as well as delayed break-up in late July (approximately 3 weeks after the eastern strait break-up). Maximum first year ice thickness in Barrow Strait is about 200 cm, with thinner ice occurring towards the east, as a result of its later consolidation in the early winter.

Multi-year ice in northern Barrow Strait does not normally present any obstacle to winter navigation. The western part of the strait, due to its proximity to Viscount Melville Sound, has about twice as much old ice as the area between Resolute and Maxwell Bay. However, actual multi-year concentrations are only about 1/10th, with less than a 5% probability of exceeding 7/10ths at any time of year. Southern Barrow Strait normally contains between 4/10ths and 6/10ths of old ice from October to December (Arctic Pilot Project, 1980).

First year ridges in Barrow Strait have a similar geometry and are consolidated much like those found in Viscount Melville Sound. Aerial surveys by INTERA (1980) showed wide differences in the number of first year ridges per km between observations in 1977 and 1978. There was also a distinct trend toward increasing ridge frequency in an easterly direction through Barrow Strait, from winter

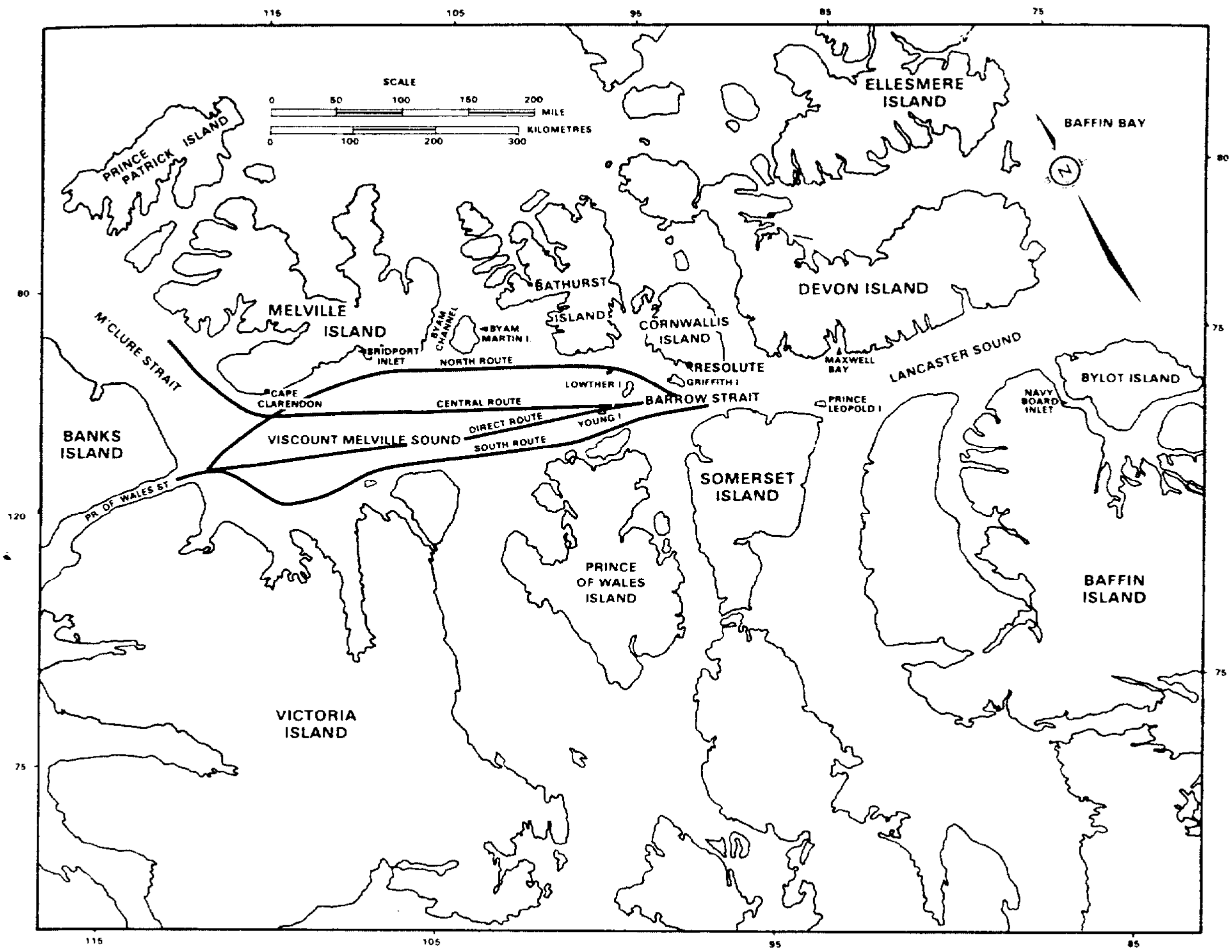

FIGURE 1.1-2 *Alternate tanker routes in Viscount Melville Sound (Source: Dickins, 1981a). Using a criterion of minimum old ice encounter between 1972 and 1980, the north route would have been chosen 58% of the time, the central 24% of the time, and the direct shortest route 18% of the time. The south route was best only once, in the winter of 1980-81.*

PLATE 1.1-2 *Open water off Melville Island in northeastern M'Clure Strait near Dundas Peninsula, late August, 1961.*

PLATE 1.1-3 *First year ice in northwestern Viscount Melville Sound in April, 1968.*

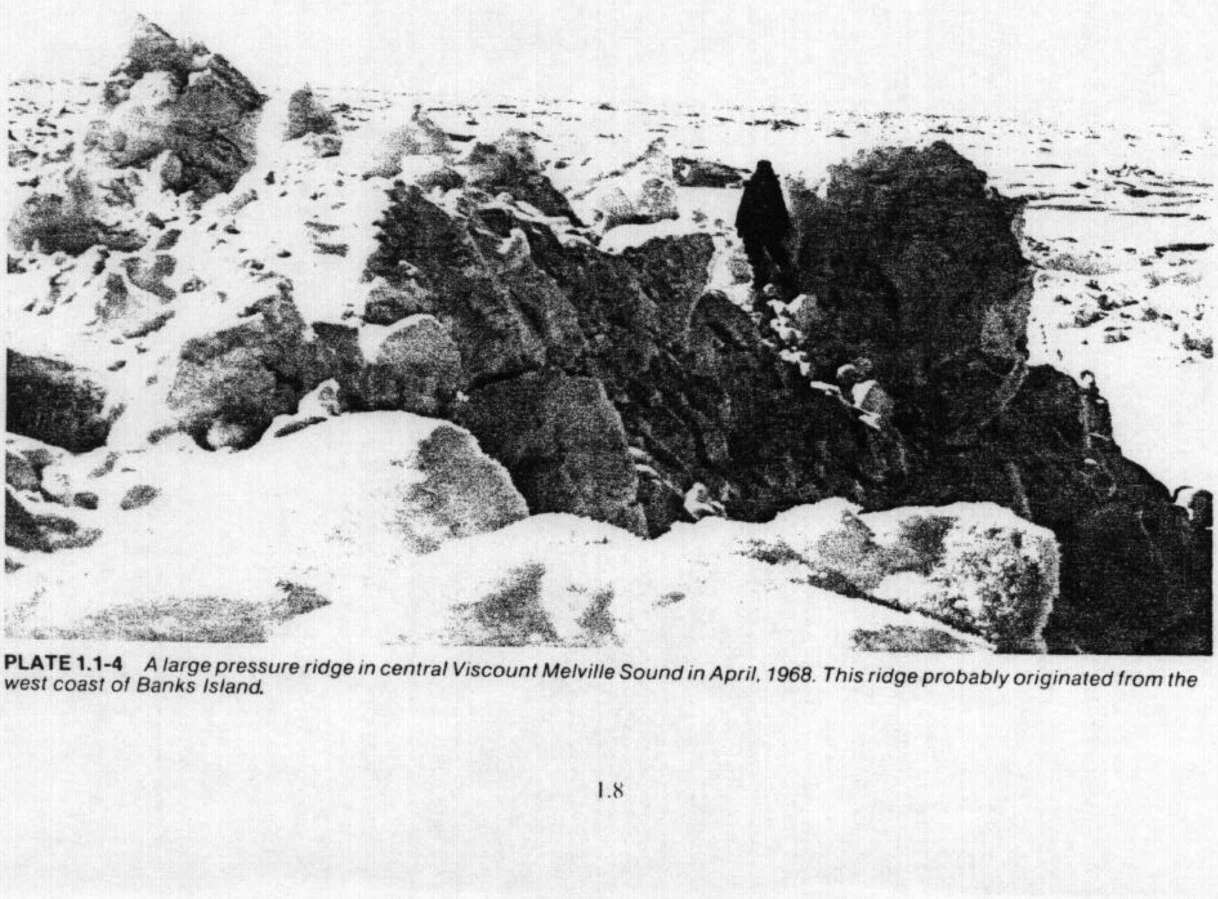

PLATE 1.1-4 *A large pressure ridge in central Viscount Melville Sound in April, 1968. This ridge probably originated from the west coast of Banks Island.*

TABLE 1.1-1

VISCOUNT MELVILLE SOUND ICE CONDITIONS ALONG THE NORTH ROUTE SHOWN IN FIGURE 1.1-2

Section	Break-Up Dates	Freeze-Up Dates	Mean Winter Multi-year Conc. /10th	Probability of Multi-year Conc. >6/10ths	Maximum First Year Thickness (cm)
E. Viscount Melville (Lowther I. to Byam Martin)	Aug 10 ± 10	Sept 28 ± 12	3	.12	200
Central Viscount Melville (Byam Martin to Bridport)	Aug 17 ± 16	Sept ± 10	2	.08	205
N.W. Viscount Melville (Bridport to C. Clarendon)	Aug 25 ± 30	Oct 1 ± 20	4	.27	205
W. Viscount Melville (Melville I. to Pr. of Wales Str.)	Aug 25 ± 20	Sept 15 ± 10	7	.7	200

Source: Dickins, 1981a

means of 1.8 to 4.5 ridges/km, respectively. Mean ridge heights ranged from 0.92 to 1.13 m, smaller than those in the Beaufort Sea.

Although break-up in eastern Barrow Strait normally begins in May when major north-south cracks occur, ice concentrations do not fall below 5/10ths until early July (NORCOR, 1977). Eastern Barrow Strait experiences both an earlier and much more variable break-up time than the western strait. Between 1961 and 1974, eastern break-up dates ranged from March 20 (1974) to July 20 (1967), while equivalent dates for the western section were between July 10 (1962) and August 20 (1965) (Lindsay, 1977). Even in the least ice months of August and September, the strait south of Cornwallis Island has average ice concentrations greater than 4/10ths, while at the same time, the east end has less than 2/10ths ice cover (NORCOR, 1977).

In summer, the ice in Barrow Strait generally drifts to the east at speeds of about 12 km/day (Figure 1.1-3). As in Viscount Melville Sound, pack ice tends to concentrate toward the south shore where the fastest eastward drift rates occur (Marko, 1977).

Icebergs occur infrequently in Barrow Strait, with less than 6% of 1,400 icebergs sighted between 1958 and 1976 in the Lancaster Sound region being observed west of 86° (Figure 1.1-4). Only on rare occasions have icebergs been sighted west of Wellington Channel (Milne and Smiley, 1978).

1.1.4 LANCASTER SOUND

The Lancaster Sound ice regime is much more dynamic throughout the year than in the rest of the Northwest Passage. In December and January, the ice in Lancaster Sound is similar in many respects to the 'North Water' of Baffin Bay. Both have open water and thin ice where the general water flow is away from a stable and landfast edge. In Lancaster Sound, the longitude of this edge varies from year to year but its most usual position is across the sound between Prince Leopold Island and Maxwell Bay.

Throughout the winter new ice forms east of the landfast ice edge and drifts with prevailing currents toward Baffin Bay (Figure 1.1-3). Until early January, ice in Barrow Strait and Wellington Channel can also contribute some ice to the sound. Prince Regent Inlet, which usually does not have a landfast edge across its entrance until April, acts as the second most important source of new ice in Lancaster Sound throughout much of the winter.

During a typical winter in Lancaster Sound, average ice thicknesses can be up to 200 cm near the landfast

EARLY NOVEMBER　　　　EARLY JANUARY

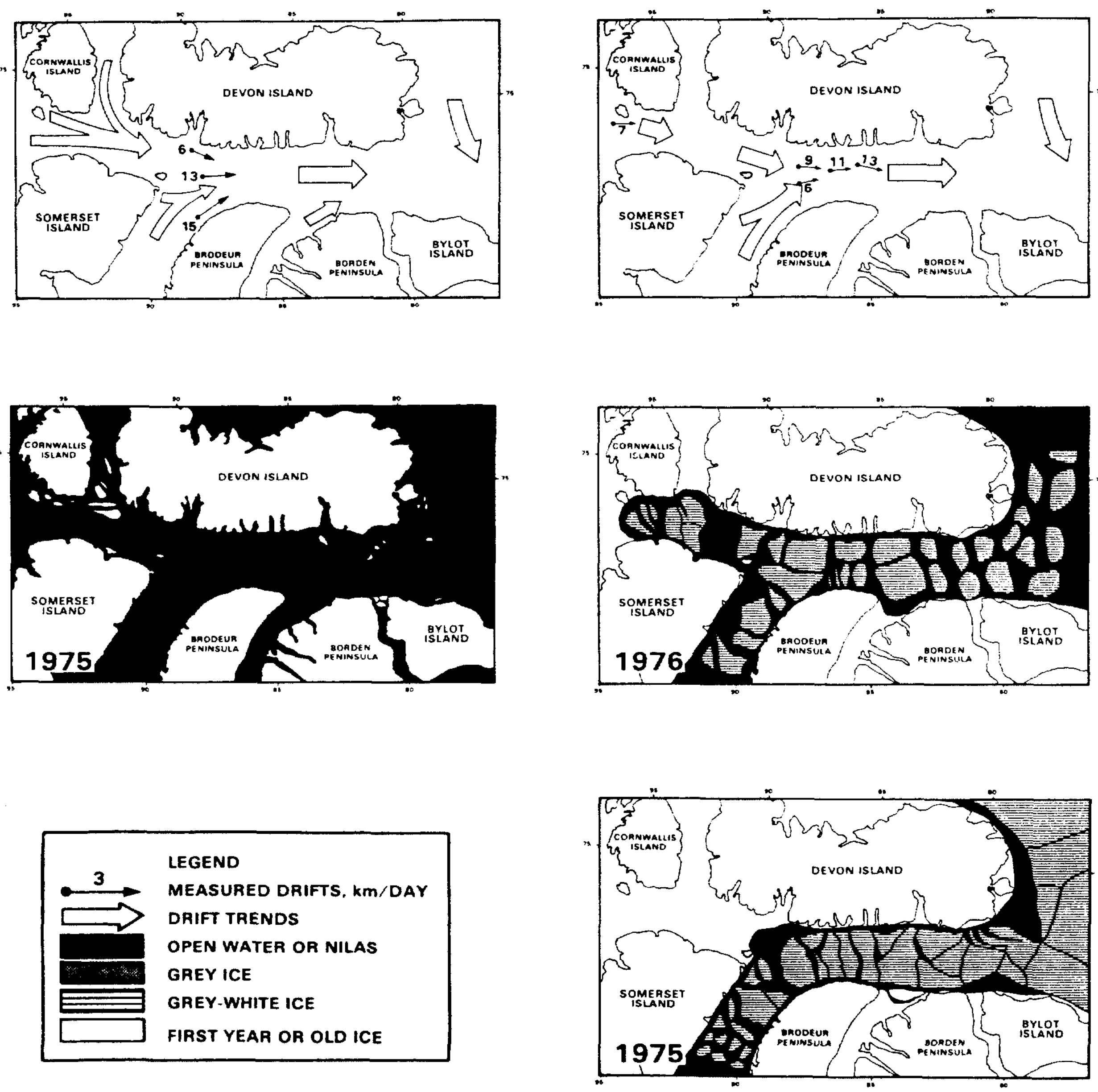

FIGURE 1.1-3 *Ice freeze-up and break-up patterns in Barrow Strait and Lancaster Sound in 1975 and 1976 (from Milne and Smiley, 1978). From late November until mid June a landfast ice edge forms in Barrow Strait or western Lancaster Sound. Its usual position is between Prince Leopold Island and Maxwell Bay. The net ice drift in Lancaster Sound in all seasons is eastward into Baffin Bay.* *(Continued on the next two pages.)*

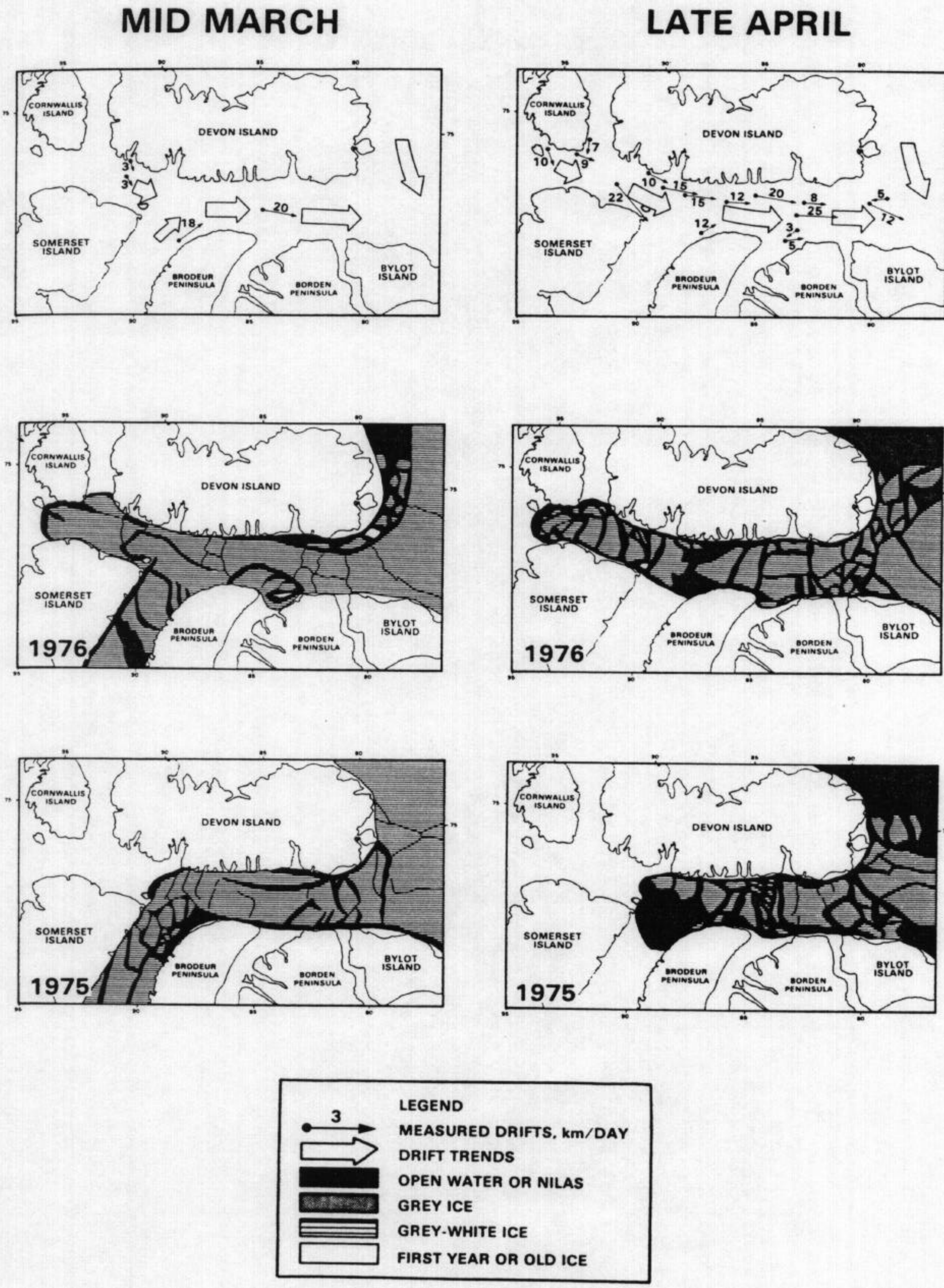

FIGURE 1.1-3 *(Cont'd.)*

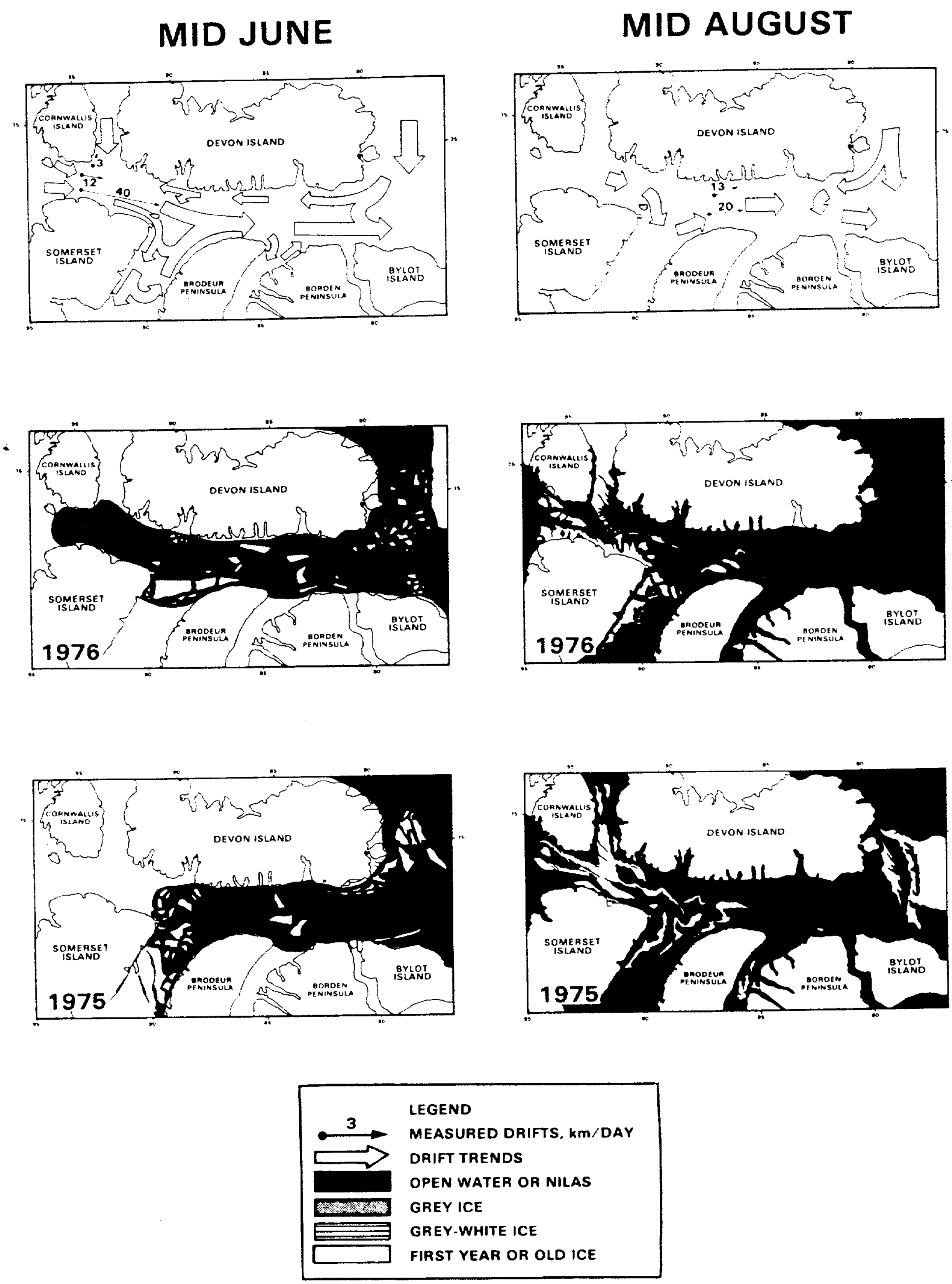

FIGURE 1.1-3 *(Cont'd.)*

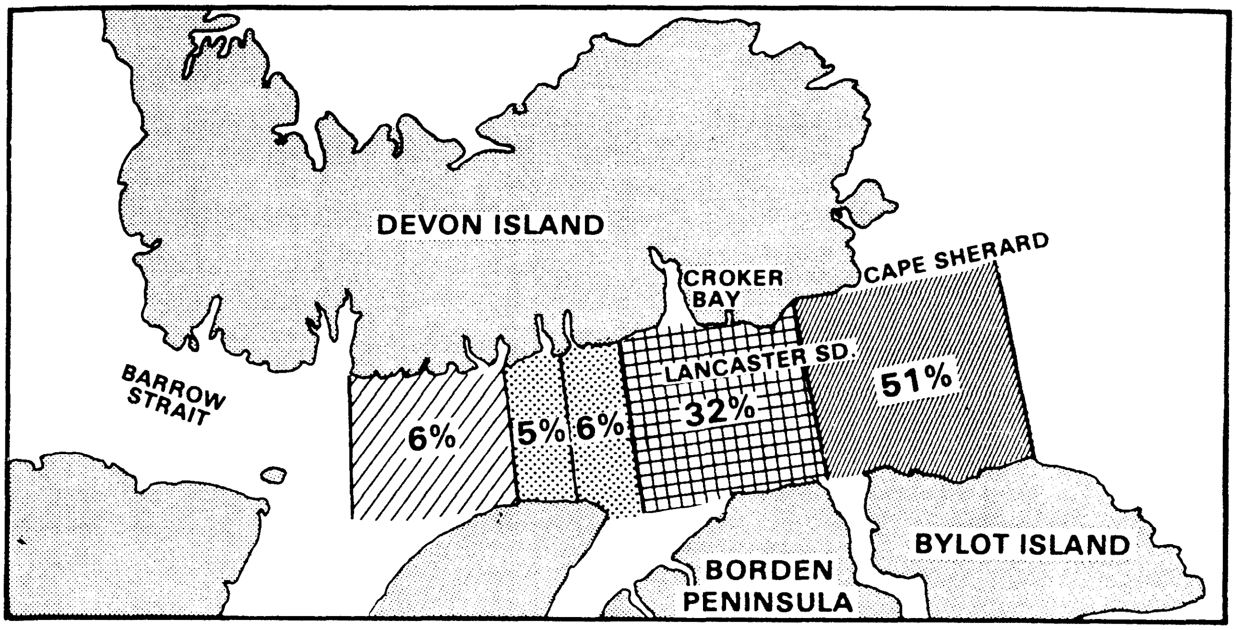

FIGURE 1.1-4 *Percentage of icebergs recorded by area within Lancaster Sound during 1958-1976 ice patrols. (Source: Milne and Smiley, 1978). Icebergs occur infrequently in Barrow Strait. Most icebergs move westward past Cape Sherard, then most turn south and leave Lancaster Sound eastward along the north shore of Bylot Island.*

ice edge in the west, to a complete range of thicknesses further east, described as nilas and white ice. For example, in Lancaster Sound ice thicknesses observed during the Manhattan voyage in May 1970 ranged from 25 to 168 cm (Billelo and Bates, 1972).

Winter multi-year ice concentrations in Lancaster Sound are typically less than 1/10th, with the bulk of this ice being concentrated in the middle and southern portions of the sound.

The number of first year ridges reaches a maximum of 5.6 ridges/km in Barrow Strait and increases to about 7.4 ridges/km in Lancaster Sound. These data were collected during a year when the stable ice edge was located much further east than normal. Normally, the number of first year ridges in the sound would be expected to reach about 10 to 12 ridges/km.

During May, the ice loosens and patches of open water start to develop along the southern coast of Devon Island. By mid June, there is a growing area of open water in the northern part of Lancaster Sound which joins up with the 'North Water' in Baffin Bay (Figure 1.1-3). Ice concentrations remain higher in the south until the Sound is completely open in July. Old ice incursions in summer from Kane Basin, Sverdrup Basin and Viscount Melville Sound can create areas with multi-year ice concentrations up 5/10ths during September and October. However, the steady easterly ice flow out of the Sound results in insignificant winter concentrations of old ice (Sowden, 1980).

Available information shows that icebergs move westward past Cape Sherard on Devon Island at drift rates up to 50 km/day. The majority of these bergs turn south by the time they reach 84°W, and leave Lancaster Sound from the east along the north shore of Bylot Island. However, many icebergs get caught in a complex series of current gyres in the centre of the entrance to Lancaster Sound for a week or more, before finally being carried out into Baffin Bay.

Between 1958 and 1976, nearly 83% of all iceberg sightings in Lancaster Sound were east of Croker Bay (Figure 1.1-4; Milne and Smiley, 1978). Summer iceberg densities north of Bylot Island can be high. In August 1949, the U.S. Coast Guard sighted an average of 1 berg every 35 km^2 in a 60 km wide band spanning the sound (Pilot of Arctic Canada, 1970).

The summer open water period in Lancaster Sound varies from about 90 days off Maxwell Bay to 130 days in the east. By mid October, the water surface is usually 7/10ths or more covered with new ice.

1.1.5 BAFFIN BAY

Approximately 20% of the proposed eastern tanker route is through Baffin Bay, where there is a wide range of ice and iceberg concentrations and movements. This section places greatest emphasis on a central routing shown in Figure 1.1-5, while relating ice conditions along this route to the bay as a whole.

The major factors controlling the ice regime of Baffin Bay are: the relatively warm, north flowing West Greenland current on the eastern side; the colder,

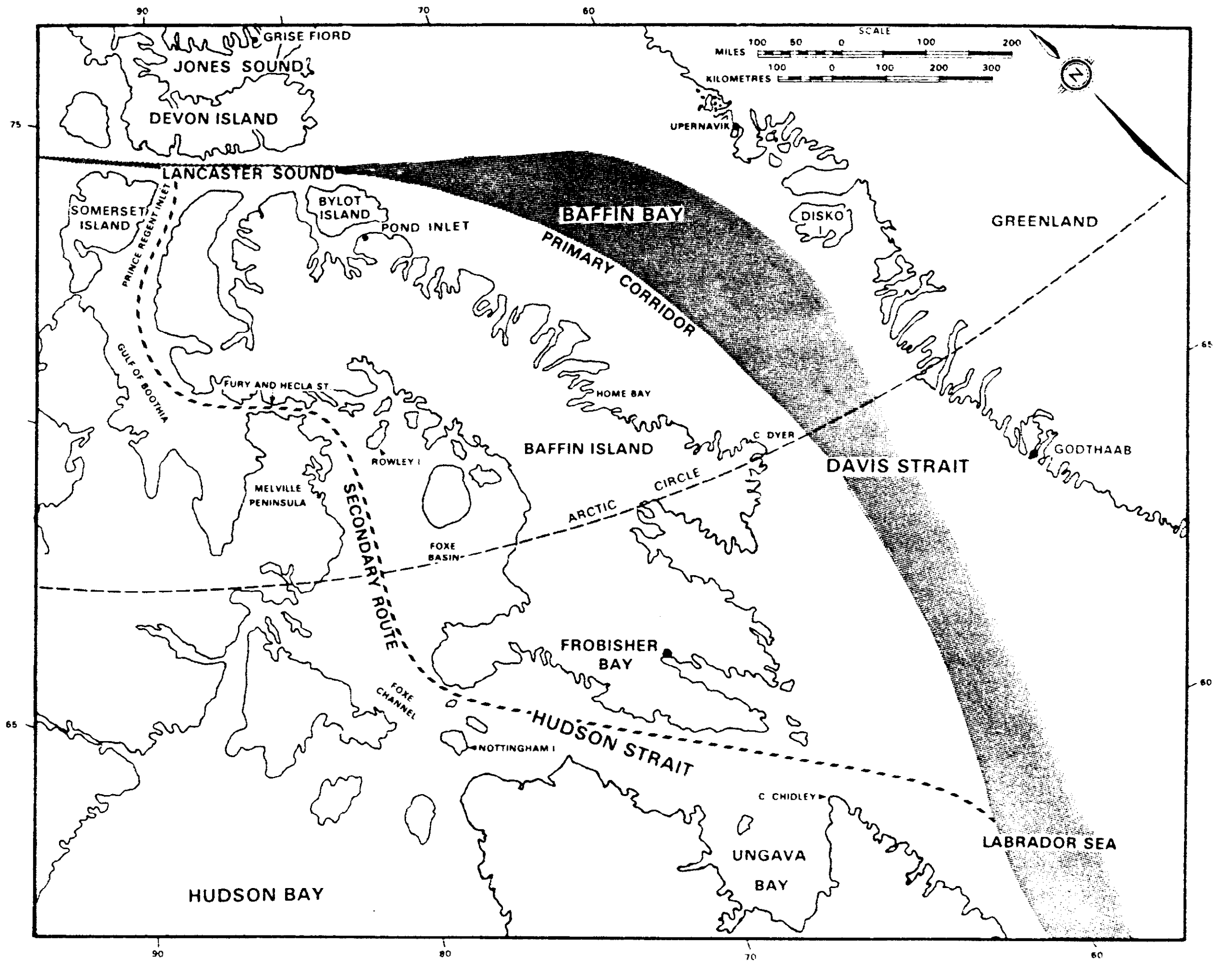

FIGURE 1.1-5 *The primary tanker corridor in Baffin Bay and Davis Strait. A secondary route (for smaller vessels) is through Prince Regent Inlet. Fury and Hecla Strait and Hudson Strait. This secondary route requires a more comprehensive set of soundings to determine whether or not it is a useful alternative.*

south flowing Canadian current on the western side; and a major polynya, the 'North Water' in the northern part of Baffin Bay (Pilot of Arctic Canada, 1970).

Between November and May, central Baffin Bay is mostly covered with first year ice less than 130 cm thick (Figure 1.1-6). Due to pressuring and relaxation of the first year ice, there is always at least 10% new, or young ice of varying thicknesses. The general water circulation causes a southerly ice drift along the east Baffin shore all winter, and there is a shear-zone lead which parallels the narrow band of landfast ice attached to Baffin Island. This drift results in generally thicker floes in southwest Baffin Bay than further north.

In winter, multi-year ice normally occurs in trace amounts although in years with most ice, old ice can accumulate in patches of less than 4/10ths coverage near the centre of Baffin Bay. These old floes drift southward from Nares Strait and Smith Sound at a rate of about 5 degrees latitude per month, so that on average, most multi-year ice exits from Baffin Bay by November or December. The timing of these old ice intrusions depends on when an ice bridge forms across Smith Sound to create the 'North Water' (Figure 1.1-6). Multi-year ice thickness data for Baffin Bay are sparse and inconsistent. Any old floes which last long enough to penetrate Baffin Bay are probably remnants of highly deformed ice, and consequently have various thicknesses. Estimates of average maximum old ice thickness range from 1.8 m (MAREX, 1974; NORCOR, 1977) to 3.3 m (Arctic Pilot Project, 1980). On-ice surveys of ridges in Baffin Bay have not yet been made public.

Near the Greenland coast of Baffin Bay, measurements of the number of ridges per km (ridge frequency) made in the winter of 1977-78 ranged from about 1 ridge/km in Melville Bay to over 5 ridges/km off Upernavik. Near the entrance to Lancaster Sound, first year ridges tended to be about 10% greater in mean height (about 1.0 m) than in other areas (INTERA, 1978). Ridges in Baffin Bay are not

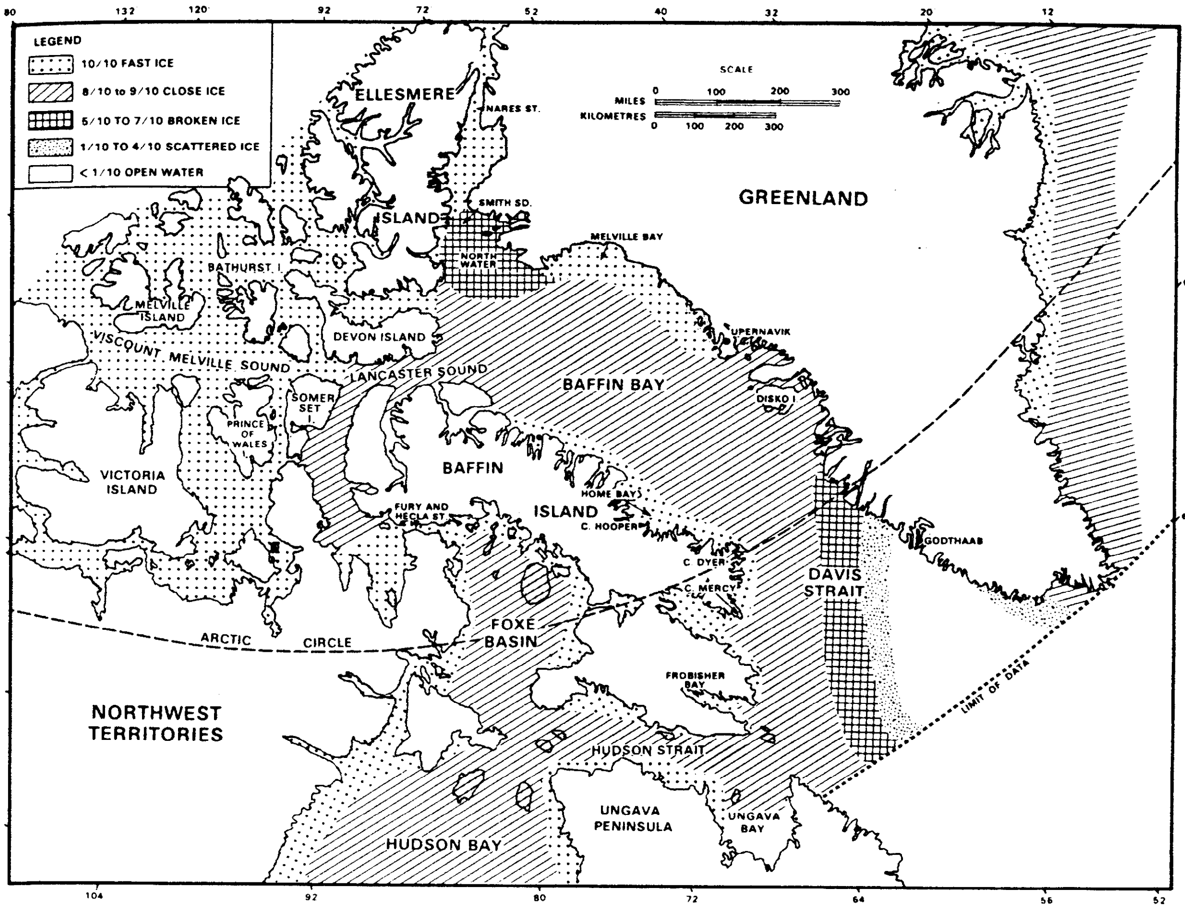

FIGURE 1.1-6 *Average ice conditions during March, the month with the maximum extent of ice cover (From: Arctic Pilot Project. 1980). About 20% of the eastern tanker route is through Baffin Bay. Factors controlling the ice are: the relatively warm north flowing west Greenland current on the eastern side; the cold south flowing Canadian current on the western side, and the major polynya, the North Water in northern Baffin Bay.*

as well consolidated as in more northerly Arctic areas: mean ridge height and ice block sizes are much less than those in the Arctic Islands or the Beaufort Sea. Ridge frequency and intensity are extremely variable in both space and time with the most severe ridging occurring in the shear zone along the Baffin Island shore.

Break-up in Baffin Bay is greatly enhanced by the southward expansion of the 'North Water.' By May, this open water area has usually expanded to include the entrance to Lancaster Sound, while at the same time the warmer current on the Greenland coast begins to form a lead northward past Disko Island. A nearly ice free channel is normally present from Godthaab to Lancaster Sound by early July, while the central Baffin pack remains at over 8/10ths ice coverage. This central pack melts more rapidly in the north than in the centre of the Bay as a result of solar heated water moving south from the 'North Water.' By mid August, the so-called 'middle pack' is reduced to a patch centred on longitude 64°W, and extending from Cape Mercy and Cape Hooper on Baffin Island as far north as 73°N latitude. Within two weeks, this remaining pack is reduced to a concentration of less than 3/10ths and is present as belts of old floes aligned with prevailing winds. Complete clearing in central Baffin Bay usually occurs by mid September, but in cooler summers, remnant old floes can survive and collect further south between Home Bay and Cape Dyer in Davis Strait (Markham, 1980).

Freeze-up in central Baffin Bay is a slow process with great annual variability, but generally progresses from northwest to southeast with first stable new ice cover appearing between early October and mid November.

Icebergs, originating principally from west Greenland glaciers north of Disko Bay, are calved in late summer and arrive off Devon Island in early autumn (Plate 1.1-5). It can take up to three years for a heavy accumulation of icebergs in northern Baffin Bay to clear. Large numbers of bergs enter Lancaster Sound, cross it, drift back out and then travel south along the

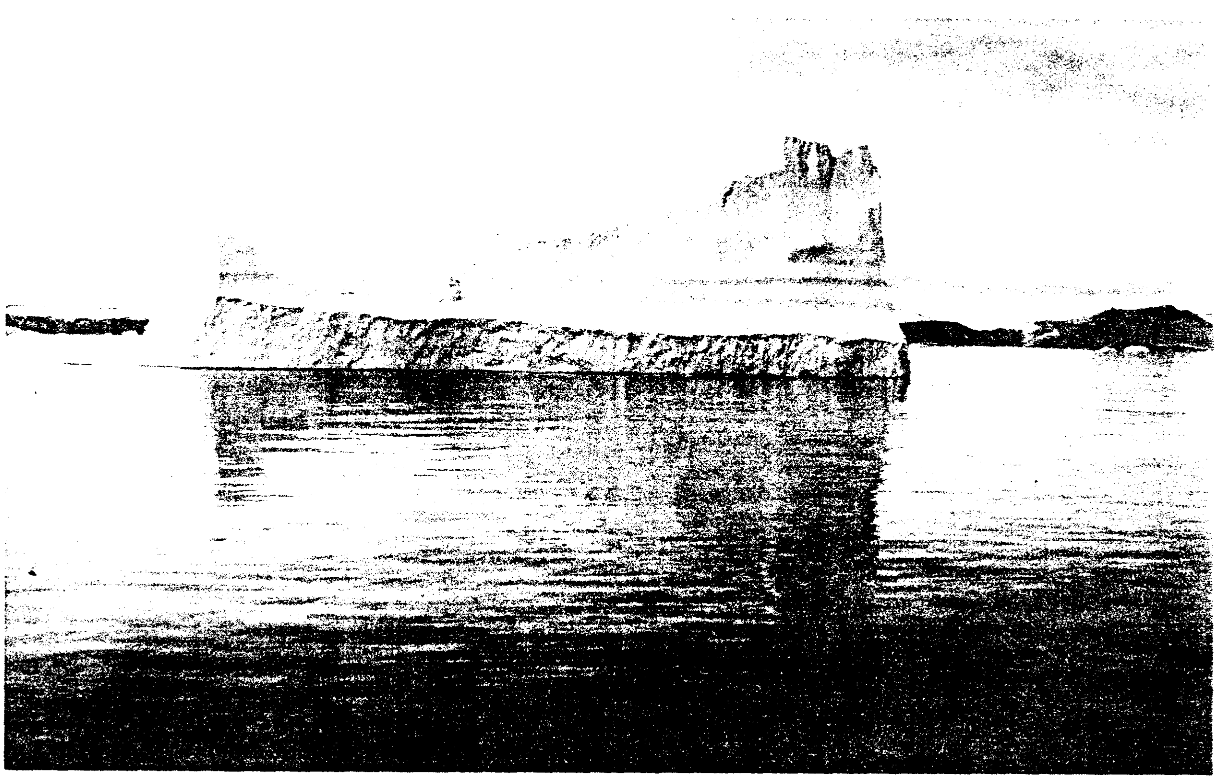

PLATE 1.1-5 *An iceberg in northern Baffin Bay, September, 1968: one of many which calve from Greenland glaciers.*

Baffin Island coast. Depending on the year, icebergs moving directly across Baffin Bay can outnumber those drifting along the more well known northerly path. The maximum iceberg concentration in Baffin Bay usually occurs in late summer, with highest densities found around the periphery of the bay. At freeze-up, many of these bergs become relatively stationary for most of the winter, and larger ones may ground near shores. There is a tremendous volume of literature describing iceberg statistics since 1940. A composite of these data shows that the minimum iceberg density occurs in central Baffin Bay, with typical densities of less than one berg per 256 km^2 (Figure 1.1-7). Out from the Greenland coast, the iceberg concentration tends to decrease exponentially with increasing distance from Greenland, from peak densities of up to one per 1.5 km^2 (Arctic Pilot Project, 1980). Iceberg height distributions show that bergs off the coast of Greenland are higher than in other areas of Baffin Bay, with 40% being between 65 and 100 meters high in Danish waters compared to less than 15% in the Canadian waters (Arctic Pilot Project, 1980).

The effects of climate on ice severity in different Arctic environments have been relatively well documented, particularly in Baffin Bay because of its historical shipping records dating back to the 1600's (Koerner, 1979; Dunbar, 1971; Jacobs and Newell, 1979; Walsh and Johnson, 1979). Although there seems to be partial agreement that a period of natural cooling is presently occurring (Volume 3A, Section 1.1.1.5), the effects of this long term climatic change have not yet been reflected in increased mean annual sea ice concentrations within central Baffin Bay. However, there has been an apparent trend toward increased variability in ice cover, with "good" (least ice) and "bad" (most ice) years occurring in groups of 3 years since 1964. Some of this increased variation may be simply a manifestation of improved ice statistics since 1963.

1.1.6 DAVIS STRAIT

The same basic water circulation patterns described for Baffin Bay (Section 1.1.5) control ice conditions in Davis Strait . However, some warm water does split-off from the west Greenland current, crossing Davis Strait from east to west at its narrowest point and then proceeds south without completing the northern Baffin Bay circuit.

Winter ice severity is greatest along the Baffin Island coast. Maximum first year ice thickness varies from about 130 cm in the west, to 70 cm along the Greenland coast (Markham, 1981).

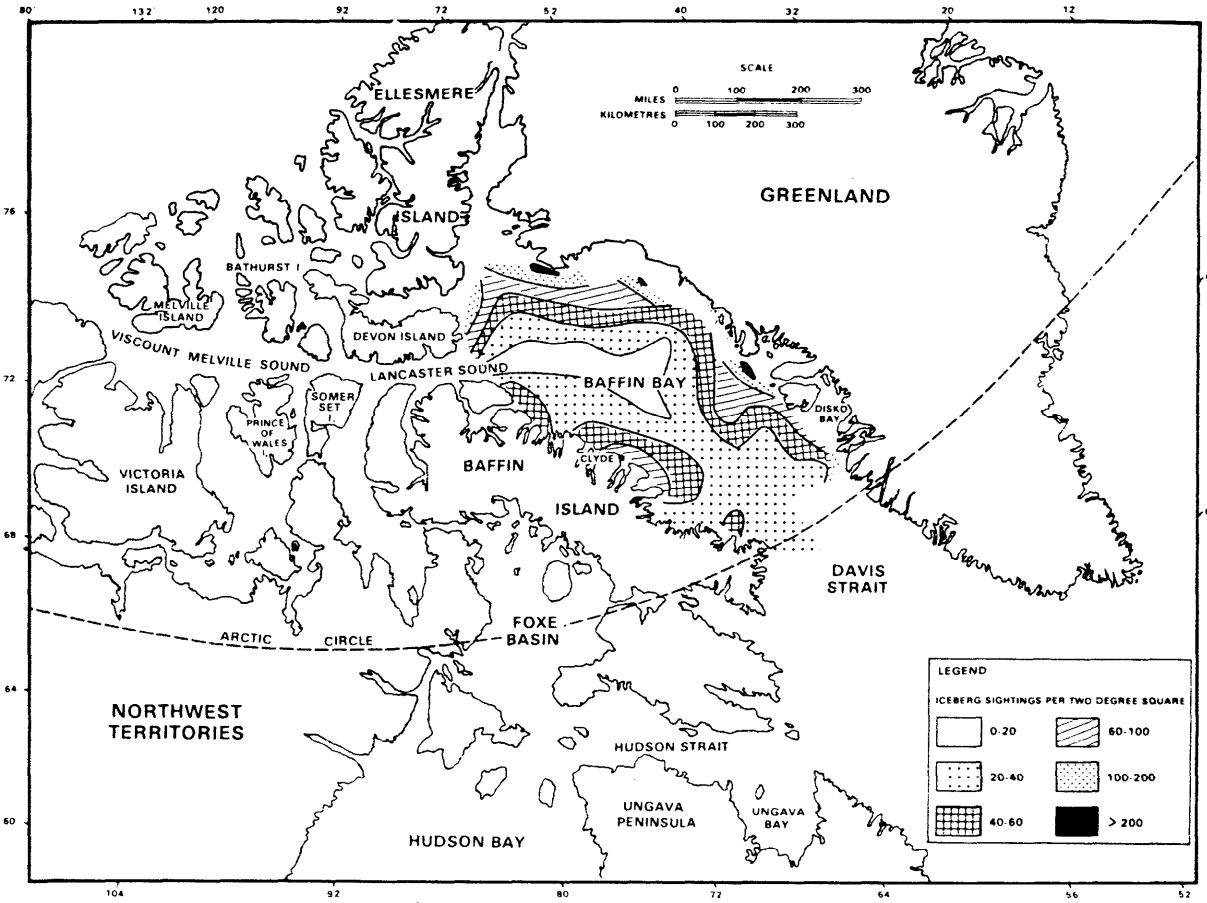

FIGURE 1.1-7 *Iceberg concentrations in Baffin Bay and Davis Strait (composite average, 1940, 1949, 1964-69: Source: U.S. Coast Guard, International Ice Patrol, 1970). Icebergs originate mainly from west Greenland glaciers north of Disko Bay. In Baffin Bay, maximum iceberg concentrations occur in late summer with highest densities found around the periphery of the Bay.*

A study in the central sections of southern Davis Strait during the winter of 1976 and 1977 showed that average ice floe diameters ranged from 10m in December to 6.7 m in February (FENCO, 1977). Average undisturbed ice thicknesses varied from 0.85 m in December to 1.4 m in February, while rafted floes were in the order of 5 to 7 m thick. Typical ridge heights in February were only 0.35 to 0.62 m but there are no ridge frequency data for central Davis Strait. Since poorly consolidated loose pack ice exists throughout most of the winter, ridges are likely to be dynamic and short term features. Off the Baffin Island shore there are fields of heavily deformed ice, but vessels on the central route (Figure 1.1-5) would not encounter this ice.

In early November, the pack ice edge advances south-east from Baffin Island, beginning with landfast ice formation in the vicinity of Cape Dyer (Figure 1.1-8). The landfast ice edge frequently breaks up and reforms until early December when some protection is offered by the offshore first year pack ice. This pack is dynamic throughout the winter and includes many leads and ice floes of variable thicknesses. Floes tend to be less than 100 m in diameter, and move rapidly in response to winds and currents. Ice drift speeds, in a general southerly direction, vary from 90 km/day near the outer pack edge to 10 km/day near the Baffin Island coast (LeDrew and Gustajtis, 1978).

Loss of ice by wind and wave erosion along the outer pack ice front is balanced by the drift of more ice south with the cold Canadian coastal current. The westerly branch of the warm Greenland current flows across Davis Strait at about its mid point and keeps the northern areas of the Labrador Sea ice free, and also retains the pack ice within the Canadian current.

From mid November to July, central Davis Strait at 70°N, is covered with close pack ice in concentrations ranging between 5/10ths and 8/10ths. At 65°N, the average ice covered period is less than 5 months from early January to May. South of this latitude, the average open water season increases from 30 weeks to greater than 45 weeks at 60°N. Freeze-up may not occur at all in south-central Davis Strait or may be as

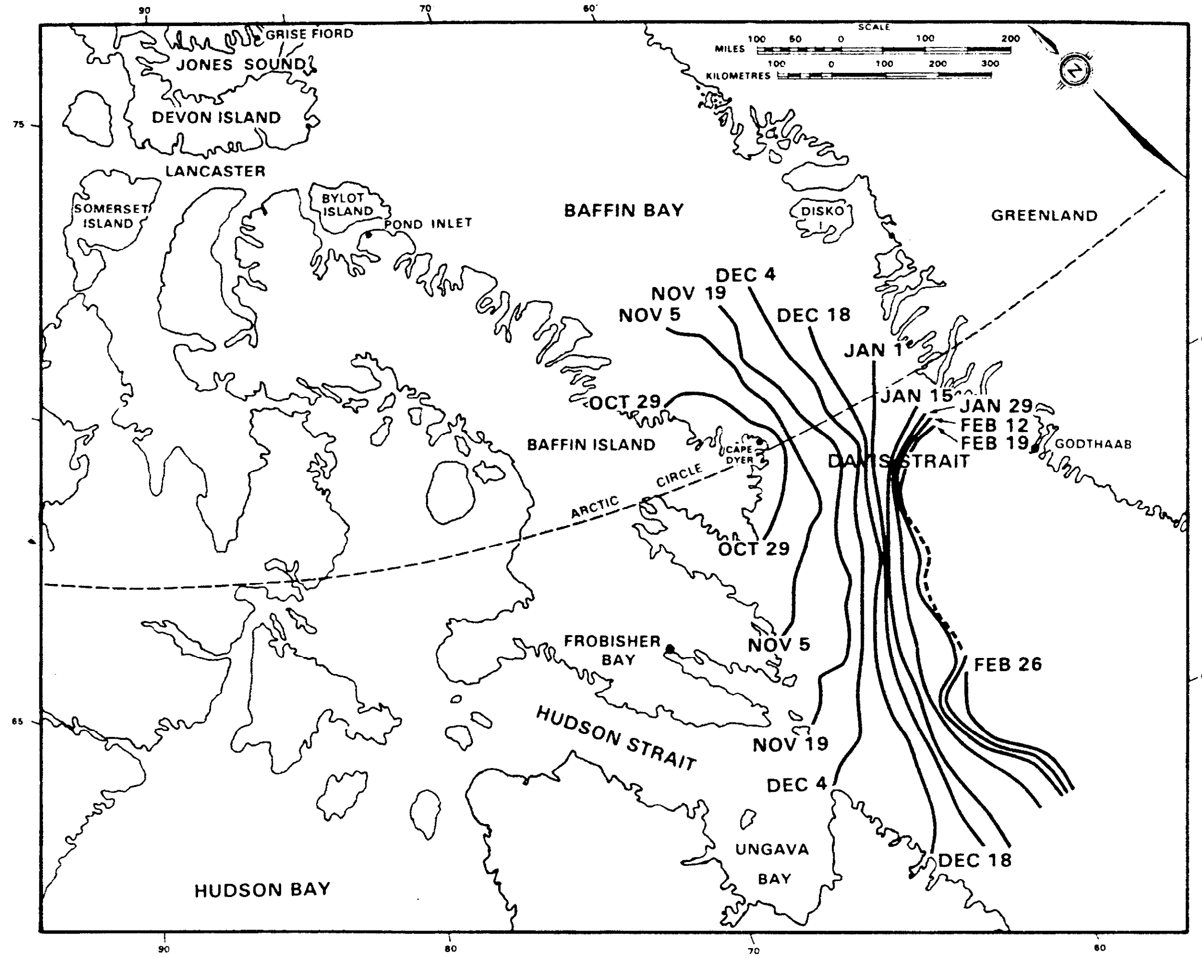

FIGURE 1.1-8 *Average dates of freeze-up in Davis Strait (Source: Fraser, 1975). At the latitude of Godthaab, the average ice covered period in central Davis Strait is less than 5 months from early January to May. Southeastern Davis Strait has essentially open water throughout the year.*

late as early January. By late April, ice cover in this area is reduced to less than 1/10th (Fraser, 1975). The southeast part of Davis Strait has essentially open water throughout the year (Figures 1.1-8 and 1.1-9).

In a heavy ice year, there may be patches of late winter multi-year ice in concentrations up to 3/10ths within north-central Davis Strait as far south as 67°N latitude. During August, this ice generally melts in place with little southerly drift. Also in a heavy ice year, Davis Strait can have multi-year ice concentrations up to 3/10ths east of 60°W in September. However, fall storms disperse this ice and move it south before freeze-up takes place offshore, leaving only traces of multi-year ice along the central shipping corridor from November to April (NORCOR, 1977). There has been a general increase in the mean annual sea ice concentration in Davis Strait since 1970 (Dickins, 1981a), but whether or not this trend will continue is unknown.

Iceberg data have been collected in Davis Strait during numerous research programs, primarily those oriented toward assessing collision probabilities at a fixed drilling location. These studies show that in most of Davis Strait, the iceberg density is generally less than 0.005 icebergs/km^2 (one iceberg in a 14 km by 14 km square), with higher densities being found close to the Baffin Island coastline (eg. up to 0.02 icebergs/km^2 or 1 in a 9 km by 9 km square near Clyde: Figure 1.1-7; Arctic Pilot Project, 1980). In some years, numerous icebergs cross Baffin Bay-Davis Strait at about 70°N and then drift with the prevailing currents south toward the Labrador Sea. This westerly movement can result in short term, mid summer iceberg concentrations as high as 0.04/km^2 (1 berg in a 5 km by 5 km square) where they cross Davis Strait. South of 65°N, iceberg densities tend to decrease from early to late summer, with the opposite trend being observed north of 68°N (Arctic Pilot Project, 1980). Maximum iceberg densities in north Davis Strait occur near the Greenland coast, while

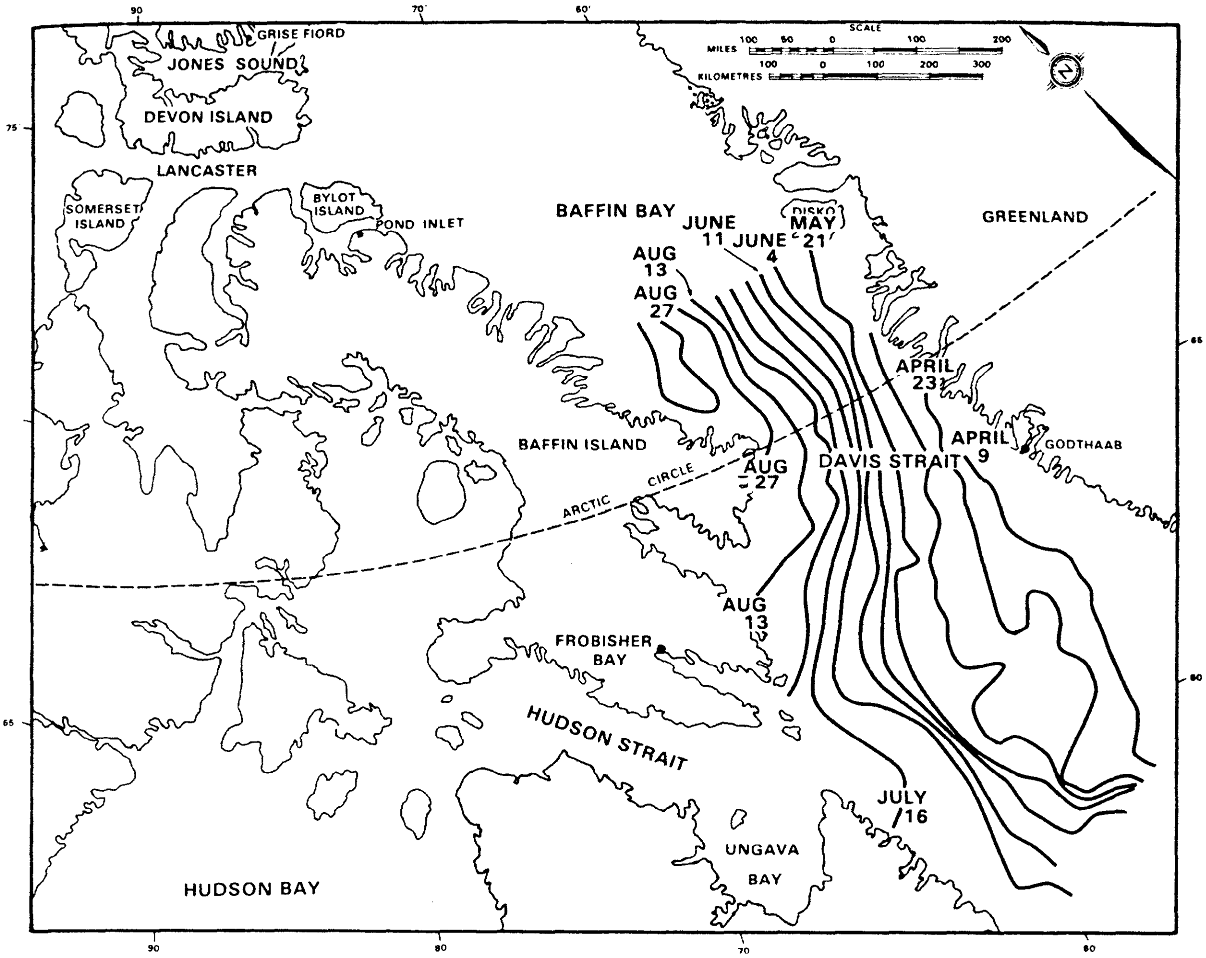

FIGURE 1.1-9 *Average dates of break-up in Davis Strait (1959-75) (From Fraser, 1975). The north flowing west Greenland Current is relatively warm in contrast to the southward flowing, cold, Canadian current in the west, hence break-up proceeds from east to west in Davis Strait.*

south of 66°N, the highest densities are found farthest from shore. The influx of east Greenland bergs during early summer influences these patterns.

Interpretations of historical iceberg surveys have been conducted by a number of groups. Analysis using 13 years of data from Davis Strait (1963 to 1976) by (FENCO, 1977) showed that only 10% of the icebergs fell into the large category (greater than 46 m high, 122 m wide), while 50% were small or growlers (less than 15 m high by 61 m wide). Iceberg flux across a given line of latitude from 60°N to 67°N (related to both density and drift rate) is highest from March to July and lowest between October and November (Anderson, 1971).

1.1.7 LABRADOR SEA NORTH

The last portion of the proposed eastern tanker route where vessels are likely to encounter sea ice is in the Labrador Sea. In extreme cases, a persistent low pressure system in Davis Strait can lead to transient seaward extensions of the Labrador pack to beyond 300 km from shore. However, vessels east of 53°W longitude would not normally encounter any ice, other than in isolated patches having less than a 6/10ths concentration from early March to mid April (NORCOR, 1977).

The part of the tanker corridor in the south Labrador Sea from 55°N into the Strait of Belle Isle has maximum ice concentrations of 7/10ths during February and March (Figure 1.1-10). Mean freeze-up and break-up dates for this region are January 24 and April 10, respectively, although the standard deviation on these dates is over 3 weeks (NORCOR, 1977).

Pack ice off Groswater Bay in February may originate from Davis Strait, Ungava Bay and Hudson Strait. In the event of a late clearing of Baffin Bay, patches of second year and multi-year ice in concentrations of less than 4/10ths can intrude into the Labrador Sea during the late winter and spring (Canadian Hydrographic Service, 1974).

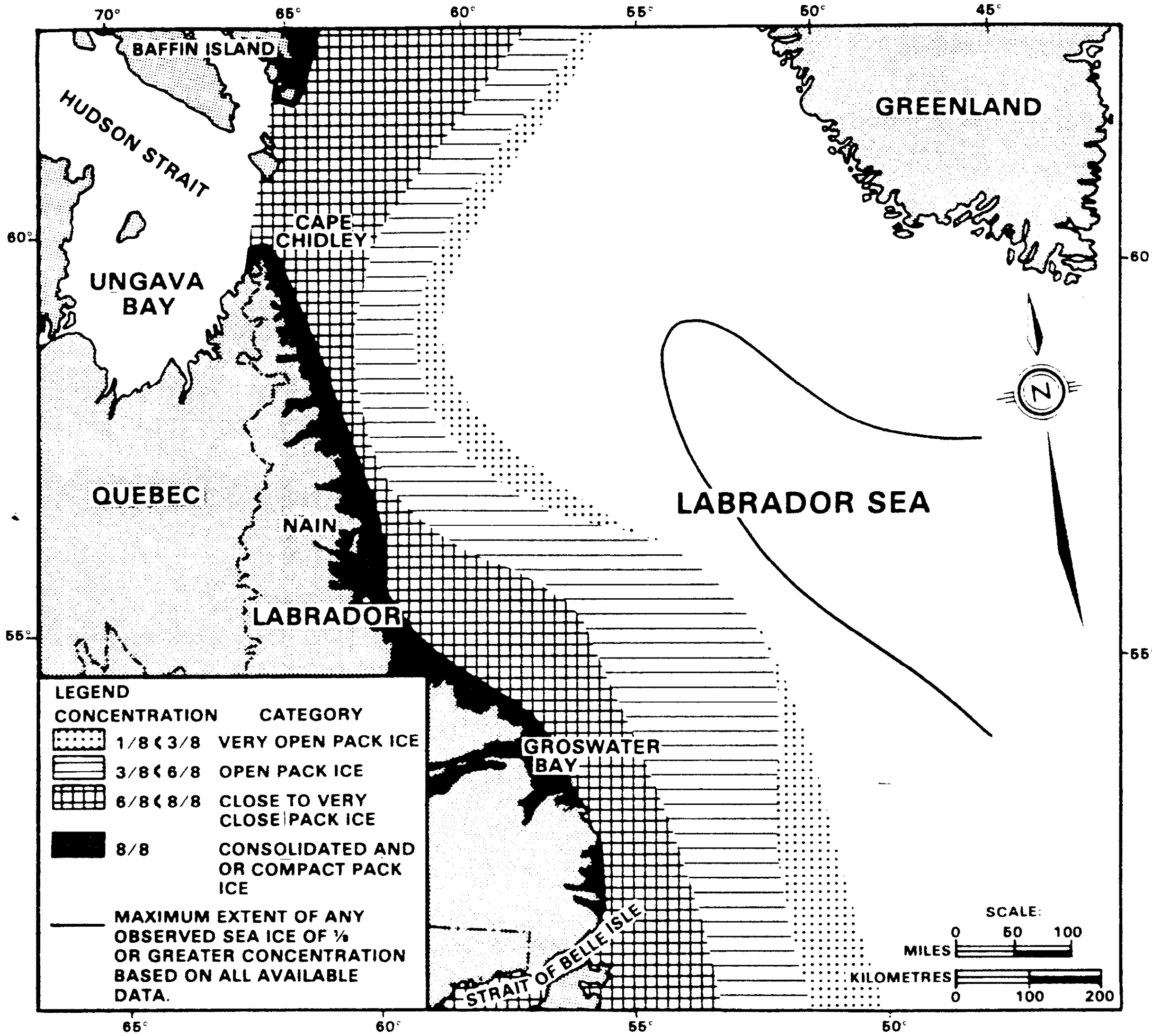

FIGURE 1.1-10 *Maximum sea ice concentrations in February and March in the Labrador Sea (Source: NORCOR, 1977). Pack ice off Groswater Bay in February may originate from Davis Strait, Ungava Bay and Hudson Strait.*

Ice thickness within the Labrador pack is extremely variable as a result of continuous rafting, wind pressure and floe interactions. Thus, while local fast ice may be only 0.9 m thick, typical floes within the pack can average 1.5 m in thickness (NORCOR, 1977). Rafted first year ice up to 3 m thick is also common, with multi-year remnants being present in low concentrations. These remnants can have thicknesses up to 15 m as measured in an extreme case which was probably an old ridge fragment (Masterson, unpublished data).

Seasonal iceberg densities between 52°N and 61°N were studied from 1963 to 1977. In the north Labrador Sea, iceberg sightings were inside the 1,000 m isobath, and therefore west of the proposed tanker route. Only off Nain in the spring (February to April) did moderate iceberg densities occur in the proposed offshore tanker corridor north of 55°N (Figure 1.1-11). Spring is the season when the majority of historical iceberg sightings off the Labrador coast have occurred. Iceberg densities in the Labrador Sea at any particular time are in the order of 10% of typical densities for Baffin Bay. A single census of bergs in Baffin Bay and Davis Strait in August 1949 identified over 40,000 individual bergs (Pilot of Arctic Canada, 1970). However, only 26,000 sightings have been reported off the Labrador coast using 61% of all available overflight data for a 13 year period (Gustajtis, 1978). Available data indicate that in a given year, only about 2,500 bergs reach Cape Chidley at the northern extremity of the Labrador Sea. Of these, only 1,400 are transported as far as the entrance to the Strait of Belle Isle. According to the Sailing

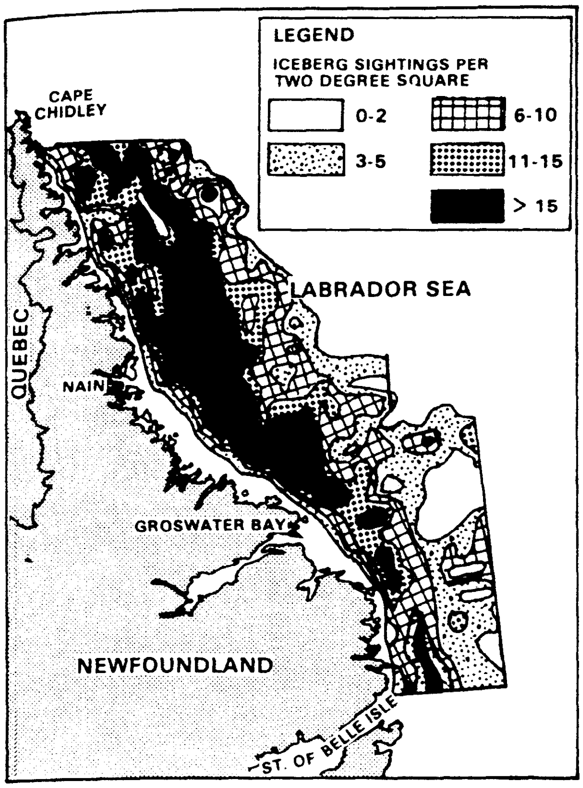

FIGURE 1.1-11 *Spring iceberg concentrations along the Labrador Coast (February-April) (From Gustajtis, 1977). In the north Labrador Sea, most iceberg sightings were shoreward of the 1000 m isobath, and therefore west of the proposed tanker route. Iceberg densities in the Labrador Sea are about 10% of those in Baffin Bay and Davis Strait.*

Directions for Labrador and Hudson Bay (Canadian Hydrographic Service, 1974), numbers of bergs crossing latitude 48°N can vary from zero (1966) to 1,600 (1972) in different years.

1.1.8 SECONDARY SHIPPING CORRIDORS

1.1.8.1 M'Clure Strait

M'Clure Strait provides an alternate to the route through Amundsen Gulf and Prince of Wales Strait. This optional route would increase the overall distance to travel by about 150 km. Average winter multi-year ice concentrations greater than 4/10ths are encountered along the entire M'Clure Strait corridor (400 km) compared to only about 140 km of these ice concentrations along the primary Prince of Wales Strait routing (Dickins, 1981a). Available ice charts (1971-1980) show about a 30% probability of encountering old ice at concentrations greater than 6/10ths along the western shore of Banks Island. Throughout the 400 km of M'Clure Strait, old ice concentrations of over 7/10ths are encountered with the same probability. Table 1.1-2 shows winter old ice concentrations reported along segments of the optional route between 1971 and 1980, compared to the west Viscount Melville Sound segment of the primary route. The latter segment is considered to be

TABLE 1.1-2

COMPARISON OF MULTI-YEAR ICE CONCENTRATIONS DURING THE PERIOD FROM 1971 TO 1980 ALONG DIFFERENT POTENTIAL TANKER ROUTES

	Multi-Year Ice Concentraton /10		
Winter	**W. Viscount Melville**	**W. Coast Banks I.**	**M'Clure Strait**
1971-72	4.5(North)	—	7.7
72-73	7.5(Direct)	—	7.3
73-74	7.0(Direct)	4.9	4.9
74-75	9.0(Central)	7.1	5.3
75-76	7.5(Central)	7.7	7.8
76-77	8.0(North)	2.9	6.7
77-78	7.0(North)	5.3	5.0
78-79	8.5(North)	6.3	7.5
79-80	9.0(North)	2.4	6.3
80-81	5.0(South)	4.5	7.8

Source: A.E.S. Ice Charts

the worst part of the primary eastern corridor for heavy ice. The favoured routing for a particular winter in Viscount Melville Sound was central, direct, north or south as shown in brackets. Figure1.1-2 shows these routes.

These data indicate that during the past decade, there have been four winters when it may have been easier to travel through 400 km of less than 6/10ths old ice in M'Clure Strait than through the 80 km of greater than 8/10ths multi-year ice in west Viscount Melville Sound from Prince of Wales Strait to Melville Island. Normally there is no preferred routing in M'Clure Strait, although during years when relatively favourable conditions exist, minimum multi-year concentrations are found along the extreme northern side of the strait (Dickins, 1981a). A northern route through M'Clure Strait would also conveniently link up with the favoured northerly route through Viscount Melville Sound.

M'Clure Strait was partially navigated from west to east in 1851 by M'Clure in the 'Investigator,' but the entire strait was not traversed until 1954 by a U.S. icebreaker. Since this time, few vessels have penetrated very far into M'Clure Strait. Perhaps the most successful marine operations in the area were the seismic surveys of the 'Arctic Explorer' and 'Carino' in September 1974, when these relatively small vessels penetrated as far as Mould Bay, Prince Patrick Island. Additional experiences with the U.S.S. 'Manhattan' in 1969 and the C.C.G. 'Franklin' in 1979 served to strengthen popular beliefs that M'Clure Strait is impassable. However, the preliminary evaluation of winter ice concentration statistics do not support this theory.

There are no public data available on ice ridging along this optional route. Very severe shear ridging occurs close to Banks Island (Dickins, pers. comm.), but a deep-draft vessel route located over 40 km from shore should not intersect ridges any more severe than those in the Beaufort Sea.

During the winter, ice off the west coast of Banks Island is in a constant state of motion, and major leads can appear at any time. There is usually an average of 4/10ths open water in this area by mid June, increasing to a maximum of 6/10ths in August and September. The new ice cover does not consolidate until well into November.

Ice in M'Clure Strait does not break up in the literal sense of the word. From late August to mid September, strong northerly winds can open up an east-west lead along the north side of the strait, but this lasts only a few weeks (Marko, 1977). Figure 1.1-12 shows an example of extremely favourable summer conditions observed in M'Clure Strait on August 27, 1970, when there was open water along the north coast of Banks Island (Marko, 1977). This is the type of transient situation which almost allowed M'Clure to navigate the Northwest Passage 131 years ago.

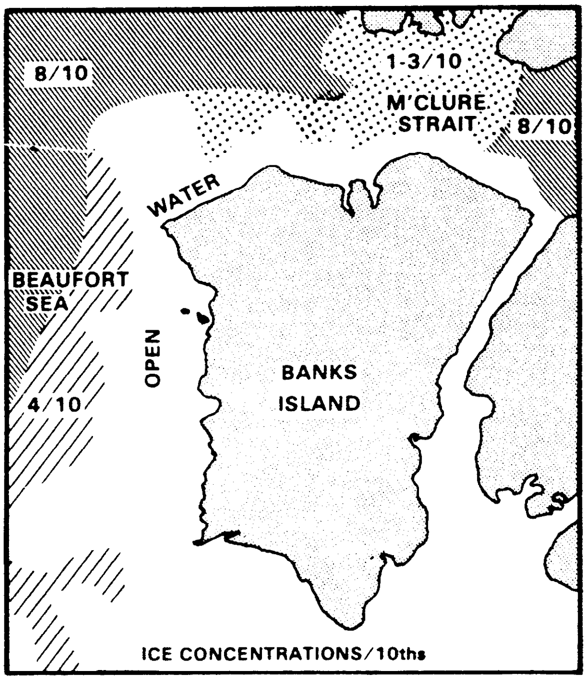

FIGURE 1.1-12 *Favourable ice conditions north and west of Banks Island, August 27, 1970 (Source: Marko, 1977). Such conditions are transient, and likely rare in M'Clure Strait, but could allow easy passage for arctic tankers.*

1.1.8.2 Fury and Hecla Strait

After Parry's abortive attempts to sail through Fury and Hecla strait in 1822, this route was not successfully traversed until 1948, when a U.S. icebreaker made the passage from west to east. Since this date, the strait has only been used by large vessels in 1956, 1961 and 1978 (C.C.G. Labrador, C.C.G. Radisson, C.C.G. John A. MacDonald).

The Fury and Hecla Strait optional route extends 1,920 km from the northern entrance of Prince Regent Inlet to the eastern end of the Hudson Strait, (Figure 1.1-5) replacing the Lancaster Sound, Baffin Bay and Davis Strait route. The distance of the two alternate routes is about the same, given a 10% tolerance for detours around severe ice conditions which are probable on any Arctic transportation route.

Prince Regent Inlet is covered mostly with first year ice from late September until early August. By April a stable landfast ice edge is usually formed across the north end of the inlet when the ice to the south becomes landfast. The ice clears from the inlet every summer, although there can be intrusions of old floes in September. Maximum winter multi-year concentrations are less than 4/10ths along the best part of the route through Prince Regent Inlet (Dickins, 1979).

The Gulf of Boothia typically has a 4/10ths to 6/10ths winter multi-year ice cover in the north with more severe, conditions occurring to the south. Available data indicates that the Gulf of Boothia does not become ice-free during the summer in two years out of ten years examined. The average duration of open water (less than 5/10ths ice) in this region is from late August to early October.

Fury and Hecla Strait has the strongest currents (up to 6 knots), the narrowest channel (1.9 km) and the longest stretch (170 km) of truly stable landfast ice along the entire secondary shipping corridor. Winter multi-year concentrations in this strait are less than 2/10ths. Ridging is also infrequent but occasionally occurs running north and south between points of land. The strait normally clears rapidly from east to west in late July, although old ice incursions in concentrations up to 4/10ths are common in August and September. Due to the strong currents, freeze-up is slow, with dark-grey (thin) ice still being visible in mid November. A regular polynya remains every winter in the Labrador Narrows (Sadler *et al.*, 1979).

Ice in Foxe Basin is in constant motion throughout the winter, and drifts counter-clockwise. Characteristic winter features in the region are a shore lead running up the west side off Melville Peninsula, and a large polynya to the west of Rowley Island (Pilot of Arctic Canada, 1970). Winter ice is invariably first year, although a few scattered old floes from the Gulf of Boothia may also be present in Foxe Basin. Ice thickness ranges from a maximum of about 80 cm in the north near Rowley Island to 170 cm in the central basin (Dickins, 1979). Ridge frequencies as high as 12 ridges/km have been documented in Foxe Basin, with average and maximum sail heights of 1.2 and 4.9 m, respectively (Pilot of Arctic Canada, 1978). In July, the northern polynya enlarges and Foxe Channel breaks up. The ice concentration in central Foxe

Basin is reduced to 3/10ths by August, with the southwest corner being the last to clear. Freeze-up proceeds from north to south starting in mid October, although white ice does not dominate the basin area until late December.

The winter ice cover in Hudson Strait is very dynamic and is comprised of three principal ice types: scattered floes and iceberg fragments from Baffin Bay; discoloured first year ice from Foxe Basin; and highly ridged and rafted local ice formed in the strait.

Ice clears from west to east in June and July. Consolidation of the ice of mixed origin takes place from late October to December, with February being the month with minimum open water (average ice concentration between 1/10th and 2/10ths). Landfast ice can be as thick as 1.5 m in May, (Allen, 1974) but along the alternate corridor thicknesses at any time would be extremely variable and generally thinner than the ice nearer the shores.

Iceberg densities along the Fury and Hecla Strait route are low compared to Baffin Bay. Most icebergs are found in August and September along the north side of the strait (7 times as many sightings as along the south shore). On rare occasions, icebergs have been observed as far west as Nottingham Island. Most bergs drift with the residual currents of Hudson Strait and with strong easterly winds; they then turn south near 70°35'W longitude, and are carried in the reverse direction past Cape Chidley into the Labrador Sea (Canadian Hydrographic Service, 1974).

In general, the open water season along the Fury and Hecla route varies from 50 days in Prince Regent Inlet to over 100 days in Hudson Strait (Dickins, 1979). This is to be compared with the 130 to 150 days of open water in Lancaster Sound and Davis Strait. First year ice thicknesses range from over 2 m in the north, to less than 1.3 m in Hudson Strait. This is 10 to 20% thicker on average, than the level ice thickness in Baffin Bay and Davis Strait.

The optimal shipping route through Prince Regent Inlet, Foxe Basin and Hudson Strait via Fury and Hecla Strait could be a viable year-round alternative (particularly for smaller vessels) to the traditional Baffin Bay passage. Bathymetric data are sparse, especially in northern Foxe basin, but available data show a minimum safe channel draft of 27 m (Dickins, 1979). In winter multi-year ice is present at an average concentration of about 4/10ths along about 260 km in the Gulf of Boothia. Maximum old ice concentrations only exceeded 6/10ths in one year of the 10 years studied by Dickins (1979).

However, this optional route could not be used until a more comprehensive set of soundings is available in certain areas. During the summer of 1981, the Canadian Hydrographic Service conducted a new series of soundings in Foxe Basin and Fury and Hecla Strait. Provisional results, not yet published, show a number of critical shoals not indicated on current charts. In addition, more data on old ice concentrations in the Gulf of Boothia are required. Recently, visual ridge counts were obtained during an Atmospheric Environment Service survey flight in April, 1981, from the Gulf of Boothia to Hudson Strait (Dickins, 1981b).

1.2 SURFACE WEATHER AND WIND WAVES

1.2.1 NORTHWEST PASSAGE

1.2.1.1 Temperature

Mean annual air temperatures at the surface for the Northwest Passage region are illustrated in Figure 1.2-1. During the summer, temperatures are relatively uniform due to the strong influence of open water. During the warmest month, July, mean air temperatures are near 2 or 3°C, with a daily variation of only 4 or 5°C (Maxwell, 1980). Temperatures inland may be as much as 5°C warmer, depending on exposure to sun and wind. However, on the smaller islands the flow of air from open water areas maintains air temperatures close to the water temperature.

Major synoptic weather systems, though rare in the Northwest Passage, occasionally occur in summer and can sweep warm air into the region. For example, a record high temperature of 28.9°C was reported at Cambridge Bay (Figure 1.2-1) in 1930, while a temperature of 22.2°C was recorded at Isachsen (see Figure 1.2-6 for location) in 1962 (Maxwell, 1980).

Once the daily mean temperature falls below 0°C, winter begins. In the Northwest Passage, this generally occurs around August 20 in the western sector, gradually moving eastward, reaching the eastern end by September 5 (Maxwell, 1980). Winter is delayed in the east due to the warmer waters of Baffin Bay, as well as a result of more frequent storms along the west coast of Greenland. Conversely, the daily mean temperatures rise above 0°C around June 5 in the west and around June 15 in the east.

During the long Arctic night of winter, the sun does not rise above the horizon between mid November and mid February in the Northwest Passage. In summer, the sun rises along the Northwest Passage in early May and does not set again until mid August. This annual variation in solar radiation profoundly affects air temperatures.

Very cold temperatures prevail during winter. For example, a record low temperature of -53.9°C was

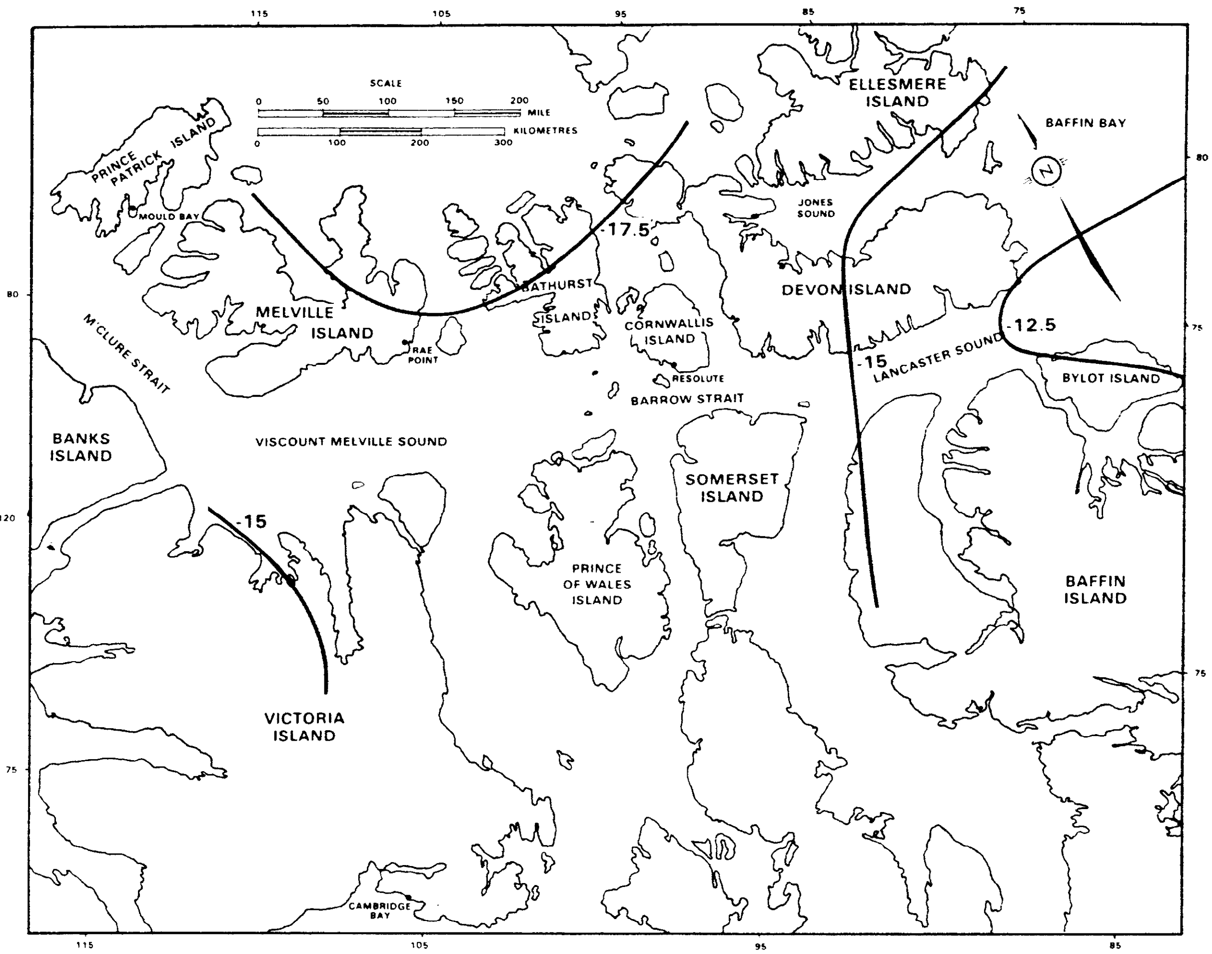

FIGURE 1.2-1 *Annual mean daily air temperatures (°C) for the Northwest Passage, 1941-1970 (from Maxwell, 1980). Mean annual air temperatures are highest at the eastern end of the Northwest Passage.*

recorded at Mould Bay in 1967 (Maxwell, 1980). Mean temperatures in January range from -38°C near Mould Bay to -25°C in Lancaster Sound (Maxwell, 1980). Records from several Arctic locations indicate a gradual decline in mean annual temperature by 0.5°C during the last 20 to 30 years (Maxwell, 1980; Thomas, 1975; Bradley, 1973). The subject of long term climate change and its possible implications for development activities is addressed in Volume 3A, Section 1.1.4.5.

1.2.1.2 Precipitation

The mean annual precipation is generally low and varies considerably from year to year throughout the Northwest Passage region (Figure 1.2-2). Several factors account for the low precipitation. The cold Arctic air retains little moisture to condense and precipitate. In addition, during winter, sea ice reduces evaporation into the air, although some water vapour sublimates from snow and ice. Finally, weather systems occur less frequently in this region than they do further south. The eastern Northwest Passage experiences more precipitation than do the western portions (Figure 1.2-2), probably due to the proximity of Baffin Bay which acts as a moisture source.

Summertime precipitation is usually in the form of drizzle (Maxwell, 1980), but rain can fall in the Northwest Passage from June to September as a result of the infrequent storms that pass through the area. The record 24 hour rainfall in the region is 47.8 mm at Mould Bay in 1962 (Maxwell, 1980).

Freezing precipitation occurs whenever supercooled water droplets strike surface with temperatures below freezing. In the Northwest Passage about 25 hours of freezing precipitation can be expected annually, with 80% of the freezing precipitation occurring as freezing drizzle (McKay and Thompson, 1969). The latter forms where wind blows from an open water area over a colder surface. Freezing rain may also occur during large storms. Since freezing drizzle is more common, ice accumulation is generally low. For Resolute, the 20 year return period accumulation is

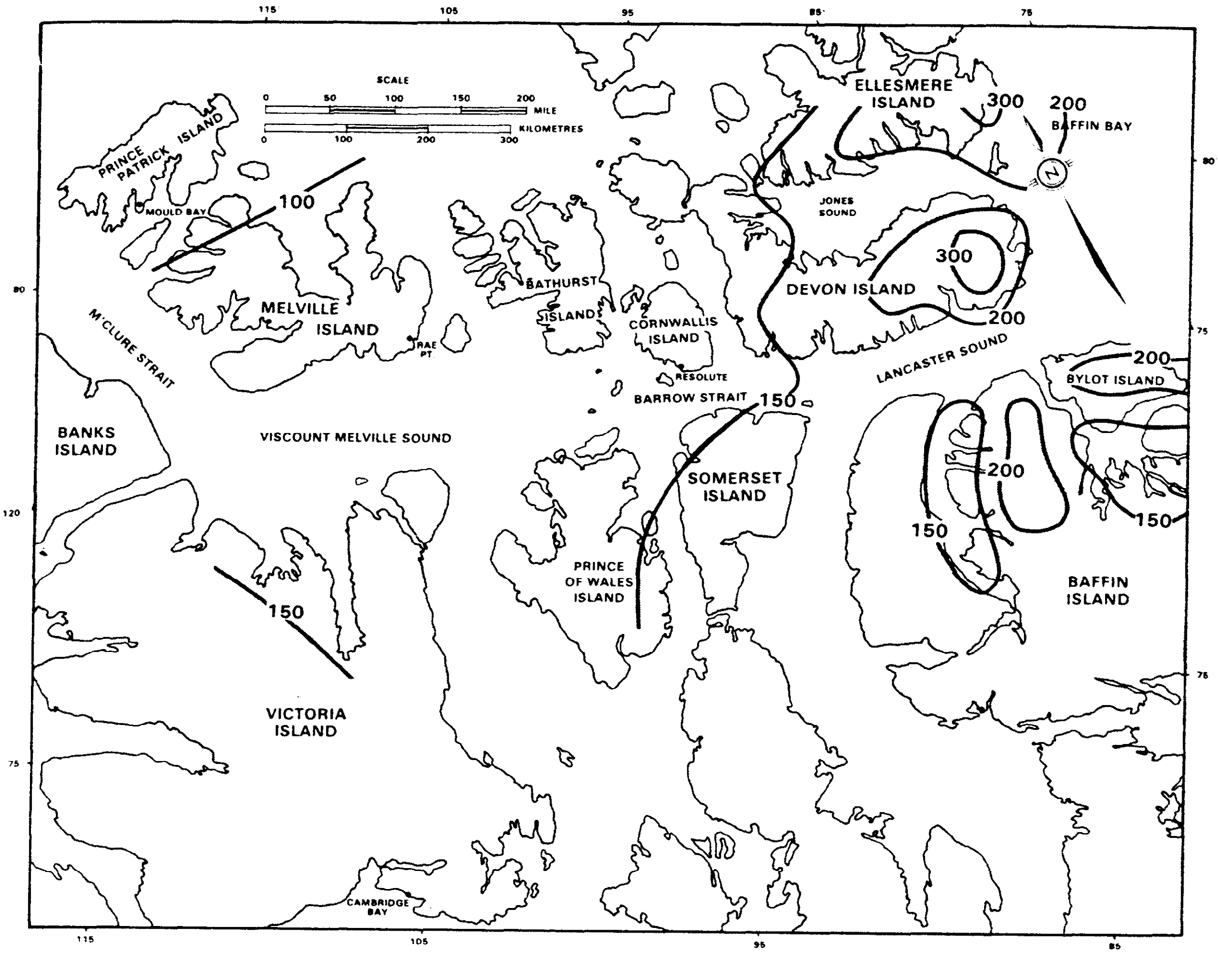

FIGURE 1.2-2 *Annual mean total precipitation (mm) for the Northwest Passage, 1941-1970 (from Maxwell, 1980). Least mean annual precipitation falls in the western part of the Northwest Passage and most in the east, due to the proximity of Baffin Bay which acts as a moisture source.*

4.6 mm on a horizontal surface and 9.6 mm on a vertical surface (Chaine and Skeates, 1974). Rae (1951) reported an accumulation of 9.1 mm of freezing precipitation over a 24 hour period at Resolute during September 1948.

Annual snowfall in the Northwest Passage varies from about 75 cm over western Melville Island to 150 cm over western Devon Island (Maxwell, 1980), again reflecting the influence of Baffin Bay.

1.2.1.3 Visibility

A variety of meteorological phenomena can reduce visibility in the Arctic. These include fog and blowing snow, sea smoke (steam fog), ice fog, and ice crystal haze.

Sea smoke or steam fog is formed when very cold air passes over open water. This kind of winter phenomenon can be expected by early October (Maxwell, 1981). Sea smoke is more common in Barrow Strait and Lancaster Sound which often have large areas of open water in winter. Under certain wind conditions, this sea smoke may blow over nearby land.

Ice fog is formed in winter when air temperatures fall below -26°C, and there is a local moisture source (Wilson, 1973). In fact, the steam fog discussed above can rapidly change to ice fog as the liquid water droplets freeze. Around human settlements and industrial sites in the Arctic, the water vapour produced by combustion in heating plants, automobiles or aircraft engines is often sufficient to produce extensive local ice fog. Arctic temperature inversions may also cause ice fog to persist when the inversion effectively traps the cold moist air near the ground.

Ice crystal haze is formed when water vapour in the air freezes and may occur in both the presence and absence of cloud cover. Ice crystal haze in the Arctic is often extensive, both horizontally and vertically.

Detailed visibility analyses for specific locations in the Northwest Passage are provided in MEP (1981). Due to blowing snow, October to April is the worst time of year for extended periods of reduced visibility. Resolute has relatively long periods (40-60 hours) of visibilities less than 0.8 km for most months of the year (Maxwell, 1980). Open water in Barrow Strait provides a nearby moisture source, sometimes even in winter. Poor visibility, less than 0.4 km, at Resolute is caused mostly by blowing snow from October to April, and by fog from mid May to early September (Maxwell, 1981).

Poor visibility, combined with low cloud ceilings, can create hazardous conditions for aircraft that are not Instrument Flight Rules (IFR) rated. The standard Visual Flight Rules (VFR) specify that ceilings should be 1,000 ft (300 m) or more, while the visibility should be 3 miles (4.8 km) or more. Tabulations of ceiling and visibility combinations for the Canadian Arctic indicate that the worst flying conditions generally occur in the summer and autumn (Maxwell, 1981). Visibility is less than 3.2 km and ceilings less than 300 m about 18% of the time from July through October in eastern sections of the Northwest Passage. This frequency increases to nearly 40% in central portions of the channel during August to October.

1.2.1.4 Winds

Weather stations nearest the Northwest Passage are Resolute, Rae Point and Mould Bay. This scarcity of regional stations only allows local winds to be described qualitatively. Wind plays a major role in ice motion in the Northwest Passage. Local topography affects the wind field and at some sites will dominate it completely. This is evident when the topography funnels or channels the wind away from its prevailing direction, and is often accompanied by an increase in wind speed. This is a well known phenomenon in mountain passes, such as those on Devon and Baffin islands (Maxwell, 1980). Similar effects may be expected in Lancaster Sound and Jones Sound due to the elevated land surrounding these channels, however these are not well documented.

Katabatic (downslope) and anabatic (upslope) winds also assume an important role in the Arctic. These are caused by the heating and cooling of air near a sloping surface. When air is cooled (eg. at night), it flows down the slope, and when it warms, it moves up the slope. In general, the anabatic wind is less pronounced than the katabatic wind. Although katabatic winds are not usually very strong, they can be reinforced by pressure gradient and stability effects, possibly causing hurricane force winds (Maxwell, 1980). This phenomenon has been documented on the Parry Peninsula and the northeast coast of Victoria Island (Maxwell, 1980; Stefansson, 1944). Strong, 35 knot anabatic winds have been reported at Resolute (Wilson, 1973).

The "sea breeze" and "land breeze" are similar to anabatic and katabatic winds, respectively. The daytime heating of a land surface next to a large water body results in the warmer air rising over the land, with cooler air from over the sea being drawn inland to take its place. The strength of the sea breeze depends on the temperature contrast between the land and the sea. During the summer, strong sea breezes develop in the Northwest Passage particularly when ice is near the shore (Maxwell, 1980). On the other hand, lower temperatures and ice cover minimize sea breezes in winter. Seasonal variations in the predominant wind directions at Mould Bay and Rae Point are examples of this process (Maxwell, 1980).

Extreme wind analyses are discussed in detail in MEP (1981). Based on ship observations from July to October, Maxwell (1981) found that 20 year return-period wind speeds gradually increase from 73 km/h in Viscount Melville Sound to the west to 138 km/h in Lancaster Sound to the east.

1.2.1.5 Waves

The height of wind-generated waves depends on the strength of the wind, its duration and the expanse of open water over which it blows (fetch). In the Northwest Passage, wave heights are relatively low compared to other sections of the proposed eastern tanker corridor. During the short open water season from July to October, fetch is limited by islands and sea ice. In addition, the ice floes scattered throughout the area dampen wave motions. Highest seas are expected when winds are from the east. In some cases, a 900 km fetch extends across Baffin Bay. During westerlies, fetches are often shortened by the presence of ice which moves south from Wellington Channel into Barrow Strait. Greatest fetches occur in late August and early September (Maxwell, 1981). Figure 1.2-3a shows the percentage of time that waves in Lancaster Sound fall into various height ranges during these months. (The "significant wave" is defined as the mean height of the highest third of all waves in the wave train). Rough seas occur more frequently during September than in August.

Extreme wave height analyses completed by Duck *et al.* (1977) for Lancaster Sound, indicate that the 25 year extreme significant wave height is approximately 5.5 m (Figure 1.2-3b). This would correspond to a 25 year maximum wave height of almost 10 m. By comparison, the 25 year extreme wave height in the Bering Sea is 31.5 m (Brower *et al.*, 1977), and 11 m in the Beaufort Sea. However, it should be stressed that the accuracy of any sea state analyses for the

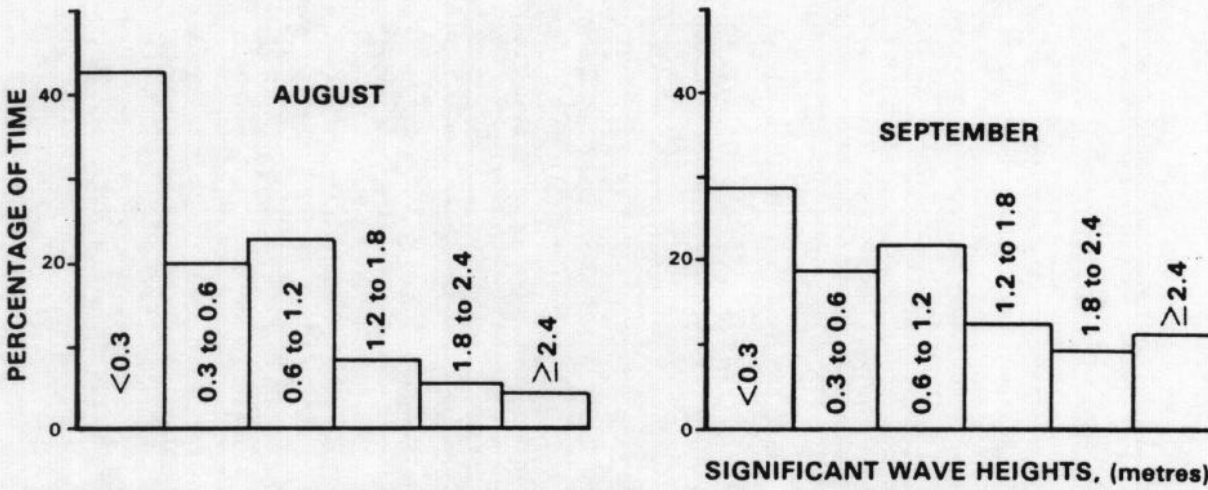

FIGURE 1.2-3a *Percentage of the time that waves in Lancaster Sound fall into various height ranges during August and September. Rough seas occur more often in September than in August. (Source: Berry, pers. comm., cited in Milne and Smiley, 1978).*

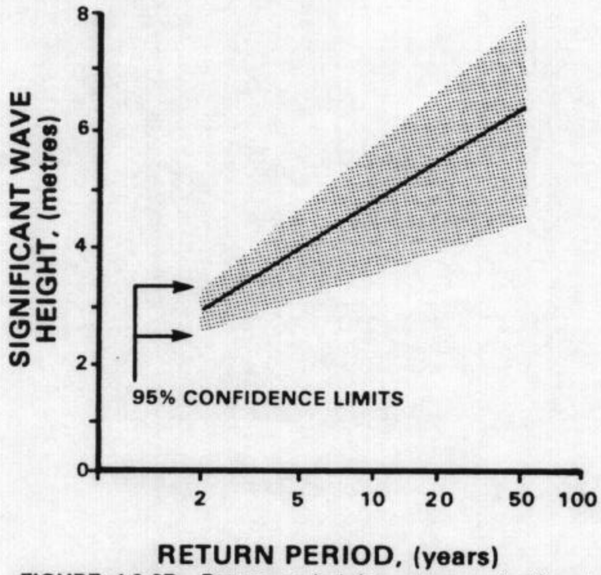

FIGURE 1.2-3B *Return period for extreme significant wave heights in Lancaster Sound based on data for the years 1954 to 1975. (Source: Duck, et al., 1977). This figure shows that a 5.5 m extreme significant wave height would be expected to occur with a 25 year return period. Such extreme waves would occur during the months of August or September when fetches are greatest.*

PLATE 1.2-1: *Greatest wave fetches in the Baffin Bay region generally occur in late August and early September. This photo shows the coast guard icebreaker John A. Macdonald cruising in 3 metre seas near Pond Inlet in September, 1979.*

Northwest Passage is restricted by the scarcity of observations and the limitations of the empirical techniques presently employed.

1.2.1.6 Structural Icing

Structural icing can be dangerous, particularly for small vessels in the Arctic. Under certain weather conditions, ice can accumulate above the water line of a vessel, greatly increasing its weight and decreasing its stability and maneuverability. Once air temperatures fall below -2°C, any form of liquid water in the atmosphere may result in structural icing. This water may be from rain or drizzle, fog (supercooled water droplets), or blowing spray. The incidence of freezing precipitation in this region has already been discussed in Section 1.2.1.2. Most parts of the Northwest Passage receive less than 25 hours of freezing precipitation per year. Icing due to fog is only a hazard in the fall when very cold air temperatures occur before the channels have iced over.

The most frequent source of structural icing is from blowing spray (Shellard, 1974). The rate of icing from spray increases as the air temperature falls and the wind speed increases, according to the relationship illustrated in Figure 1.2-4. Maxwell (1981) used

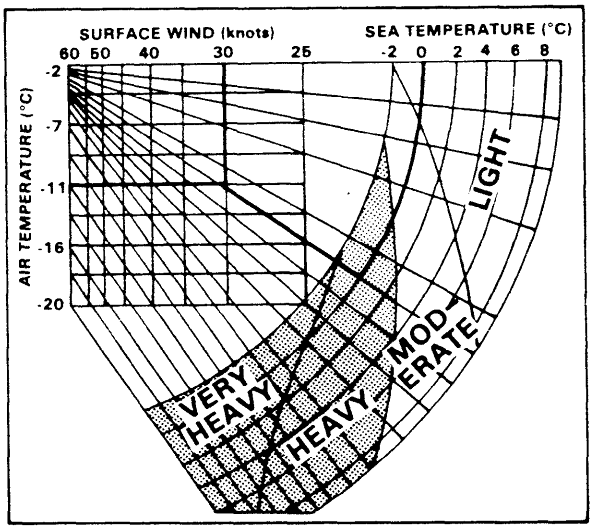

FIGURE 1.2-4 *Nomograph for forecasting ice accumulation from freezing spray (from Maxwell, 1981). To use this nomograph, select an air temperature (0° C) and a surface wind speed (knots) on the rectangular grid. From their point of intersection, follow the diagonal line to the right where it intersects the arcs showing sea temperatures (0° C). (For example, an air temperature of -11° C and a surface wind-speed of 30 knots will produce heavy freezing spray when sea-surface temperatures range between -2 to +3°C).*

this nomogram to calculate the frequency of occurrence of freezing spray at coastal stations in the Canadian Arctic. The results for September in the Northwest Passage are presented in Figure 1.2-5. Moderate freezing spray is predicted to occur up to 20% of the time in September in Lancaster Sound and Barrow Strait, with an average duration of 9.1 hours. The maximum duration of heavy and very heavy freezing spray generally occurs in the eastern Northwest Passage during September, at 42 hours and 10 hours, respectively. The analysis of Maxwell (1981) indicates that September is likely to be the worst month for freezing spray in the Northwest Passage. In August, air temperatures are usually high enough to prevent significant freezing spray, and by October, most of the channel is normally ice covered.

1.2.2 BAFFIN BAY-DAVIS STRAIT REGION

1.2.2.1 Temperature

Figure 1.2-6 shows mean annual temperatures for the Baffin Bay -Davis Strait region, based on 1941-1970 temperature normals from land stations as well as marine observations from 1953 to 1973. The marine data are limited to the open water season, July to October. All aspects of the climate of this region are discussed in more detail in MEP (1981).

The most important feature of the mean annual temperature distribution is the tongue of relatively warm air that extends northward from Davis Strait into eastern Baffin Bay. This tongue is a result of the large number of storms that track northward to these waters, as well as the relatively warm current along the western Greenland coast (Maxwell, 1980). This tongue of warm air is a characteristic feature of the temperature field over this region during all seasons. For example, an intrusion of warm air into Davis Strait during July, 1933 resulted in a record maximum temperature of 26.7°C at Pangnirtung (Maxwell, 1980).

During the summer, open water controls the air temperature, and little temperature variation is observed across the entire region. July is generally the warmest month when temperatures reach a mean maximum of just above 10°C over the interior of Baffin Island and near 5° on Ellesmere Island (Maxwell, 1980). Mean minimum temperatures are 5 to 7°C cooler. The waters of Baffin Bay and Davis Strait moderate the onshore coastal temperatures. Depending on wind direction and location, the windward coastal areas may be as much as 5°C cooler than inland locations. Over water, temperatures reach daily maxima of 7 to 10°C, with the highest values being observed near the Greenland coast. By September, these maxima have decreased by 5°C. A daily temperature range of 4 to 5°C is common throughout this region during the summer (Maxwell, 1980).

By late summer, temperatures begin to fall and sea

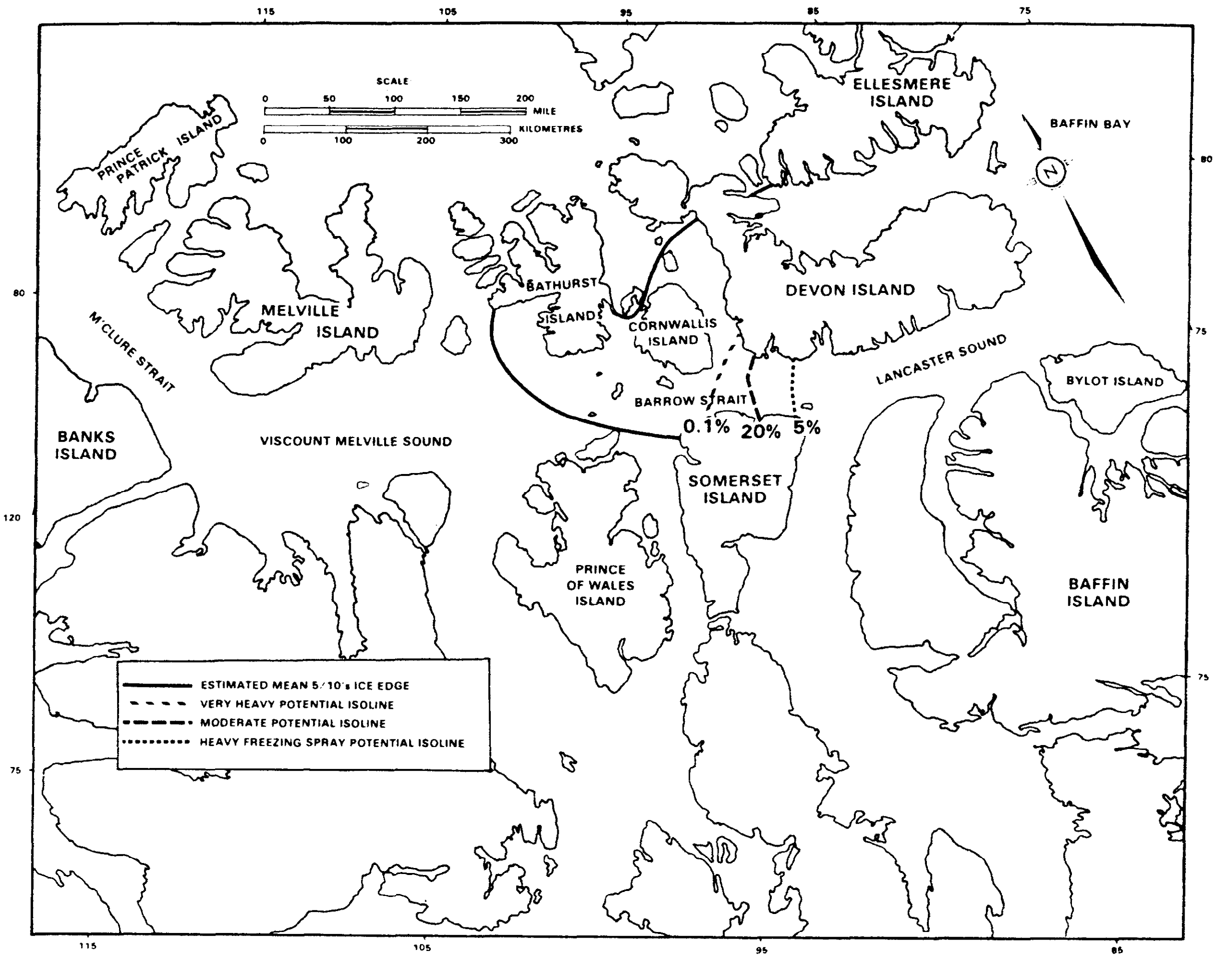

FIGURE 1.2-5 *Frequency of occurrence of freezing spray (i.e. of the time) calculated for September (from Maxwell, 1981). Most freezing spray events are expected to occur in September in the Parry Channel region.*

ice cover steadily increases. On the southern end of Ellesmere Island, winter (0°C mean daily temperature) generally begins near August 30, but its onset may be delayed until about October 10 in southern Davis Strait (Figure 1.2-7). On the west coast of Greenland where open water persists into November or December, winter may be delayed even more.

Winter is best described as a season of persistent rather than extreme cold. It is characterized by strong temperature gradients between marine and land areas as cold Arctic air is warmed during its passage over relatively warm open water. These effects are particularly evident in the 'North Water' of northwestern Baffin Bay, and off the west coast of Green land (Maxwell, 1980). The lowest mean temperatures occur in February, although the coldest winter weather may occur in any month from December to March. A record minimum of -53.3°C was reported for Pond Inlet in February, 1955 (Maxwell, 1980). By May, temperature gradients weaken and temperatures increase by 20°C from winter values. The onset of summer (mean daily temperatures greater than 0°C) varies from May 20 to June 15 throughout Baffin Bay and Davis Strait, and is influenced by latitude, elevation, and the extent of open water (Figure 1.2-8).

Figure 1.2-9 shows the duration of daylight in hours for each month of the year for various northern latitudes. Progressing northwards through Davis Strait, the number of daylight hours decreases during the winter season, until in the Northwest Passage the sun never rises above the horizon for about three months. During the long polar night, the Arctic Temperature Inversion, an important year-round characteristic of the Arctic climate, is strengthened. Conversely, in summer, the day length increases from 21 to 24 hours north of the Arctic Circle. During these months, the inversion occurs less often and is weakened. (The Arctic Temperature Inversion is dealt with in Section 1.2 of Volume 3A. Normally air temperature decreases with height; in an inversion, air temperature increases with height).

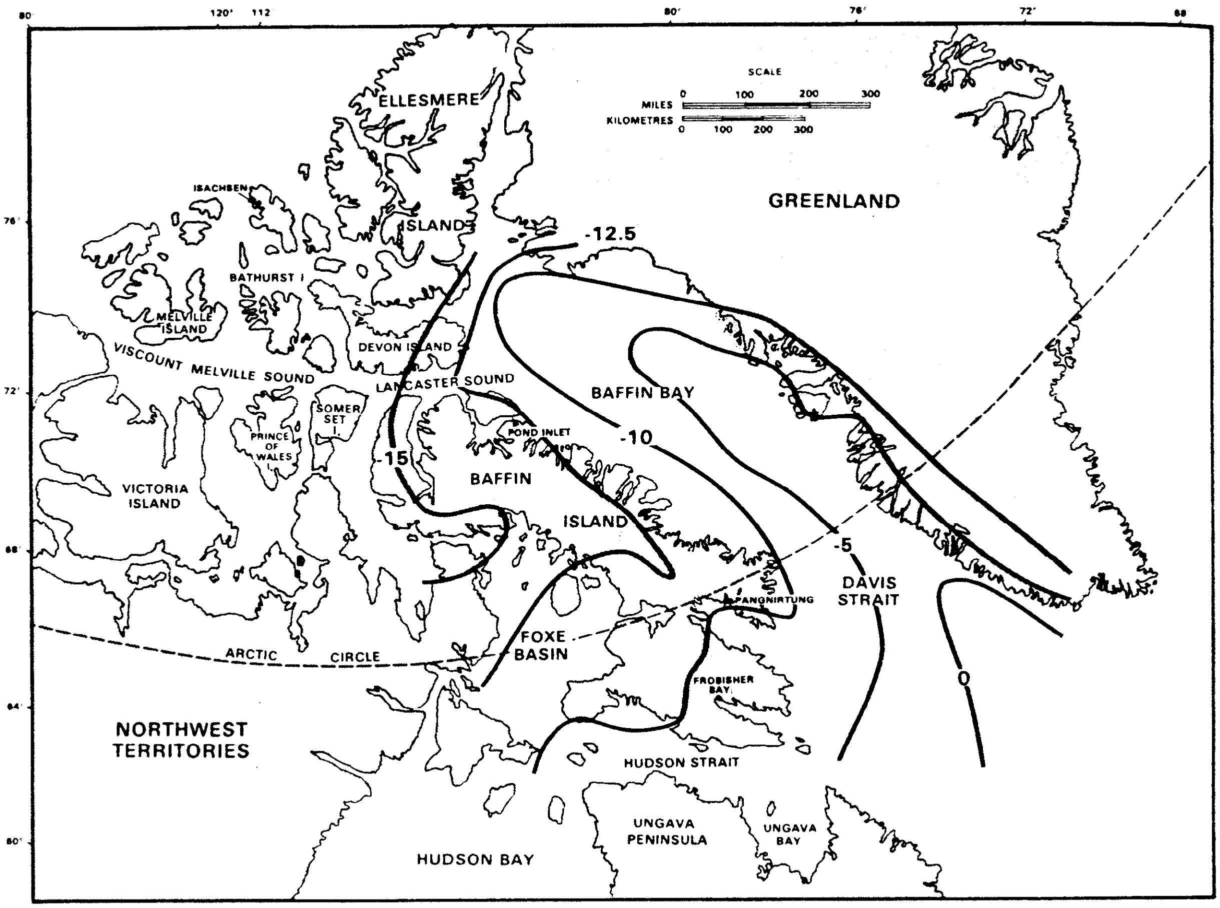

FIGURE 1.2-6 *Annual mean daily air temperatures (0° C) for the Baffin Bay-Davis Strait region. 1941-1970 (from Maxwell. 1980). The most important feature is the tongue of relatively warm air that extends northward into eastern Baffin Bay. The tongue results from the large number of storms that track northward over these waters and from the relatively warm West Greenland current (see Figure 1.3-7).*

1.2.2.2 Precipitation

Figure 1.2-10, based on data from 1941-1970, illustrates total mean annual precipitation for the Baffin Bay-Davis Strait region. Inland stations provide the most complete precipitation records, although data from ships are also available during the summer. The precipitation ranges from 150 mm over northwestern Baffin Island to nearly 700 mm in the mountainous regions of the island (Maxwell, 1980). The high precipitation recorded on the eastern coastal slopes of Baffin, Devon and Ellesmere islands reflect the importance of local onshore and upslope air flow in producing precipitation that greatly exceeds that reported in lee areas.

Precipitation over Baffin Bay and Davis Strait is strongly influenced by ice concentrations. From July to October, the water is warmer than the air, making evaporation from the water surface an important moisture source for local precipitation. In the winter, areas of open water are few. However, persistent northerly winds in winter clear the ice from north Baffin Bay leaving a large area of open water called the 'North Water.' This open water increases the local precipitation, particularly in areas of Ellesmere Island with onshore and upslope flow. During winter, significant areas of open water also persist as far north as Disko Bay on the west coast of Greenland. Added to topographic effects on the shores of Baffin Island, and the local effects of large areas of open water, is the generally higher precipitation which occurs in the southern-most regions as a result of numerous storms. The majority of storm systems in this area track northward through Davis Strait, losing most of their moisture over the southern regions (Maxwell, 1980). The Greenland ice cap and mountainous terrain of Baffin Island occlude and slow the storms, so that precipitation in Baffin Bay is lower than in southern areas (Maxwell, 1980).

Total mean annual rainfall for the region is shown in Figure 1.2-11. Comparison with Figure 1.2-10 shows

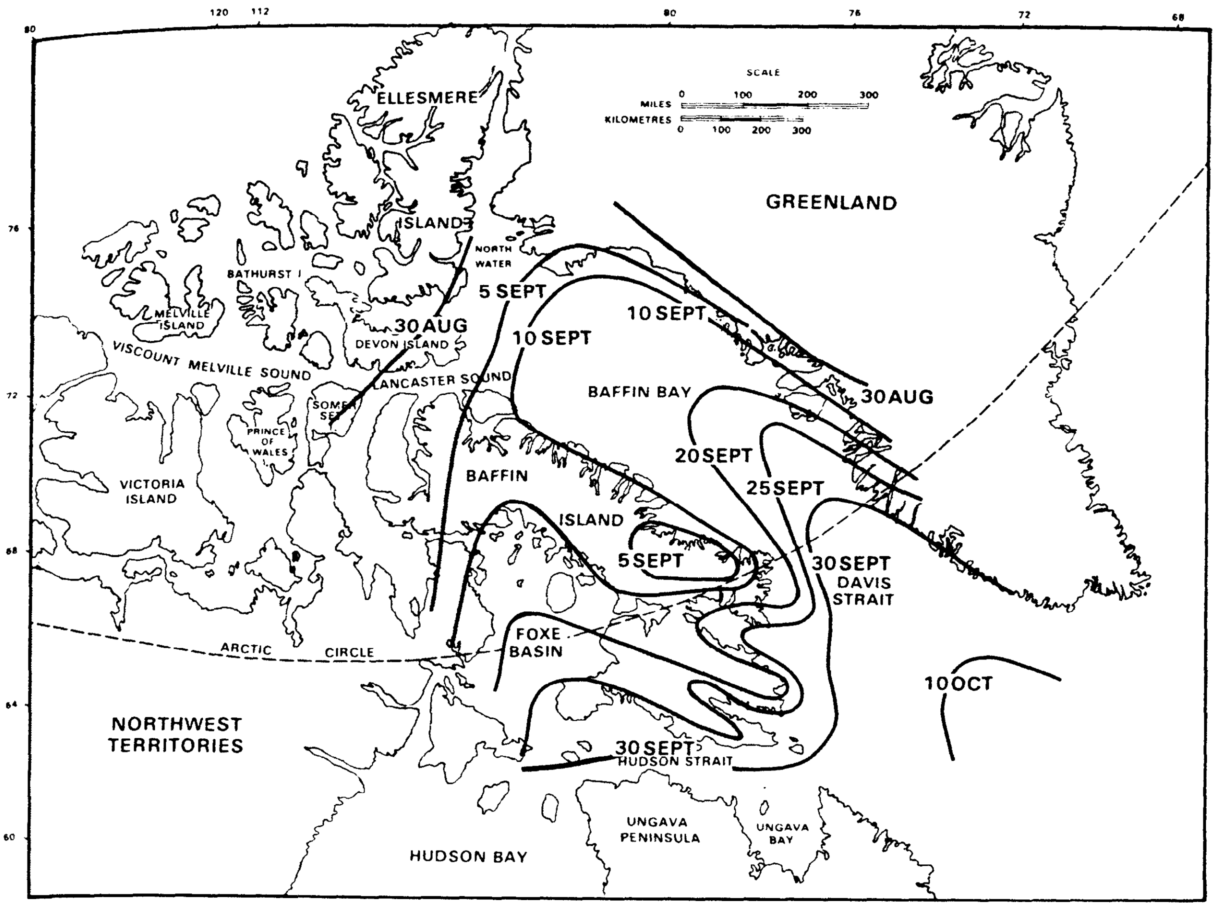

FIGURE 1.2-7 *Annual mean date of the onset of winter (0° C mean daily temperature) for the Baffin Bay-Davis Strait region (from Maxwell, 1980). Near the southern end of Ellesmere Island, winter begins on about the 30th of August, but is delayed to about the 10th of October in southern Davis Strait. Off the west coast of Greenland, where open water persists into November or December, it can be delayed even more.*

that in the extreme southern part of Davis Strait, the total annual precipitation is divided almost equally between rainfall and snowfall. However, the ratio of rainfall to the total precipitation decreases towards higher latitudes, as well as at higher elevations. The northern-most and highest locations receive only 10 to 15% of their total precipitation as rainfall, where it generally falls as a light but steady drizzle. In the northern and central parts of the region, rain only occurs during the months of June through September. The southeastern regions can be influenced by warm moist air during any season, so that rain can be expected during any month of the year. Snowfall is the dominant form of winter precipitation throughout the Baffin Bay and Davis Strait region. Ice crystals and hoar frost form a small part of the total precipitation, but can occasionally occur in appreciable amounts (Maxwell, 1980).

The frequency of freezing precipitation is of great importance to both marine transport and aviation (Section 1.2.2.6). Western Baffin Bay and Davis Strait receive from 25 to 50 hours of freezing precipitation each year, with more than 100 hours occurring off southeastern Baffin and Resolution Islands (Maxwell, 1980). Freezing drizzle accounts for 80% of the total freezing precipitation, with the remaining 20% being freezing rain. Ten to 15 mm of ice can be deposited during a storm, with amounts of up to 50 mm being documented in the southeastern Baffin and Resolution Island areas (Maxwell, 1980). Freezing precipitation occurs most frequently in the spring and fall, except along the eastern and southeastern Baffin Island coasts where it is most common in mid summer (Maxwell, 1980).

Most precipitation in the Baffin Bay-Davis Strait region falls during the summer and early fall when storm tracks are displaced northward. The least precipitation is generally recorded in February or March (Maxwell, 1980).

1.2.2.3 Visibility

Blowing snow is the main cause of reduced visibilities from October to May in the Baffin Bay-Davis Strait region. Wind blown snow is reported as "blowing

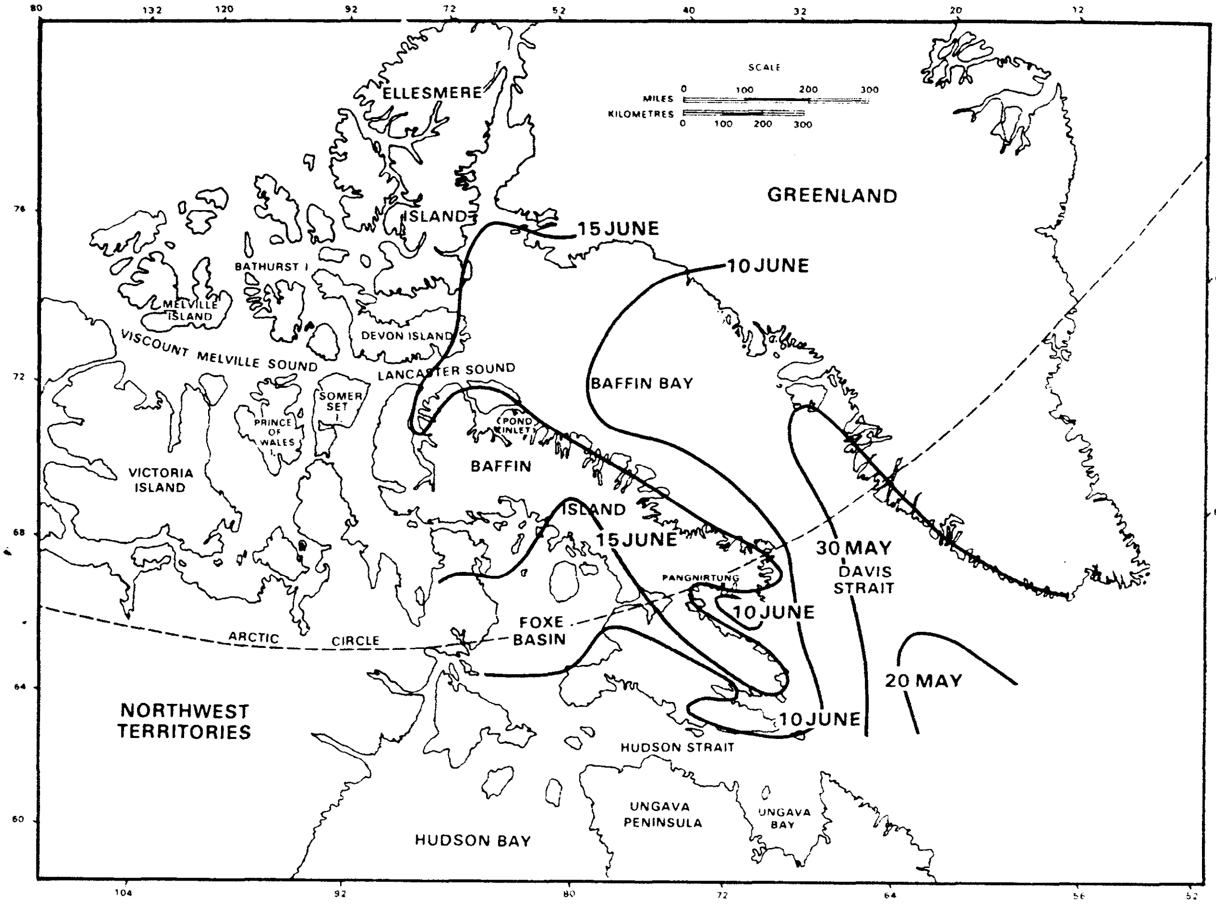

FIGURE 1.2-8 *Annual mean date of the onset of summer (mean daily temperatures greater than 0° C) for the Baffin Bay-Davis Strait region (from Maxwell, 1980). The onset of summer is earlier off the Greenland coast than in the western parts of Baffin Bay and Davis Strait partly due to the relatively warm West Greenland current and the cold Canadian current (see Figure 1.3-7).*

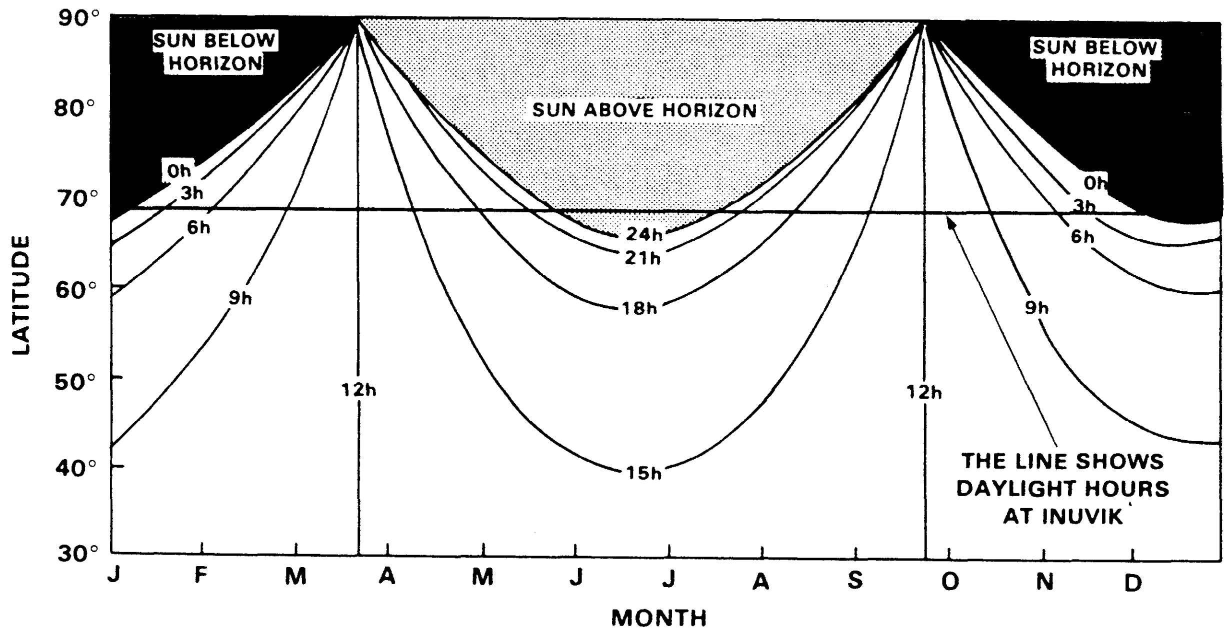

FIGURE 1.2-9 *Hours of daylight for northern latitudes. At the latitude of the Northwest Passage, the sun remains below the horizon for about three months but south of the Arctic Circle, in Davis Strait, there are no mid-winter days where the sun remains below the horizon.*

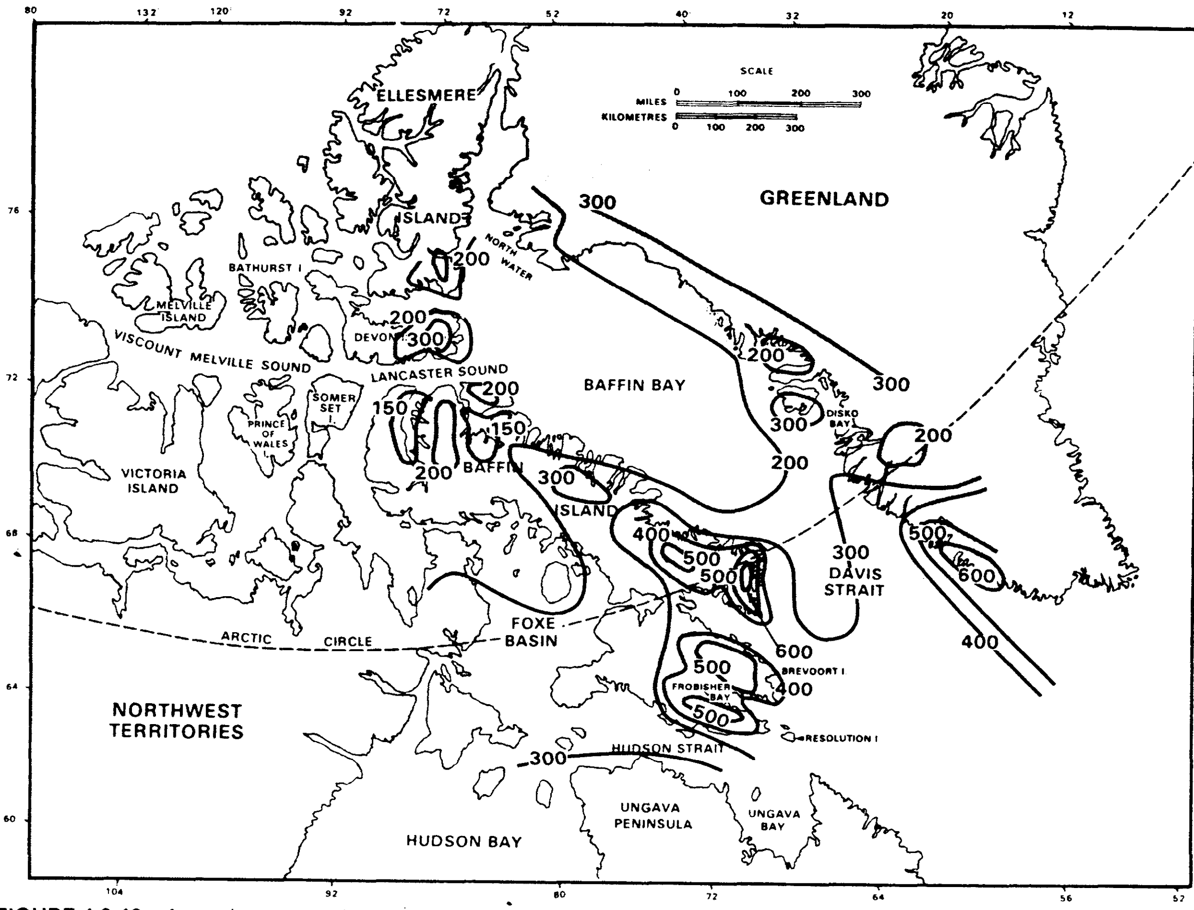

FIGURE 1.2-10 *Annual mean total precipitation (mm) for the Baffin Bay-Davis Strait region, 1941-1970 (from Maxwell, 1980). Ice concentrations strongly influence precipitation. From July to October, the water is warmer than the air so that the water is an important moisture source. In winter, the open water in the North Water in northern Baffin Bay increases local precipitation.*

snow" when visibility at eye level is reduced below 10 km (6 miles). Blowing snow is now an important design factor in northern power plants that use gas turbine engines. Blowing snow can also reduce the mobility of people if the location of doorways and roadways are not planned to avoid blockage by drifting snow. However, data on blowing snow at sea are only available for the summer when it seldom occurs.

Blowing snow is less likely to occur when deposits of snow are old and compact. On the other hand, snow that has recently fallen is more easily lifted by the wind, although if winds of 55 to 60 km/h persist for several days, the remaining snow cover will become packed and resist further erosion (Maxwell, 1981). Blowing snow usually occurs in January or February, except in Hudson Strait where it may occur a few months earlier. These events generally last for six hours or less (Maxwell, 1981), although longer periods are common. For example, one event on Brevoort Island in January lasted 132 hours. A study by Fraser (1964) at selected locations in the Arctic showed that blowing snow and strong winds greater or equal to 48 km/h, existed in 90% of the cases examined. Station records indicate that during the winter, the probability of wind exceeding this limit is greater than 20% at Resolution Island, but less than 5% at Frobisher Bay.

Fog is not only a hazard to aircraft, but can also hamper marine operations. During the summer, June to September, sea fog is the primary cause of reduced visibility. The southerly flow of warm moist air into the Davis Strait and Baffin Bay region cools as it passes over water or ice until its moisture condenses to form a dense widespread fog. With onshore breezes, this fog can penetrate inland a few kilometres before dissipating. An increase in wind speed to greater than 15-20 kph will often lift the fog to form low cloud and improve visibility to greater than 10 km. Maxwell *et al.* (1980) found that for marine areas in northwestern Baffin Bay, higher wind speeds are usually associated with high visibilities (greater than 10 km), whereas the lowest visibilities (less than 0.8 km) are usually associated with the lowest wind speeds.

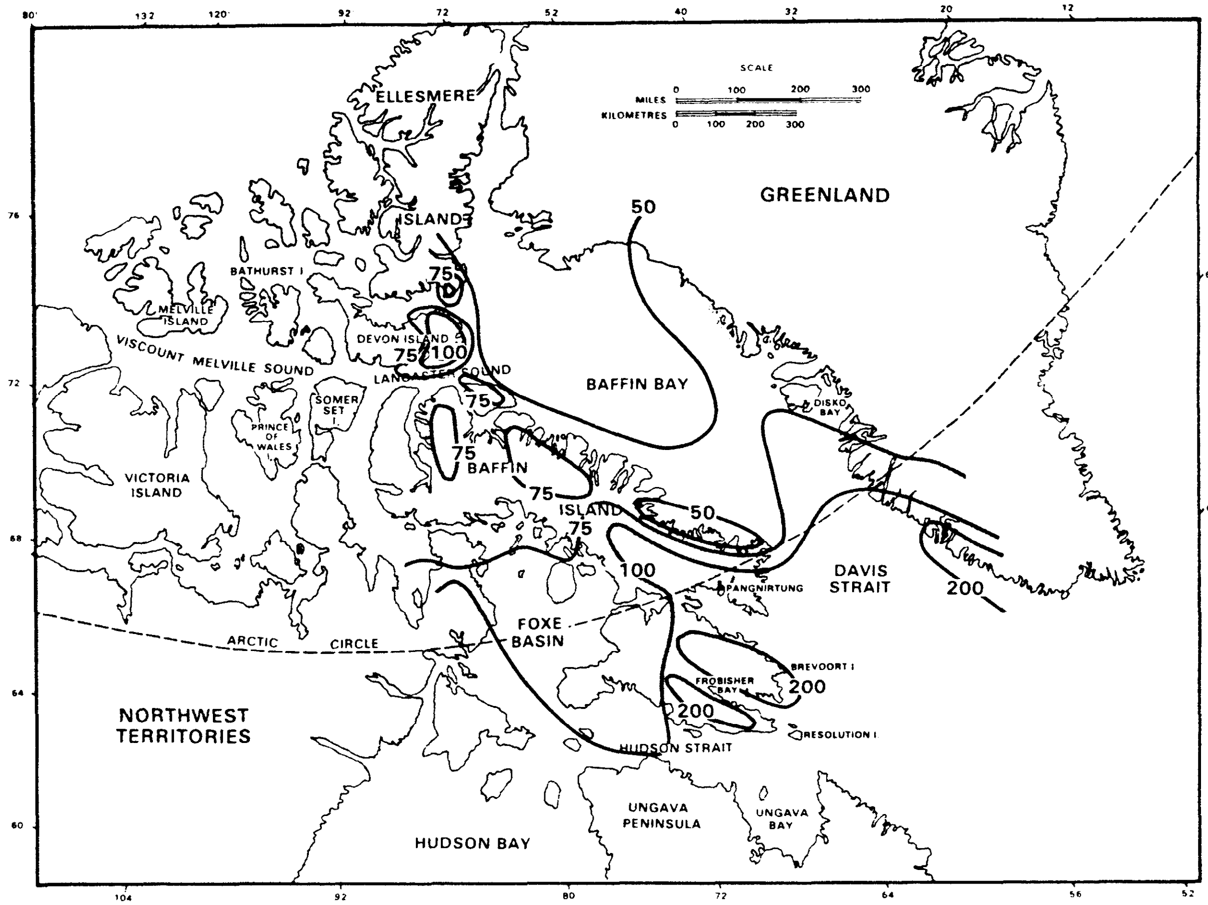

FIGURE 1.2-11 *Annual mean rainfall (mm) for the Baffin Bay-Davis Strait region, 1941-1970 (from Maxwell, 1980). Comparison with Figure 1.2-10 shows that in southern Davis Strait, the total annual precipitation is divided almost equally between rainfall and snowfall. In the mouth, rainfall is only 10 to 15% of the total precipitation.*

Coastal fog along Davis Strait frequently persists for more than 24 hours during the summer and early fall, although it normally lasts for less than 6 hours (Maxwell, 1981). The record for the maximum duration of fog in the Arctic is 342 hours at Brevoort Island during August (Maxwell, 1981). Limited marine data suggest that fog occurs most frequently in July or August, with the highest documented frequency being 44% over southern Davis Strait in July (Maxwell, 1981).

As the summer progresses, the sea fog becomes patchy but continues to persist until freeze-up. Although fog is rare in northern Baffin Bay after mid September, it occurs as late as October over southern Baffin and Resolution Islands (Maxwell, 1981). Steam fog occurs in October and November when cold Arctic air passes over the warm sea. Steam fog is more patchy than advection fog, and is seen less often as the ice cover increases during winter. In areas such as the 'North Water' where open water can be extensive, steam fog also occurs during winter.

Horizontal visibility with ice crystals suspended in the air is seldom less than 3 to 8 km while the vertical visibility remains relatively unaffected. Ice fog occurs naturally in inhabited areas at temperatures below -30°C, and in uninhabited areas at temperatures below -40°C (Maxwell, 1981). Such a low temperature threshold for its occurrence normally restricts its formation to high Canadian Arctic islands and therefore it is not common in the Baffin Bay-Davis Strait region.

"Whiteout" is an optical phenomenon that also reduces visibility. Whiteout occurs when light, diffused through an overcast sky, undergoes multiple reflections between the overcast and the underlying snow or ice surface. White objects become invisible and depth perception is lost. "Snow blindness" can result when intense low angle sunlight strikes the eye from below. This may lead to severe inflammation or burning of the cornea if the eye is not properly shielded.

Without these obstructions to vision, visibility in the clear Arctic air is excellent. In fact, most locations report visibilities over 10 km, 70 to 80% of the time throughout the year, with maximum visibility occurring during the summer. However, over the sea, the high incidence of fog reduces this percentage as confirmed by Maxwell's (1981) analysis of July to October data. Visibilities are reduced below 10 km in fog from 25 to 44% of the time in July, and from 20 to 30% of the time in August. A high incidence of fog is similarly reflected in data from Resolution and Brevoort islands.

As over the Northwest Passage, the worst flying conditions (low cloud ceiling and visibility) in this region generally exist in the summer and fall. From July to October, visibilities are less than 3.2 km and cloud ceilings less than 300 m between 27 to 33% of the time over Baffin Bay and Davis Strait (Maxwell, 1981).

1.2.2.4 Wind

Ice drift and high seas driven by the wind are of importance to ships in the region. The highest wave heights in the Canadian Arctic have been recorded in southern Davis Strait where winds can blow over large expanses of open water.

In the Baffin Bay-Davis Strait region, topography has an important effect on local wind fields. Winds near the coasts of Baffin, Devon and Ellesmere islands are controlled in part, by the local topography and are therefore not necessarily the same as the winds over adjacent waters. The mountainous terrain near the eastern island coasts, the mountain glaciers, and the strong temperature contrast between the land and the sea, influence surface winds in this region.

Channelling and intensification of the wind through mountain passes or narrow straits can produce strong winds, particularly when winds are aligned with topographical features. This is commonly the case along the coast of Baffin, Devon and Ellesmere islands.

Katabatic winds were previously described in Section 1.2.1.4. Glaciers in the mountainous areas of this region are responsible for producing the strong thermal gradients required to initiate very strong downslope surges of air such as the well known katabatic winds from the Greenland ice cap.

In contrast, the relatively warm "Foehn" wind descends over glaciers and tends to melt the accumulated ice and snow. Foehn winds have been known to approach hurricane speeds on the west coast of Greenland (Maxwell, 1980).

Local sea and land breezes occur when there are strong temperature contrasts between the land and the sea. During the winter, land breezes can develop from the edge of the pack ice or from open water areas. In the summer, sea breezes are particularly noticeable, when the pack ice is close to shore or when the general air flow is weak. After the summer months are over, sea breezes in fiords virtually disappear because fiord air drainage towards the sea dominates.

In Davis Strait, the predominant wind direction throughout the year is northwesterly (Marko *et al.*, 1981). During July and August, the incidence of southeasterly and easterly winds increases, although gale force winds (greater than 65 km/h) are generally from the north or northwest.

An extreme wind analysis completed by Maxwell (1981) for July through to October shows 20 year return period extreme wind speeds varying from 86 km/h in central regions to 118 km/h in southern Davis Strait (Figure 1.2-12). Off southeastern Devon Island, a 20 year return period extreme wind of 99 km/hr was obtained by Maxwell *et al.* (1980). The highest mean and extreme wind speeds are expected during periods when storms are more frequent and intense. This usually happens during the fall in Baffin Bay and northern Davis Strait, and during the winter in southern Davis Strait (Maxwell, 1981).

1.2.2.5 Wind Waves

The size of the water bodies, as well as the large expanses of open water, cause wave heights in the Baffin Bay-Davis Strait region to exceed those found elsewhere in the Canadian Arctic. Swell waves also propagate into the region from distant storms. These, added to wind-waves, contribute to the significant wave heights, particularly in southern Davis Strait.

Sea state statistics derived from ship observations off the west coast of Greenland and Davis Strait predict that between October and May, wave heights will exceed 3 m from 5 to 12% of the time, and will generally be highest in April. An analysis of wave data by Imperial Oil *et al.* (1978) indicated that in southern Davis Strait (63°N, 59°W), the average significant wave height was 1.2 m during the years 1970-1977. (The "significant wave" has a mean height equal to the mean height of the highest third of all waves in the wave train). The 3 m wave height at this location was exceeded 10% of the time, with a maximum exceedance of 35% in one month. Waves in the 2 to 5 m range persisted for several days, whereas the highest storm waves occurred over much shorter periods. Significant wave heights, averaging 1.84 m, were highest during November and December when the waters are normally free of ice and storms are most severe. A maximum wave height of 9.5 m was reported during this period. However, compari-

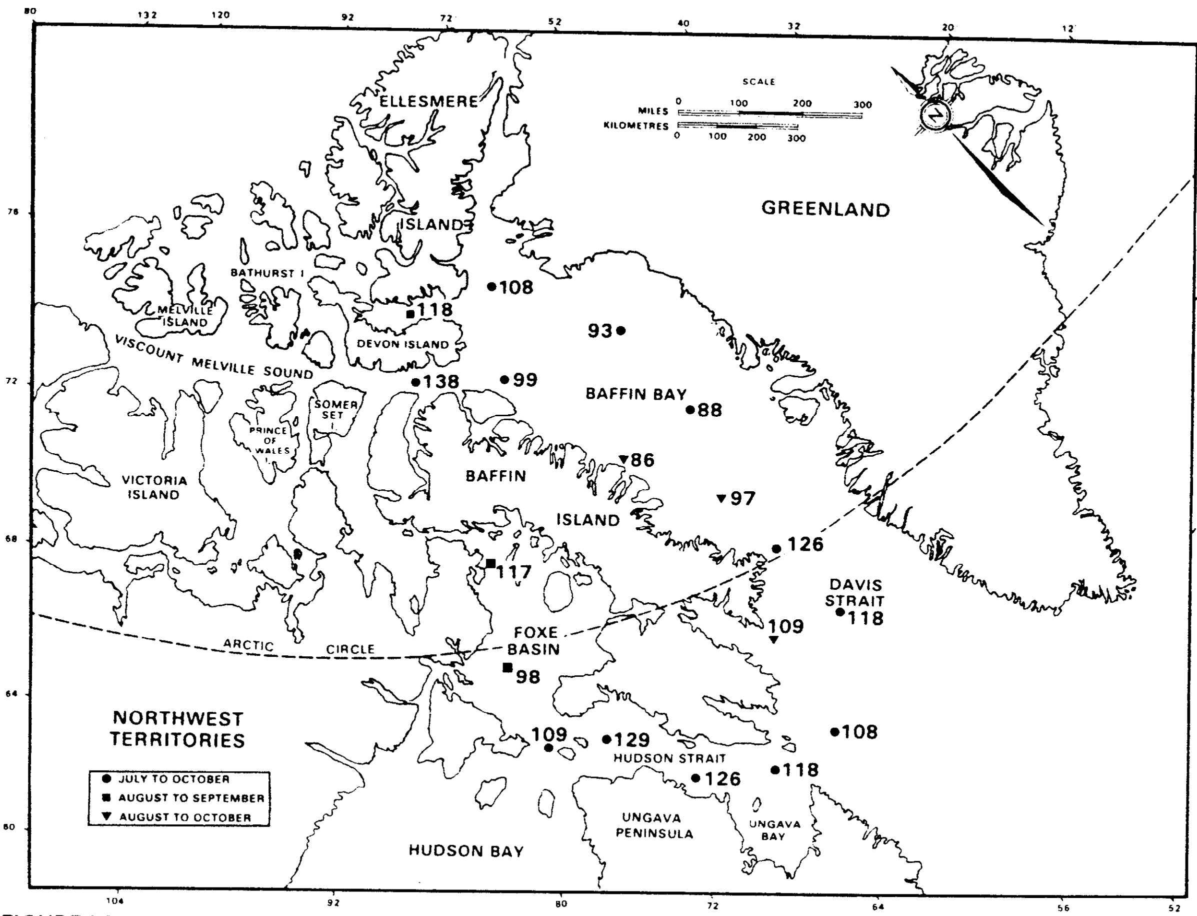

FIGURE 1.2-12 *Extreme hourly wind speeds (km/hr) with a 20-year return period for various locations (from Maxwell, 1981). The highest mean and extreme wind speeds are expected when storms are more frequent and intense. This is usually during the fall in Baffin Bay and northern Davis Strait and during the winter in southern Davis Strait.*

son of this analysis with wave rider buoy data from the Marine Environmental Data Service, Ottawa, suggests that the extreme wave heights were overestimated.

A seasonal extreme wave and wave climate analysis was performed by Maxwell (1981) using all marine observations available for the months of July to October. This study shows that wave heights are expected to decrease as one moves northward through Davis Strait. This decrease is expected since the more northerly waters have shorter fetches and greater concentrations of ice. In the northern waters of Baffin Bay, there is only a 1% probability that wave heights will exceed 3.5 m during the summer (Maxwell, 1981). This probability for 3.5 m wave heights increases to 5% in southern Davis Strait. Here there is also a 1% probability that wave heights will exceed 5.5 m. Extreme significant wave heights with 20 year return periods increase from 6.3 m in northern Davis Strait to 8.1 m in southern Davis Strait (Figure 1.2-13). These would correspond to maximum wave heights of 11.3 and 14.6 m, respectively. However, the few marine observations available result in these wave predications having wide confidence limits.

1.2.2.6 Structural Icing

In the Canadian Arctic, icing caused by freezing rain or drizzle is relatively infrequent and occurs mostly in the spring and fall. Most areas record less than 25 hours of freezing precipitation annually. However western Baffin Bay and Davis Strait receive 25 to 50 hours each year, while southern Davis Strait, in the vicinity of Brevoort and Resolution islands, may receive up to 100 hours (Maxwell, 1981). The eastern and southeastern coasts of Baffin Island also differ from High Arctic locations by showing distinct mid summer maxima in freezing precipitation occurrences. The more frequent freezing precipitation in the southern waters suggests that there could be greater icing hazards to marine operations in these waters.

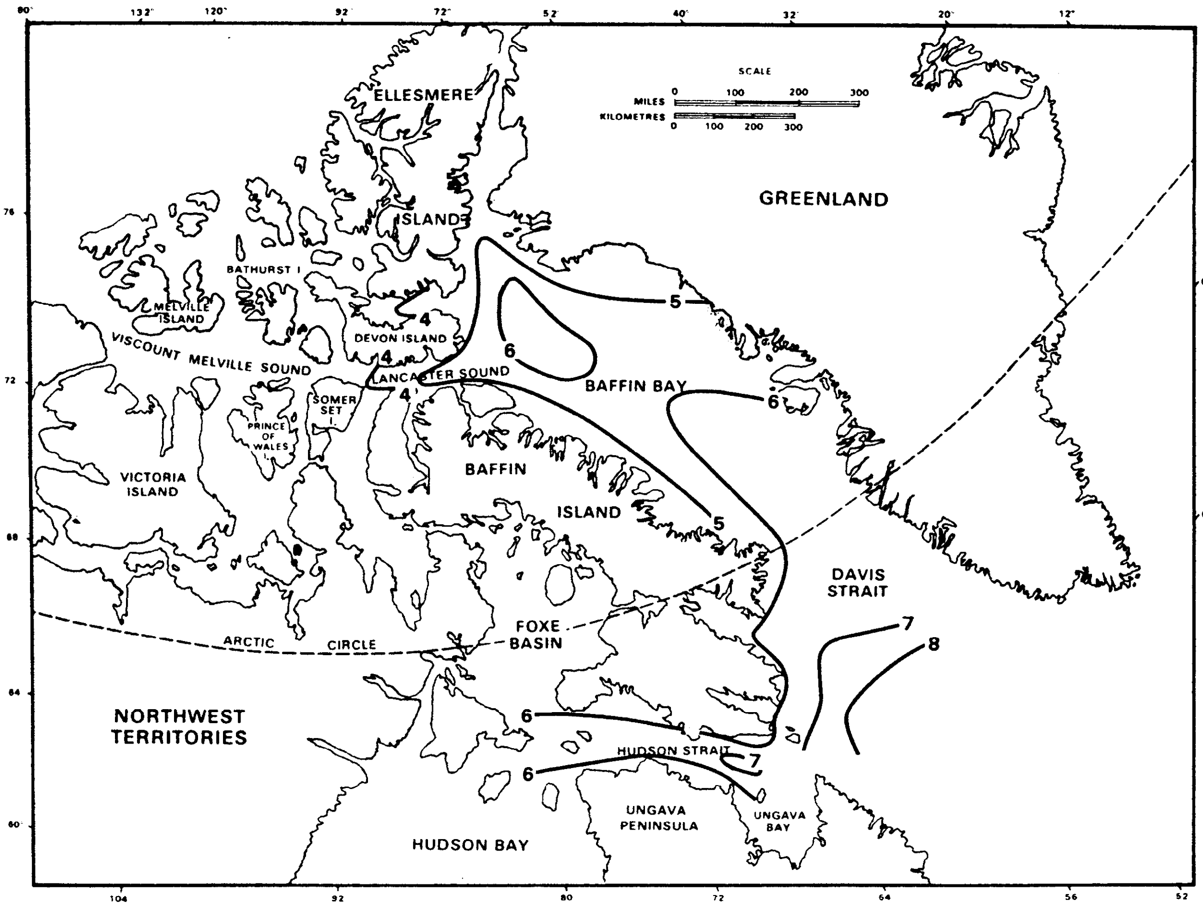

FIGURE 1.2-13 *Extreme significant wave heights (m) with 20-year return periods for the Baffin Bay-Davis Strait region (from Maxwell, 1981). Extreme significant wave heights are expected to decrease as one moves northward through Davis Strait since there are shorter fetches and greater ice concentrations to the north in the strait.*

Freezing fog, as distinct from freezing rain or drizzle, forms when the water droplets of either sea (advection) fog or steam fog are supercooled. During the summer, when sea fog is common in southern Davis Strait, temperatures are above 0°C and freezing fog is unlikely. During the fall, cold Arctic air flowing over the warm 'North Water' can result in supercooled water droplets which condense to form freezing steam fog (Maxwell, 1981). However, the ice boundary surrounding such areas of open water limits the occurrence of this phenomenon.

Freezing spray is another form of icing. Maxwell (1981) used the nomogram, previously shown in Figure 1.2-4, to determine the possible frequency of freezing spray events at Arctic coastal stations. His determinations were then used to plot percentage frequency isolines over adjacent marine areas. Although the general pattern of icing events is what would be expected, the results could not be verified since no marine observations of freezing spray were available for this study.

Freezing spray is most likely to occur from September to November, when there is little sea ice and air temperatures are just below freezing. The freezing spray potential in the Baffin Bay-Davis Strait region during October is shown in Figure 1.2-14. Most freezing spray events are expected in October. During this month, moderate freezing spray conditions can exist more than 20% of the time in Baffin Bay and Davis Strait. Along the eastern coast of Baffin Island and Baffin Bay, heavy freezing spray is expected 5% of the time, while in northern Baffin Bay over 1% of the time very heavy freezing spray is expected. (Maxwell, 1981).

By November, the leading edge of the ice pack has advanced far enough southward to confine freezing spray events to waters off the west coast of Greenland, and eastern and southern Baffin Island. In these remaining waters, heavy and very heavy freezing spray events are expected in November. For example, in Hudson Strait heavy freezing spray is expected 10% of the time while very heavy freezing

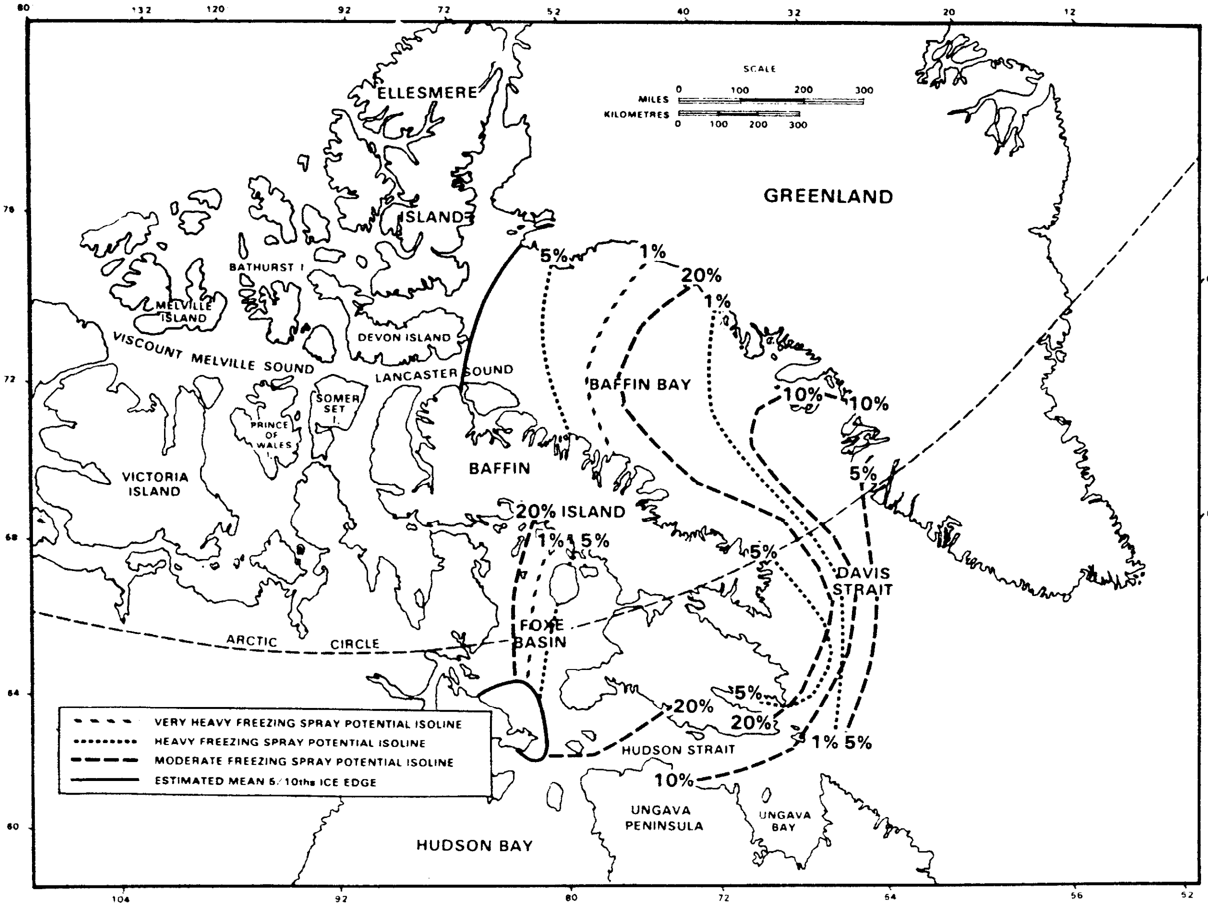

FIGURE 1.2-14 *Frequency of occurrence of freezing spray (% of the time) calculated for October (from Maxwell, 1981). Most freezing spray events are expected to occur in October in the Baffin Bay-Davis Strait region.*

spray is expected 5% of the time (Maxwell, 1981).

Generally, 40% of all moderate freezing spray occurrences persist beyond six hours with a maximum duration of 81 hours, using data recorded at Resolution Island during the month of November. Most heavy and very heavy freezing spray occurrences are expected to last for an average of less than six hours, with maximum durations of 33 and 60 hours, respectively, expected in November at Resolution Island.

1.3 WATER MASSES AND THEIR MOVEMENTS

1.3.1 NORTHWEST PASSAGE

1.3.1.1 Setting

Knowledge of water mass movements and their variability are important for understanding and predicting ice movements relative to shipping and to assist in developing trajectories for possible oil spills should they occur. The data base describing the physical and chemical oceanography of this region is much less comprehensive than that available for the Beaufort, Baffin Bay and Davis Strait regions. In this section the oceanography of the region is discussed under the following geographical sub-regions: Prince of Wales Strait, Viscount Melville Sound and the Eastern Northwest Passage (Barrow Strait and Lancaster Sound).

The bathymetry of a region influences water masses and their movements (Figure 1.3-1). Section 1.4 will discuss bathymetry in further detail. Prince of Wales Strait is less than 200 m in depth and generally shallower than 100 m. A 90 m deep sill near the Princess Royal Islands prevents the exchange of deep waters between Amundsen Gulf and Viscount Melville Sound.

The waters of Viscount Melville Sound are indirectly

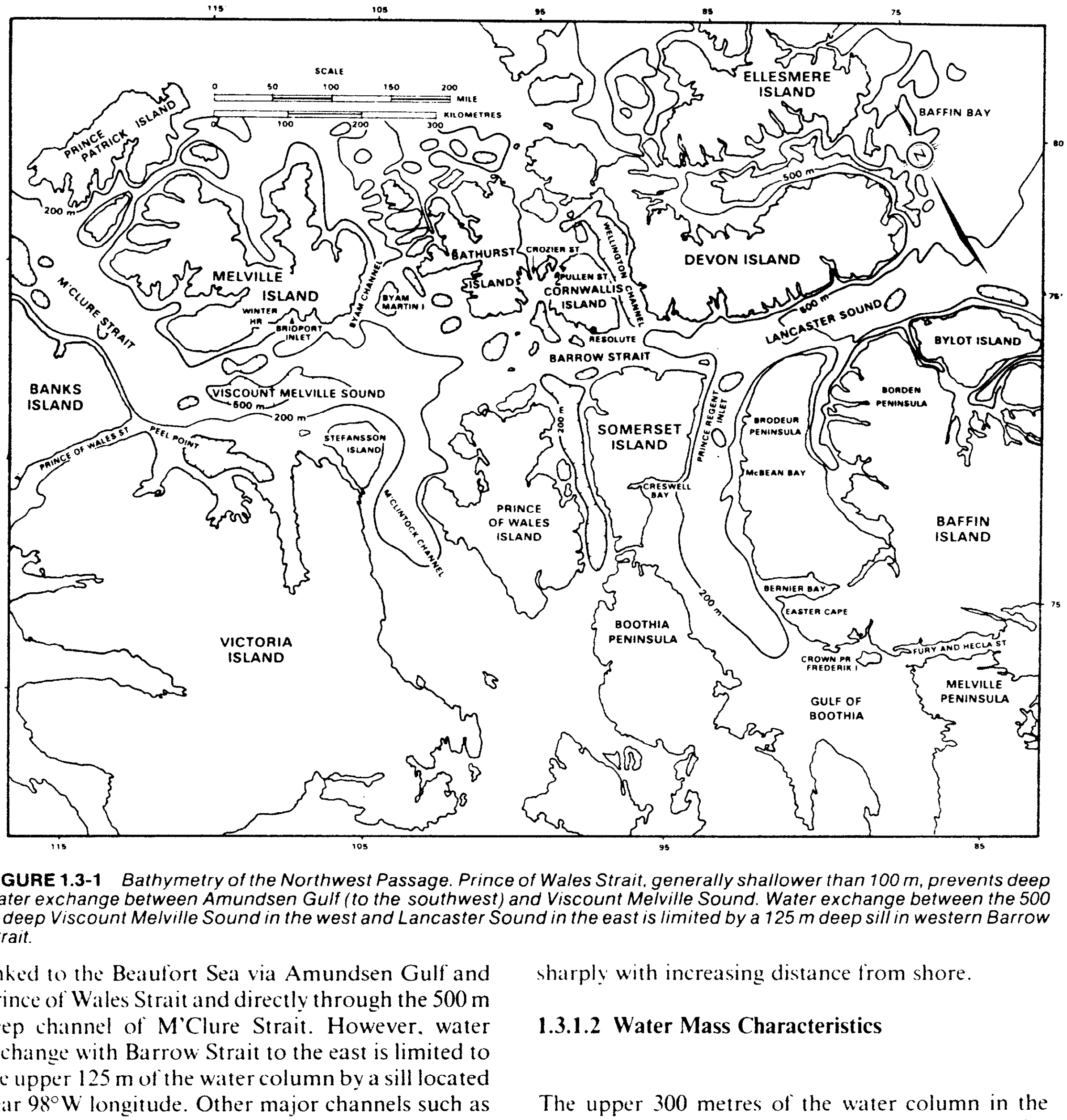

FIGURE 1.3-1 *Bathymetry of the Northwest Passage. Prince of Wales Strait, generally shallower than 100 m, prevents deep water exchange between Amundsen Gulf (to the southwest) and Viscount Melville Sound. Water exchange between the 500 m deep Viscount Melville Sound in the west and Lancaster Sound in the east is limited by a 125 m deep sill in western Barrow Strait.*

linked to the Beaufort Sea via Amundsen Gulf and Prince of Wales Strait and directly through the 500 m deep channel of M'Clure Strait. However, water exchange with Barrow Strait to the east is limited to the upper 125 m of the water column by a sill located near 98°W longitude. Other major channels such as Byam and Austin Channels open into the sound from the north and M'Clintock Channel from the south.

Barrow Strait and Lancaster Sound are the major links between the waters of the Arctic Archipelago and Baffin Bay. Shallow sills, principally across western Barrow Strait, southern Wellington Channel, Crozier Strait and Pullen Strait, limit the circulation of western and northern water to the upper 150 m of the water column. At greater depths, contact is maintained with the adjacent waters of Baffin Bay through a deep trench which runs along the channel axis and connects the relatively shallow, less than 300 m deep, Barrow Strait to the 800 m deep waters of eastern Lancaster Sound. The coastal shelves in this region tend to be less than 10 km in width, and fall off sharply with increasing distance from shore.

1.3.1.2 Water Mass Characteristics

The upper 300 metres of the water column in the Northwest Passage has the characteristics of the relatively cold (0°C to -1.8°C), low salinity (less than 31.0 to 34.4 ⁰/oo) Arctic water layer (Bailey, 1957; Collin, 1962; Muench, 1971; Fissel *et al.*, 1980). This layer extends to the bottom in Prince of Wales Strait and includes a characteristic upper layer less than 40 m thick which is modified by solar heating, wind mixing and ice melting. Its properties and thickness vary markedly with season and location, with salinities ranging from 28.0 to 32.5 ⁰/oo and temperatures from -1°C to 3°C, or higher (Fissel *et al.*, 1980). Away from the coasts, the thickness of this sublayer usually increases during the open water season, while near the coasts the increased freshwater runoff from land often enhances stratification and inhibits layer deepening. Below the upper layer, the water properties of the Arctic water mass are relatively uniform.

Atlantic water occurs at depths of 250 m or more at the eastern and western ends of the Northwest Passage. It enters Viscount Melville Sound from the Beaufort Sea through M'Clure Strait, and is generally confined to the central and western sound by a shoaling bottom to the east. Baffin Bay is the source of Atlantic water in the eastern Northwest Passage. Consequently, the Atlantic water in Viscount Melville Sound has higher salinities (34.5°/oo compared to 34.2 to 34.5°/oo) and lower temperatures (0°C to 0.35°C compared to 0°C to 2°C) than in Lancaster Sound and Barrow Strait.

1.3.1.3 Mean Circulation

The principal features of the mean circulation in the Northwest Passage are illustrated in Figures 1.3-2a and 1.3-2b. Regions of strong steady flow, weak and variable flow and the usual locations of strong transient flow-features are also shown.

(a) Prince of Wales Strait

The circulation of Prince of Wales Strait appears to be highly variable. Available information indicates that non-tidal flows in the strait are almost entirely driven by local winds (Lemon *et al.*, 1981). The dominance of northerly winds suggests that southerly flows should predominate over northerly flows. This is indicated in Figure 1.3-2a by an open current vector directed north eastward and a solid arrow directed south westward in northern Prince of Wales Strait. The relatively frequent west-northwesterly winds in this region tend to move ice and surface water toward the east shoreline of the strait (Lemon *et al.*, 1981).

(b) Viscount Melville Sound

In Viscount Melville Sound, the mean surface waters flow mostly to the east. Near-surface currents have

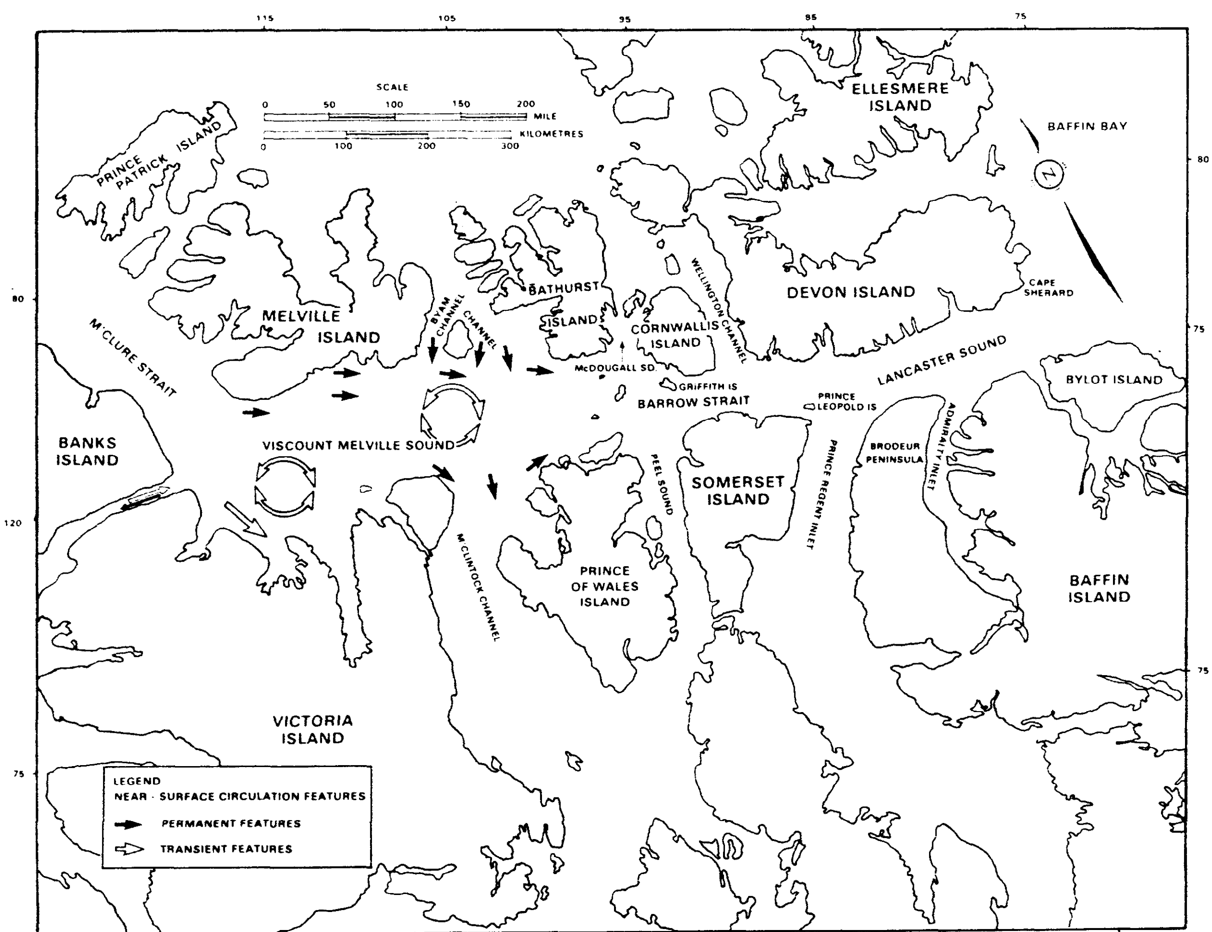

FIGURE 1.3-2a *Mean near-surface circulation in Viscount Melville Sound (from Marko, 1977; Lemon et al, 1981). In Viscount Melville Sound, the mean surface flow is to the east. Southerly currents in Byam and Austin channels, and east and southeasterly flows across the north end of M'Clintock Channel are indicated by ice drift data.*

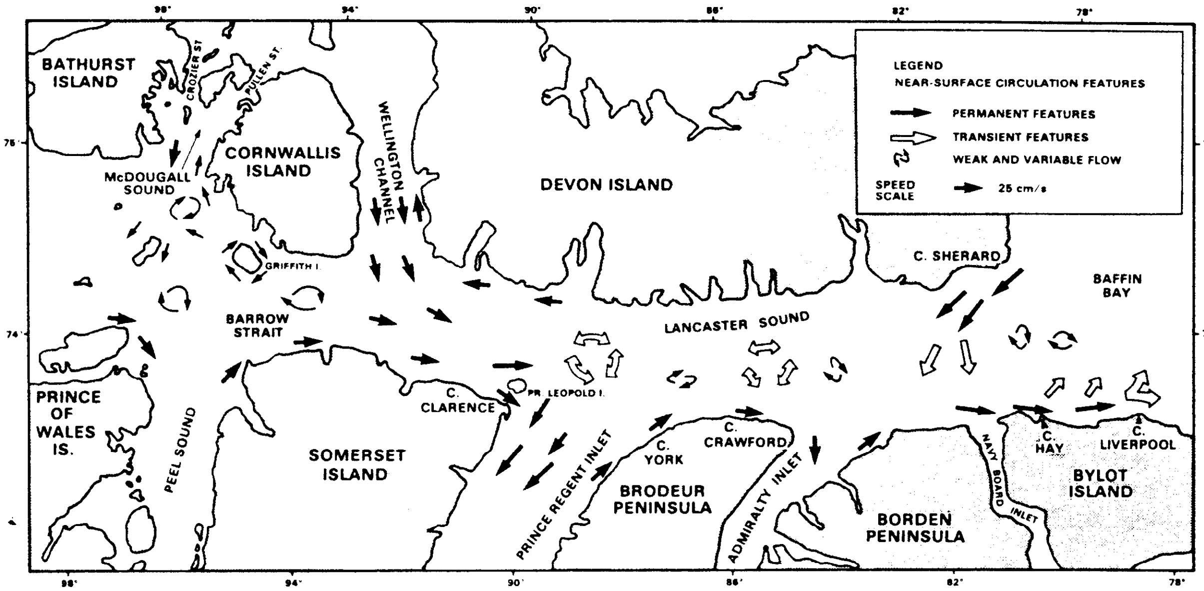

FIGURE 1.3-2b *Mean near-surface circulation in the eastern Northwest Passage (from Fissel et al, 1980). In eastern Barrow Strait there appears to be a net easterly flow. There is a net southerly flow into Prince Regent Inlet with a narrow counterflow to the north along Brodeur Peninsula. In Lancaster Sound, there is a net easterly flow, strongest to the south side of the sound, but with a weaker westerly flow along the south coast of Devon Island. Eddying movements move water across the sound.*

two components; one which is 10 to 30 degrees to the right of the wind direction at about 2% of the wind speed, and a 3 to 5 cm/s residual easterly flow (Lemon *et al.*, 1981). Three to 5 cm/sec easterly currents have been measured during the late winter-spring period at the eastern and western borders of Viscount Melville Sound. It may also be possible to resolve the average south-southeasterly currents in Byam and Austin Channels (Figure 1.3-2a) into separate southerly residual currents of 2 and 5 m/s, respectively, and wind-driven components.

Less current data are available for the ice covered southern half of Viscount Melville Sound than for the northern sound. Easterly and southerly flows across the northern end of M'Clintock Channel are suggested mainly through ice drift data (Marko, 1977; Lemon *et al.*, 1981). However, data on currents are lacking for eastern Viscount Melville Sound, particularly near the junctions with Barrow Strait, and Peel and MacDougall sounds.

(c) Eastern Northwest Passage

The circulation of the eastern Northwest Passage, including the waters of Lancaster Sound and Barrow Strait is extremely complex. Zones of relatively stable, strong flow have been observed in this region (Fissel *et al.*, 1980). In other areas, long term mean flows are weak, although strong, temporary eddies and wind driven circulations often occur on time scales of up to two weeks. This situation is illustrated by the mean circulation patterns shown in Figure 1.3-2b.

The main circulation features in the eastern Northwest Passage are as follows:

1. In McDougall Sound and Wellington Channel, there is a southerly flow with northerly counterflows along the eastern edges of these channels (Fissel and Marko, 1978).

2. In eastern Barrow Strait, there appears to be a net easterly flow. In the eastern and southern part of the strait, an easterly flow has been well documented (Fissel and Marko, 1978; Marko, 1978). A counterclockwise current around Griffith Island has also been reported (Fissel and Marko, 1978; McNeill *et al.*, 1978).

3. The flow in eastern Barrow Strait appears to be toward Prince Leopold Island; then it turns south and southwest, penetrating some 100 to 200 km into Prince Regent Inlet. A narrower, slower northeasterly outflow occurs along the Brodeur Peninsula. There is also an apparent net westerly flow along the southern coast of Devon Island.

4. The Baffin Bay current enters the east end of Lancaster Sound and has speeds up to 75 cm/s near Cape Sherard, (Fissel *et al.*, 1980). These currents weaken when they turn southward towards Bylot Island (Figure 1.3-2b).

Elsewhere in the eastern Northwest Passage, wind driven currents appear to dominate the surface flow in areas with weak and variable mean flows. Net westerly drifts along the south Devon Island coastline tend to contribute to the great eddying movements which move water across and along the length of central Lancaster Sound.

1.3.1.4 Low Frequency Variability

(a) Viscount Melville Sound and Prince of Wales Strait

Local winds are the major cause of changes in the surface circulation on time scales ranging from 1 day up to several weeks. Typical variations in surface movements are evident in the drift track shown in Figure 1.3-3. Larger deviations from the general easterly flow are also evident from measurements of net westerly ice drifts (Verral *et al.*, 1974).

There is also some evidence of seasonal variations in surface flow rates through the adjacent channels of the Archipelago. Such a winter increase of the flow in Crozier Strait has been postulated by Greisman and Lake (1978).

(b) Eastern Northwest Passage

In the eastern waters of the Northwest Passage, variations in the surface flow patterns again appear to be controlled by local winds, but the origins of transient strong flows such as the eddies which occur in central and western Lancaster Sound are not well understood. These eddies have characteristic diameters of 20 to 30 km, daily net speeds of 10 to 20 cm/s, rotation periods of 5 to 10 days, and their currents

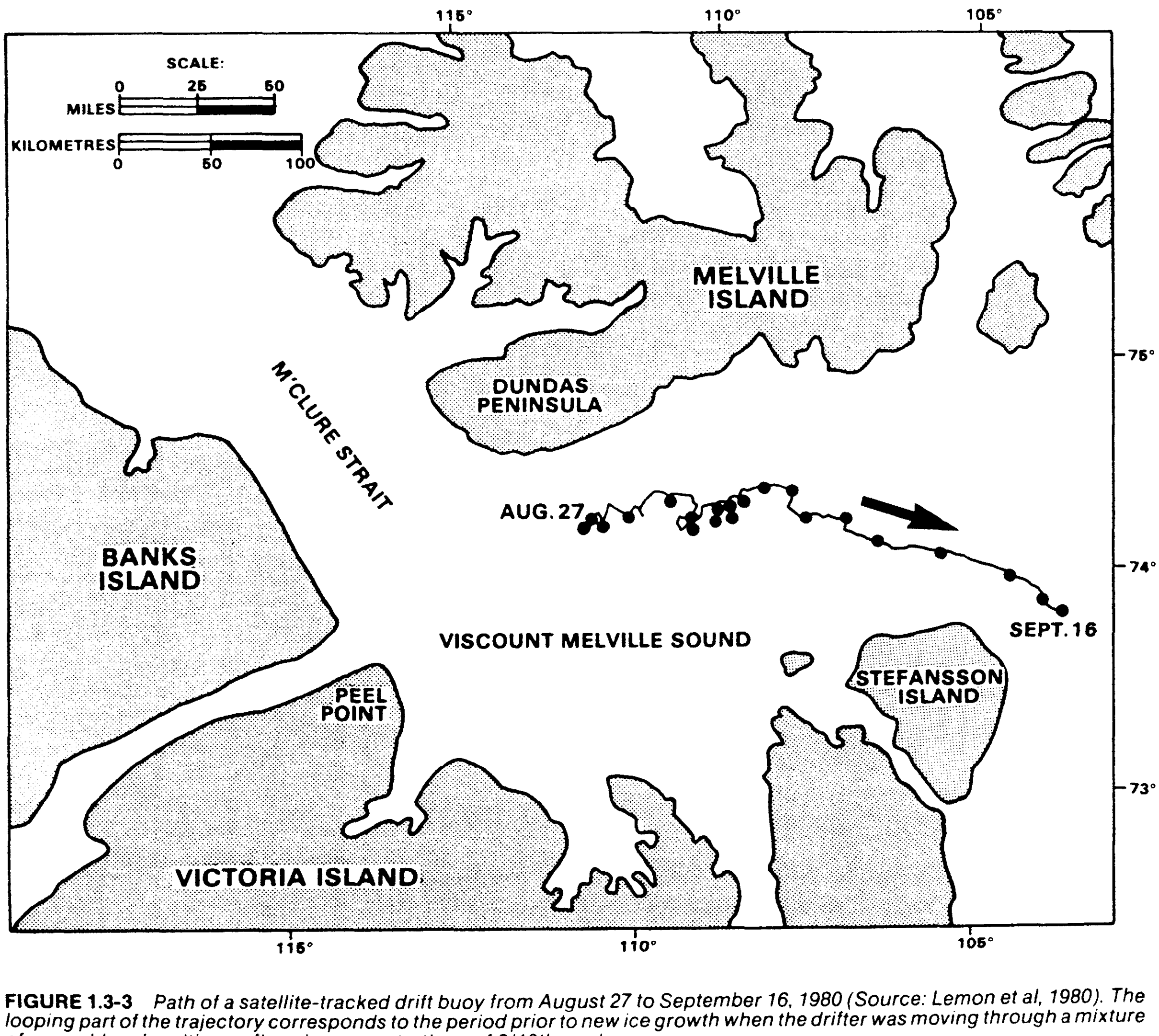

FIGURE 1.3-3 *Path of a satellite-tracked drift buoy from August 27 to September 16, 1980 (Source: Lemon et al, 1980). The looping part of the trajectory corresponds to the period prior to new ice growth when the drifter was moving through a mixture of year-old and multi-year floes in concentrations of 2/10ths or less.*

move both clockwise and counterclockwise (Fissel *et al.*, 1980; Fissel and Birch, 1981).

The Baffin current which intrudes into northeastern Lancaster Sound has been shown to shift position and change in width over time scales of a few days to a few weeks (Fissel and Birch, 1981). This current generally crosses Lancaster Sound in a south or southwest direction and then returns to Baffin Bay along with the easterly or northeasterly flow on the south side of the sound (Figure 1.3-2b).

There is some evidence for seasonal and year to year variations in the circulation near the junction of Lancaster Sound and Baffin Bay. Seasonal measurements of currents at several depths in the water column suggest that appreciable changes occur in Lancaster Sound during the period from November to June (Fissel *et al.*, 1980; Fissel and Birch, 1981). Off southeast Devon Island, this change takes the form of a general decrease in the flow, while off Bylot Island, a much more erratic behavior, including flow reversal, is observed.

The year to year variability in eastern Lancaster Sound currents has been observed in three consecutive summer programs (Fissel *et al.*, 1980; Fissel and Birch, 1981). Current speeds were found to vary by less than a factor of two and little change was observed in the overall summer flow pattern.

1.3.1.5 High Frequency Variability

(a) Viscount Melville Sound and Prince of Wales Strait

The dominant semi-diurnal, near surface tidal currents in Viscount Melville Sound have speeds generally less than 5 cm/s, while tidal flows of 10 cm/s occur in Prince of Wales Strait (Peck, 1978). The tidal range in the Sound is approximately 1 m, with tidal current amplitudes in the north being about twice as large as those in the south.

Inertial oscillations at approximately semi-diurnal frequencies are common in this region as seen in the looping portions of the drift buoy trajectories shown in Figure 1.3-3. These high frequency variations in currents occur following large, abrupt changes in the surface winds.

(b) Eastern Northwest Passage

The tidal contribution to currents in the eastern waters of the Northwest Passage generally consist of a mixture of comparable magnitude diurnal and semi-diurnal flows. The tidal energy enters this region largely from Baffin Bay, although there is a small diurnal contribution from the Beaufort Sea (Greisman and Lake, 1978).

Recent studies show that in the western part of the Northwest Passage, tidal currents are the dominant form of high frequency variability (Greisman and Lake, 1978). These semi-diurnal tidal currents appear to be enhanced near the western Barrow Strait sill. Tidal currents in this region also tend to be aligned with bathymetric contours.

In eastern Lancaster Sound, the slower speeds, approximately 10 cm/s, of the individual tidal current components are of lessened significance due to the generally higher mean current speeds in the area. However, faster tidal currents do occur locally, usually close to shore, and have been documented at some locations such as off the tip of the Brodeur Peninsula (Fissel and Wilton, 1978).

Other forms of higher frequency variability include internal tides which result from interactions between the surface tide and bathymetric features, as well as inertial oscillations. Internal tides are difficult to observe at semi-diurnal frequencies since they can be masked in a tidal analysis by inertial oscillations in the upper water column. The characteristic gradients in vertical amplitude of internal waves are visible, however, in the analysis of diurnal frequencies of the stratified coastal waters near Cape Hay on northeast Bylot Island (Fissel *et al.*, 1980; Fissel and Birch, 1981; Fissel, 1981).

Long term, time-series current measurements collected at a mid-channel mooring north of the Borden Peninsula indicate that typical and maximum amplitudes of 12.4 hour period inertial currents are 4 cm/s and 11 cm/s, respectively (Fissel *et al.*, 1980). These currents have similar speeds to the usual offshore tidal currents. As in other Arctic waters, these phenomena are preferentially generated during times when the wind changes rapidly.

1.3.1.6 Nutrients

Water samples collected along three cross-channel transects near Resolute Bay indicated a general depletion of nutrients in the upper 30 to 40 m of the water column (Jones and Coote, 1980). At 100 m depths, phosphate, silicate and nitrate concentrations were found to be 1.8, 25 and 12μg-at/L, respectively, while only slightly higher concentrations were measured at a depth of 170 m. The phosphate and silicate concentrations at depths greater than 150 m also decreased from west to east along the channel. In addition, Jones and Coote (1980) also reported a north to south increase in nutrient levels within the intermediate water layer between the depleted surface layer and 150 m.

These results are consistent with the limited mixing of Arctic Ocean and Baffin Bay waters which occurs in this region. The Arctic water, which enters through Barrow Strait, is rich in silicates and phosphate, presumably due to contributions from the Bering Sea. However, the presence of the 155 m deep sill at the western end of the strait limits the enrichment effects of the Arctic water to shallower depths. The west to east decline in deep water nutrient concentrations is a reflection of a corresponding easterly increase in the dominance of the lower water column by the nutrient-poor Baffin Bay water. Similarly, the north to south increase in the intermediate layer nutrient levels can be attributed to the southern segment of the intrusion of Baffin Bay waters into Lancaster Sound which is mixed with nutrient-rich Arctic Ocean water (Section 1.3.1.3).

There are no available data describing nutrient concentrations and their vertical distribution in Viscount Melville Sound or Prince of Wales Strait.

1.3.2 BAFFIN BAY - DAVIS STRAIT

1.3.2.1 Setting

(a) Baffin Bay

Baffin Bay is situated between the mountainous, heavily glaciated coastlines of west Greenland and the Canadian Arctic Archipelago, and is where Arctic Ocean water which moves southward and eastward through the Archipelago contacts Atlantic Ocean water. However, water exchange between the two oceans is restricted by a 650 m deep sill in northern Davis Strait and by the generally shallower Archipelago channels.

Depths in central Baffin Bay itself exceed 2,300 m (Figure 1.3-4). The continental shelf is relatively narrow on its western perimeters, and is broken by major subsurface canyons extending outward from Lancaster and Jones sounds, as well as from smaller coastal indentations off eastern Baffin Island. In the east, the extensive continental shelf edge is typically located some 200 km or more from the west Greenland coastline.

(b) Davis Strait

The deep basin of western and central Baffin Bay rises gradually south of 70°N latitude toward the broad sill at the north end of Davis Strait (Figure 1.3-4). The mid channel portion of the strait deepens again south of 66°N, and is accompanied by a narrowing of the broad west Greenland continental shelf. This shelf and a narrower counterpart adjacent to southeastern Baffin Island are traversed by trenches near Cumberland Sound and Frobisher Bay. The southeastern portion of Davis Strait is deep and slopes upward to the northwest to the broad continental shelf region.

1.3.2.2 Water Mass Characteristics

(a) Baffin Bay

Baffin Bay is a mixing basin for waters from the Arctic and Atlantic Oceans and from Greenland and North American land run-off. Several basic water types have been identified (Muench, 1971). The temperatures and salinity properties of these waters are shown in Figure 1.3-5 and are summarized below:

i) Baffin Bay Arctic Water: Temperatures are below 0°C except in the variable solar heated surface layer; salinities range from less than 31‰ to approximately 34.4‰. This water originates from the Arctic Ocean, enters the region principally through Smith, Jones and Lancaster sounds, and is maintained by convection associated with ice formation.

ii) Baffin Bay Atlantic Water: Temperatures are above 0°C and salinities are between 34.2‰ and 34.5‰. Baffin Bay Atlantic water is formed as follows: West Greenland Current water arises from the mixing of East Greenland Current water and North Atlantic water which flows around the southern tip of Greenland and north through Davis Strait. The water is relatively warm (2° to 10°C) and saline (33.5 to 34.7‰) in Davis Strait, but as it flows northward it mixes with Baffin Bay Arctic water, gradually cooling and sinking to form the Baffin Bay Atlantic water.

iii) Baffin Bay Deep Water: Temperatures are below 0°C and the salinity is approximately 34.5 ‰.

(b) Davis Strait

Six distinct water masses have been identified in Davis Strait (Campbell *et al.*, 1964; Seaconsult, 1978). Their designations, locations and range of properties are summarized in Table 1.3-1. Each of these water masses typically undergo considerable modification through mixing in this region. Four of the water masses: the Atlantic Intermediate, Surface Western, Surface Eastern, and the Irminger-Atlantic waters are directly related to water masses in the mid and upper levels of Baffin Bay. On the other hand, the Atlantic Deep and Atlantic Bottom waters are only found in the deep southern portion of Baffin Bay. Figure 1.3-6 shows the distribution of water masses in Davis Strait in an east-west section near the southern end of the strait.

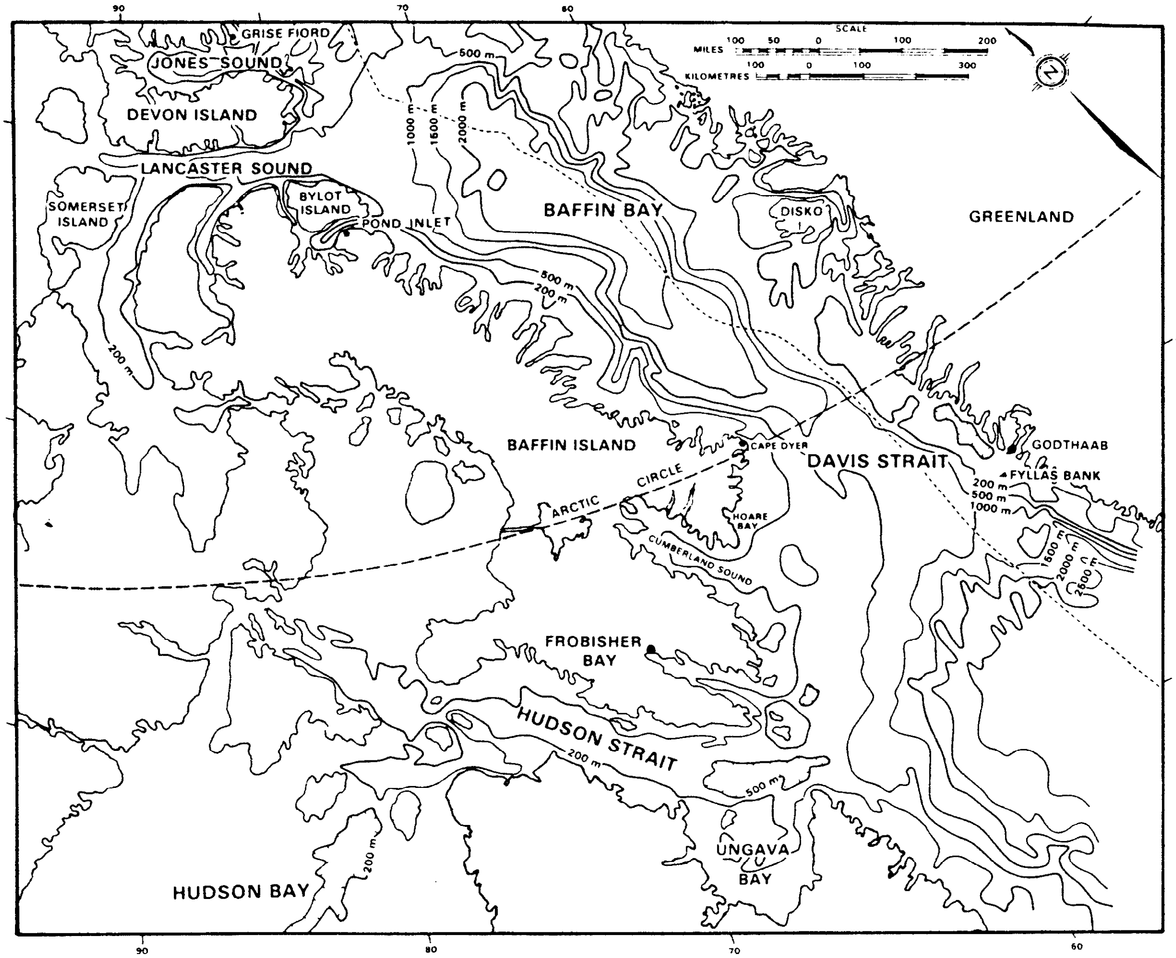

FIGURE 1.3-4 *Bathymetry of the Baffin Bay-Davis Strait Region. There is a broad sill at the northern end of Davis Strait separating waters in the deep basin of central Baffin Bay from the deep southeastern Davis Strait. Deep trenches penetrate Cumberland Sound and Frobisher Bay.*

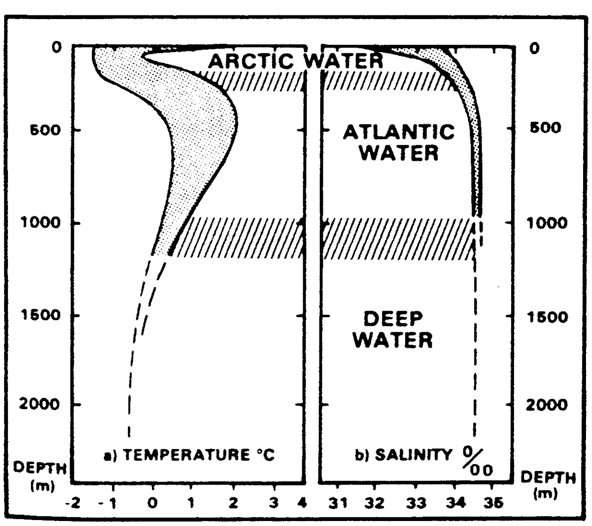

FIGURE 1.3-5 *Temperature and salinity envelopes for the waters of the Baffin Bay region (from Muench, 1971). Hatching indicates variations in depths of the Arctic, Atlantic and deep waters in Baffin Bay. Baffin Bay is a mixing basin for waters from the Arctic and Atlantic oceans and from Greenland and North American land run-off. The Atlantic water in Baffin Bay is formed from a mixture of the north flowing West Greenland current and Baffin Bay Arctic water.*

1.3.2.3 Mean Circulation

(a) Baffin Bay

The mean water circulation in Baffin Bay is cyclonic (anti-clockwise), similar to its mean atmospheric annual pressure and surface wind patterns. The warm, saline water of Atlantic origin flows northward along the Greenland coast, while Arctic water moves southward along the western side of the Bay (Figure 1.3-7). Muench (1971) has postulated that the southerly flow is driven by higher sea levels in the Arctic Ocean. The net flow through Smith Sound to the north is southerly at speeds ranging up to 10 cm/sec, although northerly reversals occur under certain tidal and possibly atmospheric conditions. The outflow of Smith Sound merges with the water which has moved north along the Greenland coast.

The surface water flow to the east of Devon Island is a combination of remnants of the West Greenland

TABLE 1.3-1

WATER MASSES OF DAVIS STRAIT

Water Mass	Description
Surface Eastern (E)	Upper component (depths <100 m) of West Greenland Current; temperature ≤ 2° C, salinity< 34 ‰.
Irminger-Atlantic (I-A)	Lower (100 m≤depths ≤700 m) component of West Greenland Current; temperatures of 3° to 4° C, salinities usually above 34 ‰.
Surface Western (W)	Upper (depths < 300 m) component of Baffin and Labrador Currents; temperatures ≤1° C and salinities < 34° ‰.
Atlantic Intermediate (A-I)	At 500 to 1000 m levels in the central Labrador Sea, with temperatures near 3.4° C and high salinity of 34.87 ‰. Contains a salinity minimum.
Atlantic Deep (AD)	At depths of 2000-3000 m; temperatures of 2° to 3° C and salinity > 34.9 ‰. Contains a salinity maximum.
Atlantic Bottom (AB)	In deep levels of Labrador Sea (depths > 3000 m); temperature 2° C, salinity 37.87 ‰. Contains T and S minimums.

(Source: Campbell et al, 1964; Seaconsult, 1978)

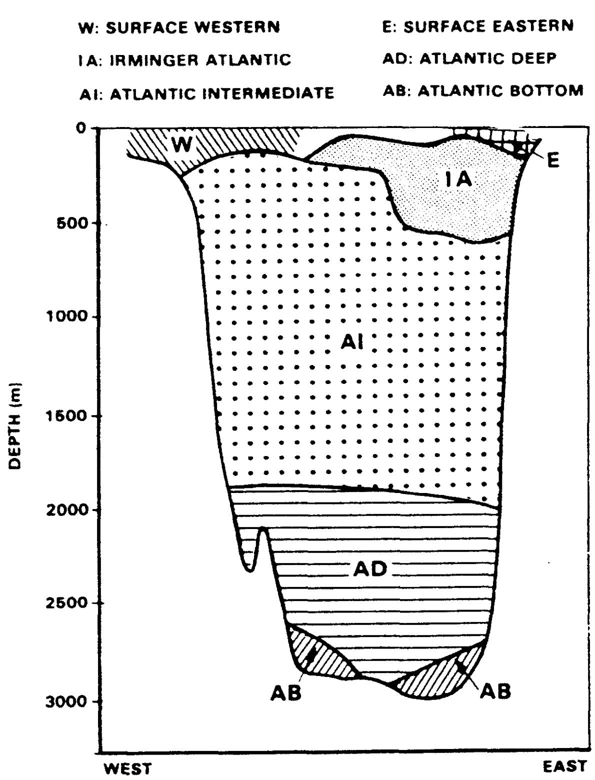

FIGURE 1.3-6 *The distribution of water masses in Davis Strait in an east-west cross-section near the southern end of the strait (Sources: Campbell et al., 1964; Seaconsult, 1978). The surface eastern water mass (E) flows northward as the upper part of the West Greenland current while the surface western water mass (W) moves southward as the upper component of the Baffin and Labrador currents.*

current, the Smith Sound outflow and the output of Jones Sound (Fissel *et al.*, 1981; Lemon and Birch, 1980). This flow varies with offshore distance, and occasionally a nearshore anti-clockwise eddy forms between the core of the current and the northern half of the eastern Devon Island coastline. In areas offshore of the main current, weak meander-like circulation features are present.

A surface convergence off the southeast coast of Devon Island produces a strong narrow current which intrudes part-way into Lancaster Sound (Section 1.3.1.4). Typical current speeds of the fast-flowing core section of this intrusion are 75 cm/s (Fissel *et al.*, 1981; Lemon and Birch, 1980). As this current leaves eastern Lancaster Sound, it flows eastward along the northern coast of Bylot Island at speeds of 50 cm/s. It then flows south paralleling the eastern Bylot Island coastline, usually 30 to 50 km offshore. At times, a large scale (60-70 km) meandering of this current occurs associated with northerly countercurrents located further offshore. Between the Bylot Island coast and the main body of the southerly current, anti-clockwise eddies about 20 km in diameter are frequently observed (Fissel *et al.*, 1980). At the southern end of the eastern coast of Bylot Island, a portion of the flow turns westward into the mouth of Pond Inlet.

The path of the Baffin current off the eastern shores of Baffin Island is steered by local bathymetry. The core of this current follows the continental slope at

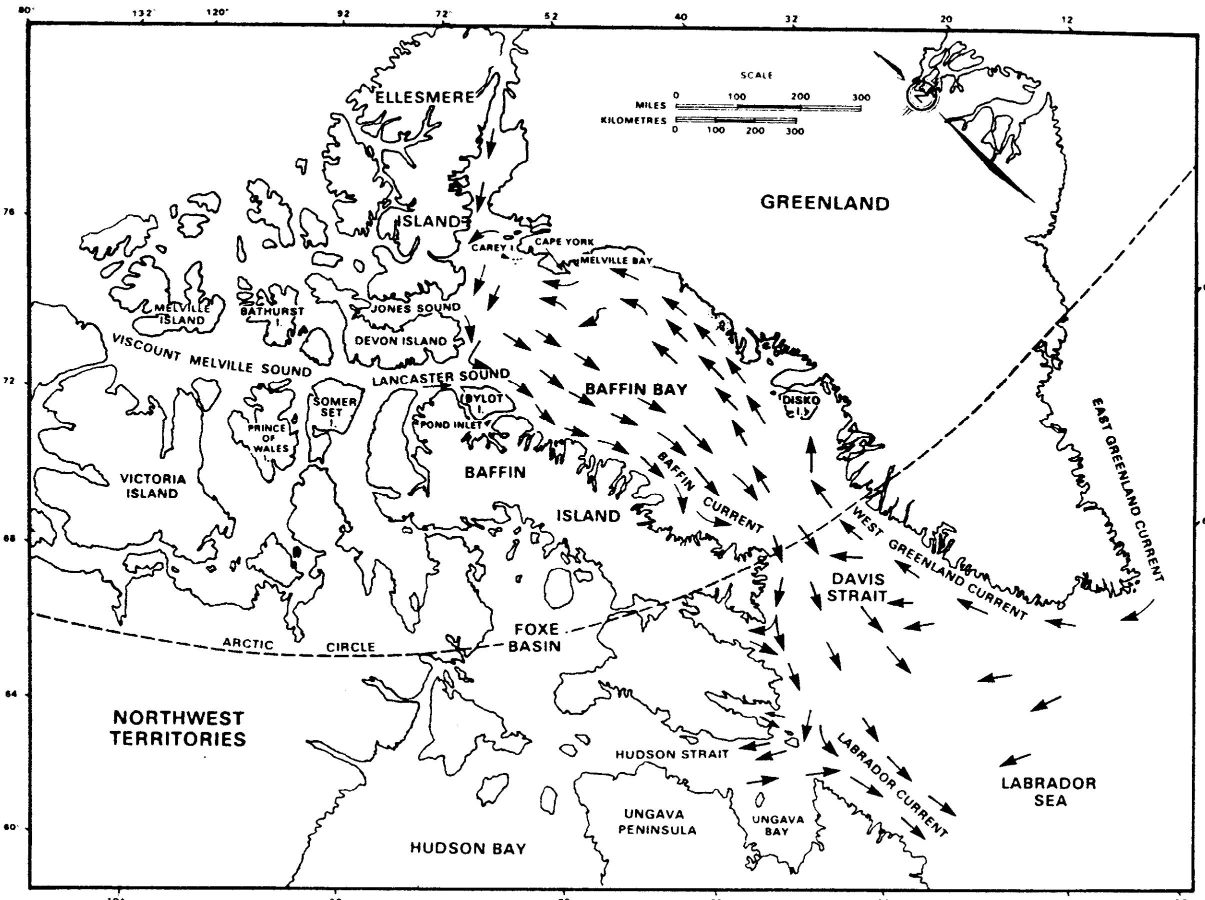

FIGURE 1.3-7 *Mean near-surface circulation of the Baffin Bay-Davis Strait region (from: Marko, pers. comm.). The mean near surface water circulation in Baffin Bay is anti-clockwise, similar to its mean annual pressure and surface wind patterns. The warm, saline water of Atlantic origin flows northward along the Greenland coast, while cold Arctic water moves southward along the western side of the Bay.*

speeds of typically 30 cm/s (Fissel *et al.*, 1980). Lower current speeds of 10 to 20 cm/s are found on the shelf and further offshore towards the deeper basin. Recent studies suggest that the bathymetric influence is sufficient to deflect the flow toward shore (Figures 1.3-7 and 1.3-8) along several extensive underwater canyons which cut the Baffin Island continental shelf (Fissel *et al.*, 1980; Marko *et al.*, 1981). These onshore flows appear to be a major mechanism for moving bergs, ice and offshore water into coastal areas.

Little is known about the north-flowing west Greenland current due to a lack of current measurements in the area south of Cape York. Estimates of current speeds based on the spatial distributions of water density suggests a 5 cm/s flow, increasing to 20 cm/s south of Cape York (Muench, 1971). However, current speeds could be well in excess of these estimates (Mognihan and Muench, 1971).

(b) Davis Strait

The circulation in Davis Strait (Figure 1.3-7) is dominated by several well documented flows, namely the East Greenland, Irminger, Baffin, and Labrador currents. The first two of these mix to form the West Greenland current, which subsequently divides into a northerly component following the Greenland coast, and a broader flow which turns westward and then southward between latitudes 64°N and 67°N. The Baffin and Labrador currents are the northern and southern components of the southerly flow of cold, low salinity Arctic water which moves along the western side of the strait. The western portion of this flow intrudes into Hudson Strait. The waters east of approximately 63°W longitude continue their southward flow and are joined by the cold outflow of Hudson Strait to form the Labrador current.

1.3.2.4 Low Frequency Variability

(a) Baffin Bay

Surface currents in the central part of Baffin Bay are southerly, and have speeds of 5 to 10 cm/s over most of the deep basin (Fissel *et al.*, 1980; Fissel and Birch, 1981). Mean current speeds change seasonally in

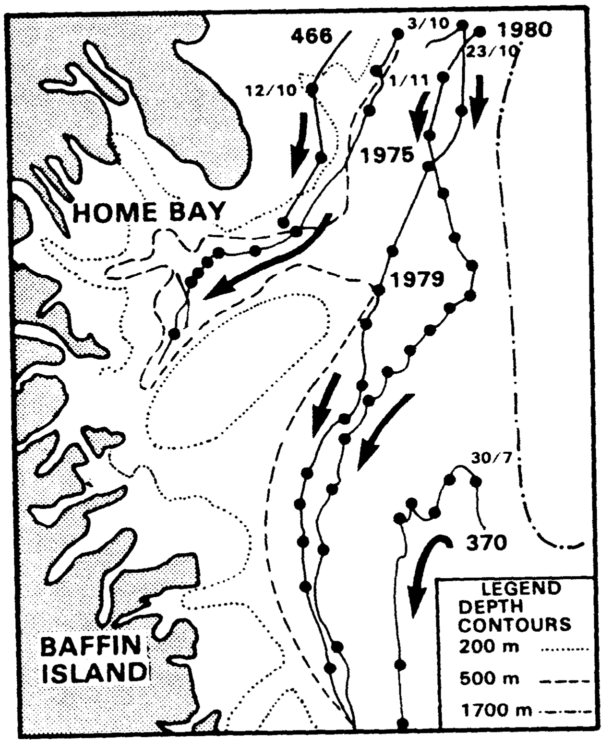

FIGURE 1.3-8 *Drogued drifter trajectories off the southeast coast of Baffin Island (from Fissel et al., 1980). The path of the Baffin current off the eastern shores of Baffin Island is steered by local bathymetry and the core of this current flows at speeds of typically 30 cm/s.*

response to the atmospheric circulation patterns. In northwest Baffin Bay, current speeds appear to slow down during the winter, corresponding to at least a halving of the coastal current flow. Further offshore, seasonal reductions in the southward flow are somewhat smaller. Available data show little year-to-year difference in the overall patterns of the summer flow with current speeds varying by, at most, a factor of two. (Fissel *et al.*, 1980; Fissel and Birch, 1981). Spatial variability in this area is also associated with occurrences of eddies and meanders. The presence of these features has been inferred from the distribution of water properties off Cape York and has been documented in detail near Devon and Bylot islands (Fissel *et al.*, 1980; Fissel and Birch, 1981).

(b) Davis Strait

The surface water and ice movements in Davis Strait are influenced by strong currents which enter the region from the northwest and southeast, and by the overall mean cyclonic surface wind pattern in the area. The latter pattern results from the frequent passage of intense storms which enter the region from the west and southwest, and the large seasonally dependent air pressure gradients which are often characteristic of the eastern Arctic (Section 1.2.2). It is also possible that the seasonal presence of low salinity water near the coast contributes to the observed low frequency variability in circulation.

The rapid changes in wind patterns and storm intensities appear to cause most of the surface current variability having time scales of one or more days.

1.3.2.5 High Frequency Variability

(a) Baffin Bay

The tides in Baffin Bay are mixed, but predominantly semi-diurnal. Tidal amplitudes are smallest off the east coast of Baffin Island, and increase in all directions away from 72°N latitude and 64°W longitude. To the east of Devon Island, for example, the semi-diurnal component has an amplitude of 80 cm. Tidal current speeds in the north near the Carey Islands are typically 10 cm/sec, while further south, to the east of Lancaster Sound, recent data indicate smaller semi-diurnal current speeds generally less than 8 cm/s (Fissel, 1981). The consistency in the directions of these currents is indicative of bathymetric steering. Inertial oscillations have been detected in current records obtained near the eastern entrance to Lancaster Sound (Fissel *et al.*, 1980). At this latitude, the characteristic frequency of these oscillations is close to that of the semi-diurnal tide. Nevertheless, these data suggest that currents associated with these oscillations can have typical speeds of 10 to 30 cms, which are in excess of typical tidal current magnitudes. The oscillations are most pronounced in the upper Arctic water layer, and are almost certainly driven by the changes in local winds.

(b) Davis Strait

Most of the surface current variation in Davis Strait results from diurnal and semi-diurnal tidal components. The tide is primarily diurnal in character and, enters the strait from the Atlantic Ocean and the Labrador Sea. In Hudson Strait, tidal current amplitudes may approach 100 cm/s, and reversals of the mean flow are common (Dohler, 1964).

There is evidence of internal tides in the Davis Strait region. These are thought to be generated by the interaction of surface tides with the bottom topography of steep continental slopes (Seaconsult, 1978; Schott, 1977). The amplitudes of these currents are expected to be equal to or less than half of the surface tide amplitudes.

1.3.2.6 Nutrients

(a) Baffin Bay

Nutrient samples collected in northwestern Baffin Bay, from July to early October in 1978, showed typical nitrate, phosphate and silicate concentrations of 5, 0.5 and 5 to 10 μg-at/L respectively, at a depth of 50 m (Sekerak *et al.*, 1979). The corresponding concentrations near the eastern entrance to Lancaster Sound were 15, 1.2 and 40 μg-at/L, respectively. The average concentrations for nitrate-nitrites, phosphates and silicates integrated over the upper 50m of the water column, decreased 54, 36, and 47%, respectively, over the mid to late summer months. Horizontal variability was most evident in the nitrate and phosphate distributions, with maximum concentrations occurring in the area northeast of Bylot Island. An observed southward decrease in the concentrations of nitrate and phosphate off the Baffin Island coast was not clearly reflected in the silicate distribution.

(b) Davis Strait

Phosphate and silicate concentrations in eastern Davis Strait are moderately high in the upper 100 m of the water column, and increase with depth and from north to south throughout the eastern portion of the strait (Jones and Folkard, 1968). Corresponding north to south ranges are 0.25 to 1 μg-at/L and 2 to 12 μg-at/L for phosphate and silicate, respectively. A tendency for high phosphate levels to occur along the Greenland coast south of 67°N may be evidence of upwelling in the Fyllas Bank area (Figure 1.3-4; Hermann, 1968). Some local surface phosphate depletion has been documented during the late summer.

In the western portion of Davis Strait, there appear to be depressed levels of nutrients in the upper water layer, particularly nitrates. Although nitrates appear to be the limiting nutrient for phytoplankton growth and production (Ryther and Dunstan, 1971; Grainger, 1971), their complete depletion only occurs locally. Surface nitrate concentrations as high as 10 μg-at/L have been measured, while concentrations at 200 m (MacLaren Atlantic Ltd., 1978a) generally exceed 5 μg-at/L. Silicates are distributed in a similar manner, but are subject to a lesser degree of surface depletion associated with phytoplankton growth. Phosphate concentrations are generally low, ranging from 0.2 to 0.4 μg-at/L at the surface to in excess of 0.5 μg-at/L at 200 m. Nutrient concentrations show little relationship to geographical position in western Davis Strait, with the exception of the area adjoining Hudson Strait where water column instability may help to replenish surface water nutrients.

Most nutrient depletion occurs in summer, from June to September, in western Davis Strait, particularly phosphates and nitrates. Silicate levels are erratic, but tend to be higher than in early spring, possibly as a result of post-bloom dissolution of diatom frustules (MacLaren Atlantic Ltd., 1978a).

1.4 BATHYMETRY

This section describes the general bathymetry along the proposed eastern shipping corridor. The primary route is through the Beaufort Sea, Amundsen Gulf, Viscount Melville Sound, Barrow Strait, Lancaster Sound, Baffin Bay and Davis Strait. Alternates to the primary route are possibly through M'Clure Strait to Viscount Melville Sound and through Fury and Hecla Strait to Davis Strait via Foxe Basin and Hudson Strait (Figure 1.4-1).

The status of hydrographic surveys carried out within the primary route and its alternates varies greatly. Lancaster Sound, Barrow Strait, Amundsen Gulf, the southeastern portion of the Beaufort Sea, and a small section of Hudson Strait and northwestern Foxe Basin have been surveyed to modern standards. Modern surveys have a high enough sounding density to delineate all shoals in the region and give a good indication of what the ocean floor is like. Viscount Melville Sound as well as most of M'Clure Strait and the remainder of the Beaufort Sea have only been partially surveyed. Soundings in these waters were either made through the ice at regular horizontal distances or are concentrated along ship tracks.

The future routes of Arctic tankers will be within corridors surveyed to modern standards. These corridors will be wide enough to allow the ships within them to exploit favorable ice conditions and open water. The location and width of future shipping corridors will be determined by factors such as traffic levels, ice conditions, bathymetry, and environmental and socio-economic considerations. Class 10 icebreaking tankers will have a loaded draft of 20 m so that corridors must be defined having water depths in of 25 metres or more.

Future hydrographic survey requirements will depend upon the location and width of shipping corridors. Given the complexity of all the factors involved, these corridors have not yet been fully defined. In Viscount Mellville Sound, for example, a northern, central and southern shipping corridor will eventually be needed to take advantage of favorable ice conditions. There will likely be other areas along the primary route where it may prove advantageous to define alternate shipping corridors, primarily to avoid heavy ice.

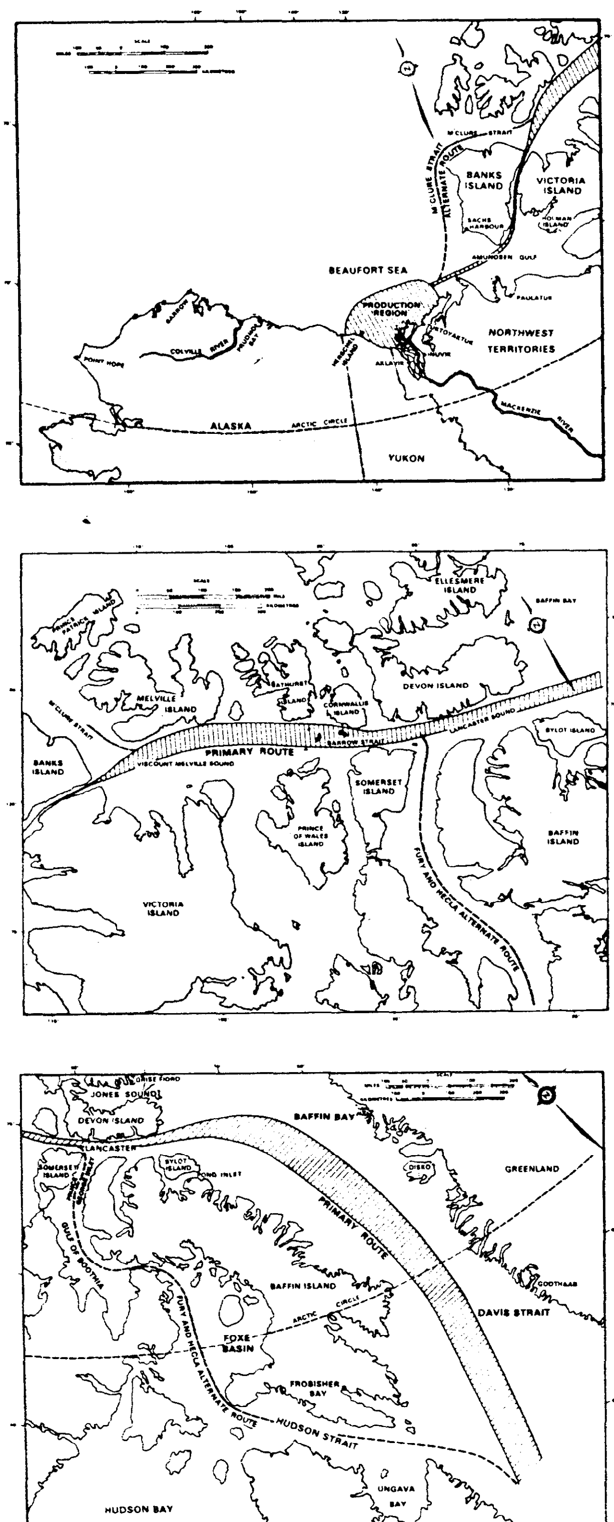

FIGURE 1.4-1 *The eastern tanker route and its possible alternate branches through M'Clure Strait and Fury and Hecla Strait. The alternate route west of Banks Island and through M'Clure Strait would add 150 km to the total route and in most years Arctic tankers would encounter high concentrations of multi-year ice in M'Clure Strait. At present, an alternate route through Fury and Hecla Strait, though no longer, is not viable because of sparse soundings and possibly insufficient water depths.*

1.4.1 THE PRIMARY TANKER ROUTE

The primary deep-draft Arctic tanker route from the southeastern Beaufort Sea to the Atlantic seaboard is through Amundsen Gulf, Prince of Wales Strait, Viscount Melville Sound, Barrow Strait, Lancaster Sound, Baffin Bay and Davis Strait (Figure 1.4-1). The bathymetry of these waterbodies is described in the following sections.

1.4.1.1 Southeastern Beaufort Sea

From the Mackenzie Delta eastward to Cape Bathurst, the continental shelf extends off the coastline for distances of 100 to 150 km to the 100 m isobath (Figure 1.4-2). Beyond the 100 m isobath the ocean floor drops off steeply so that at distances of 150 to 200 km from the coastline, water depths surpass 1,000 metres. West of the Mackenzie Delta, a deep trench in Mackenzie Bay cuts into the continental shelf with the 100 m isobath extending southward to a position about 25 km west of Herschel Island.

From Herschel Island (139° W) to Cape Bathurst (128° W) more favorable ice conditions will tend to be encountered by a routing close to the 30 m isobath within the seasonal ice zone (Dickins, 1981), where in the winter and spring thin ice and leads can extend northward of the landfast ice edge for distances of up to 50 kilometres. The landfast ice edge is generally over the 20 m isobath.

A peculiarity of the continental shelf off the Beaufort coast is the presence of conical shaped mounds or pingo-like features (see Volume 3A, Section 1.4.6). The Canadian Hydrographic Service has so far identified over 200 of these features between the 20 and 200 m isobath, in the area from 128° W to 136° W longitude. Since they can come to within 18 m of the water surface they constitute a hazard to deep draft vessels.

Figure 1.4-2 shows a hazardous region for pingo-like features which is located between the 30 and 100 m isobaths off Richards Island and Tuktoyaktuk Peninsula. The Canadian Hydrographic Service has recently brought the bathymetry of the southeastern Beaufort Sea up to modern standards where accurate positioning and modern equipment is used. The spacing between soundings is designed to reflect the nature of the ocean floor and all shoals and navigational hazards are examined in detail.

In 1981, the Hydrographic Service began surveying a 10 mile wide shipping corridor along the Beaufort coast. This corridor survey is likely to be completed by September, 1983. This corridor will take advantage of the thin ice and leads which occur in the seasonal ice zone. Soundings every 100 m, backed up

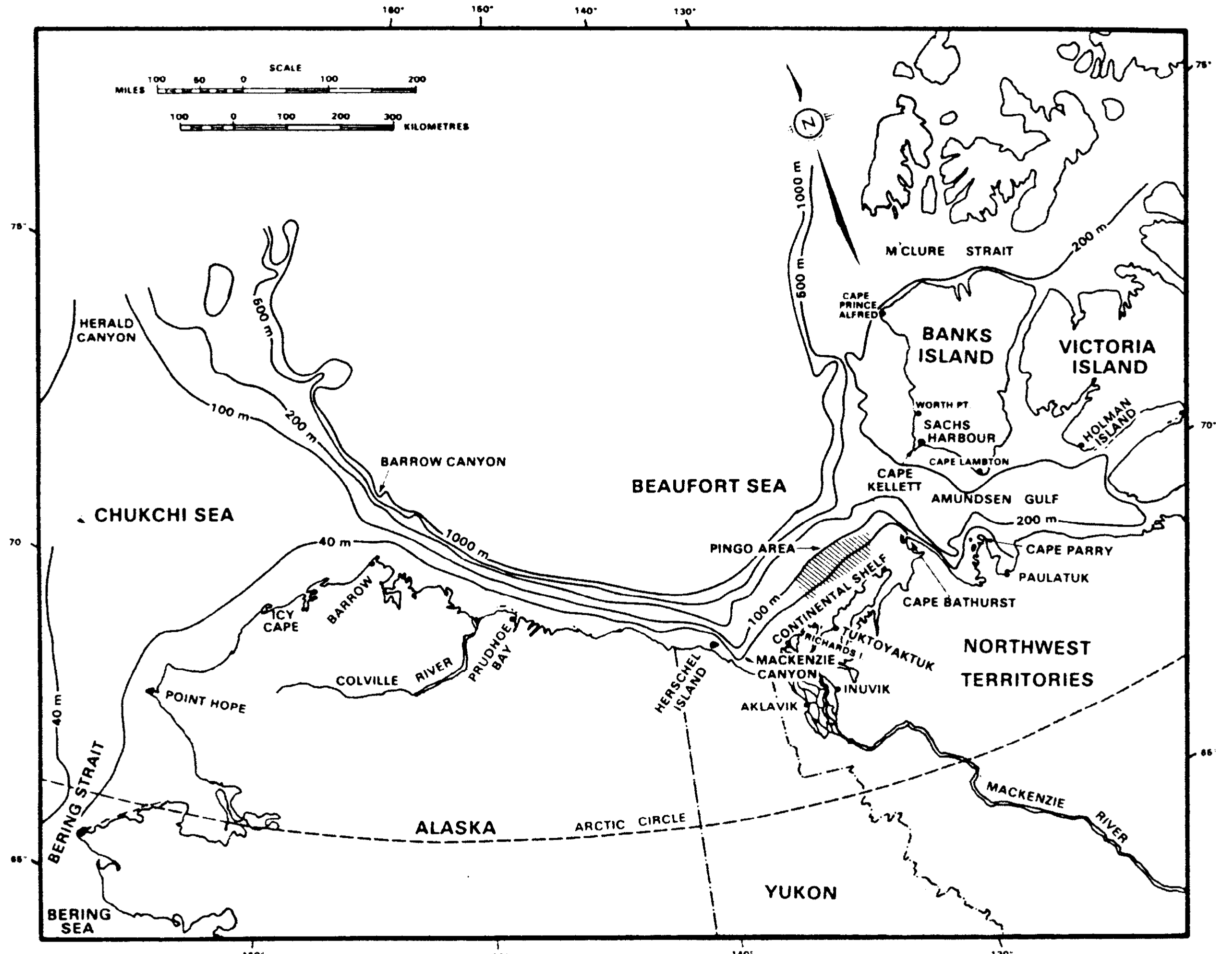

FIGURE 1.4-2 *Coastal bathymetry of the Beaufort Sea and Amundsen Gulf. In winter and spring most favourable ice conditions for Arctic tankers in the southeastern Beaufort Sea would be in a routing close to the 30 m isobath within the seasonal ice zone beyond the landfast ice edge. A ten mile wide shipping corridor is currently being surveyed through the pingo area and within the seasonal ice zone.*

by sonar readings, will identify all hazardous pingo-like features through the corridor.

1.4.1.2 Amundsen Gulf

From the southeastern Beaufort Sea, the shipping route leaves the shallow continental shelf waters and crosses the deeper waters of Amundsen Gulf. Here, the 100 m isobath tends to lie within 10 km or less of either coastline, with the deepest soundings occurring towards the middle of the channel, where water depths range between 200 and 500 metres.

A distance of 112 km separates Cape Parry and Cape Lambton (on Banks Island) en route to the entrance of Prince of Wales Channel. During winter up to 20% of the first year ice between these two capes can consist of thin ice and frozen leads. Later in the spring, a large polynya develops north of Cape Bathurst (see Section 1.1, Volume 3A). Icebreaking tankers will be able to maneuver through the deep waters of the gulf to take advantage of these favorable ice conditions.

Water depths gradually decrease from about 350 to 90 m northwest of Cape Lambton and along the entrance of Prince of Wales Strait.

The bathymetry of Amundsen Gulf was recently surveyed to modern standards by the Canadian Hydrographic Service.

1.4.1.3 Prince of Wales Strait

Prince of Wales Strait is a narrow 275 km long channel which connects the waters of Amundsen Gulf with those of Viscount Melville Sound to the north (Figure 1.4-3).

The southern entrance to the strait is about 44 km wide between Alexander Milne Point on Banks Island and Ramsay Island just off the southwestern tip of Prince Albert Peninsula on Victoria Island. The strait narrows to 25 km, one-third of the way northward, between Stewart Point and Hay Point. Along the southern one-third of the strait the eastern and western 50 m isobaths are separated by 21 to 39

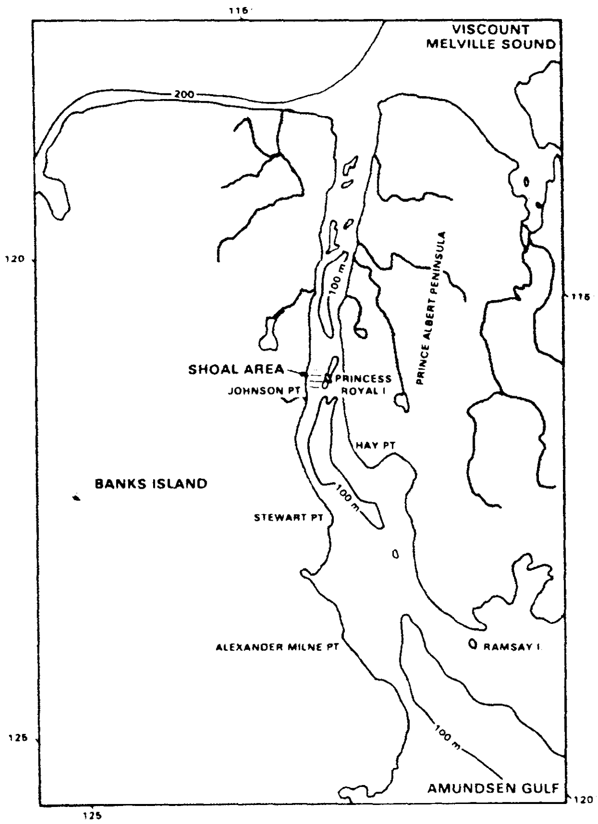

FIGURE 1.4-3 *Prince of Wales Strait. During winter, the strait is normally covered with landfast first year ice within which are embedded multi-year ice floes in concentrations of 1/10th in the south to 4/10ths in the north. The Canadian Hydrographic Service expects to complete a sounding survey through the strait in 1982. More detailed soundings will be needed before regular Arctic tanker traffic commences.*

km with the deepest waters occurring in the middle of the channel. Maximum water depths decrease from about 150 m at the southern entrance to about 100 m between Stewart Point and Hay Point.

North of Stewart Point the strait bends northeasterly and the width of the strait remains near 25 km until it narrows to 18 km near Johnson Point. From Stewart Point to Johnson Point, separation between the 50 m isobaths varies from about 2 to 14 kilometres. The deepest water becomes off-centre toward the west as the strait bends to the northeast. An area of shoaling water lies off Banks Island between Johnson Point and Princess Royal Island where the water depths vary between 3 and 30 metres. The eastern and western 50 m isobaths are separated by about 5.5 to 7.5 km along the 15 km section of the strait beginning just south of Princess Royal Island. The deepest waters along this section are close to the western 50 m isobath, where depths of 132 m occur within 1 km of the east coast of Princess Royal Island.

Once north of Princess Royal Island and its associated shallow waters, the width of the strait ranges from between 12 and 19 km to its northern end at Viscount Melville Sound. Distances between the eastern and western 50 m isobaths vary between 10 and 14 km along this section with the deepest waters occurring in the centre of the strait. These depths range between 100 and 150 m but decrease toward the northern end to water depths in the range between 60 and 90 metres. Prince of Wales Strait has not yet been surveyed to modern standards. Existing charts are characterized by a sparsity of soundings. The Canadian Hydrographic Service will complete a recent survey of the strait beginning in the summer of 1982 (various personnel communications, Canadian Hydrographic Service, Ottawa). Soundings for this survey are being made through the ice. Confirmation of these soundings will be made along proposed tracks of icebreakers before regular traffic commences. For navigational purposes, the narrow channel and the presence of shoals will require a high density of soundings.

During winter Prince of Wales Strait is normally covered with landfast first year ice within which are embedded multi-year ice floes. Multi-year ice concentrations are usually around 1/10th through the southern half of the strait increasing to 4/10ths at its northern end (Dickins, 1981).

During the spring break-up, multi-year ice concentrations between 1/10th and 3/10ths may enter from Viscount Melville Sound and drift south through the strait. At times, large multi-year ice floes up to 15 km wide can temporarily clog the strait. The narrow channel of navigable waters in this area could limit, to some degree, the ability of icebreaking tankers to maneuver around large multi-year ice floes.

1.4.1.4 Viscount Melville Sound

The waters of Viscount Melville Sound lie in the western half of Parry Channel (Figure 1.4-4) and can be entered either through Prince of Wales Strait or from the west through M'Clure Strait.

Viscount Melville Sound has only been partially sounded. Soundings, especially through its central and southern portions, are particularly sparse. More measurements have been taken at the western and eastern entrances to the sound and along its northern coast, as indicated by Charts 7831 and 7830 (Canadian Hydrographic Service). To the northwest and northeast of Stefansson Island there are large areas with no soundings. The Canadian Hydrographic Service has no immediate plans to conduct further surveys in the sound. Future shipping routes through the centre and southern parts of the sound will have to be surveyed to modern standards. This as well as other bathymetric requirements are described in Volume 7.

From the sound's western entrance to the eastern end

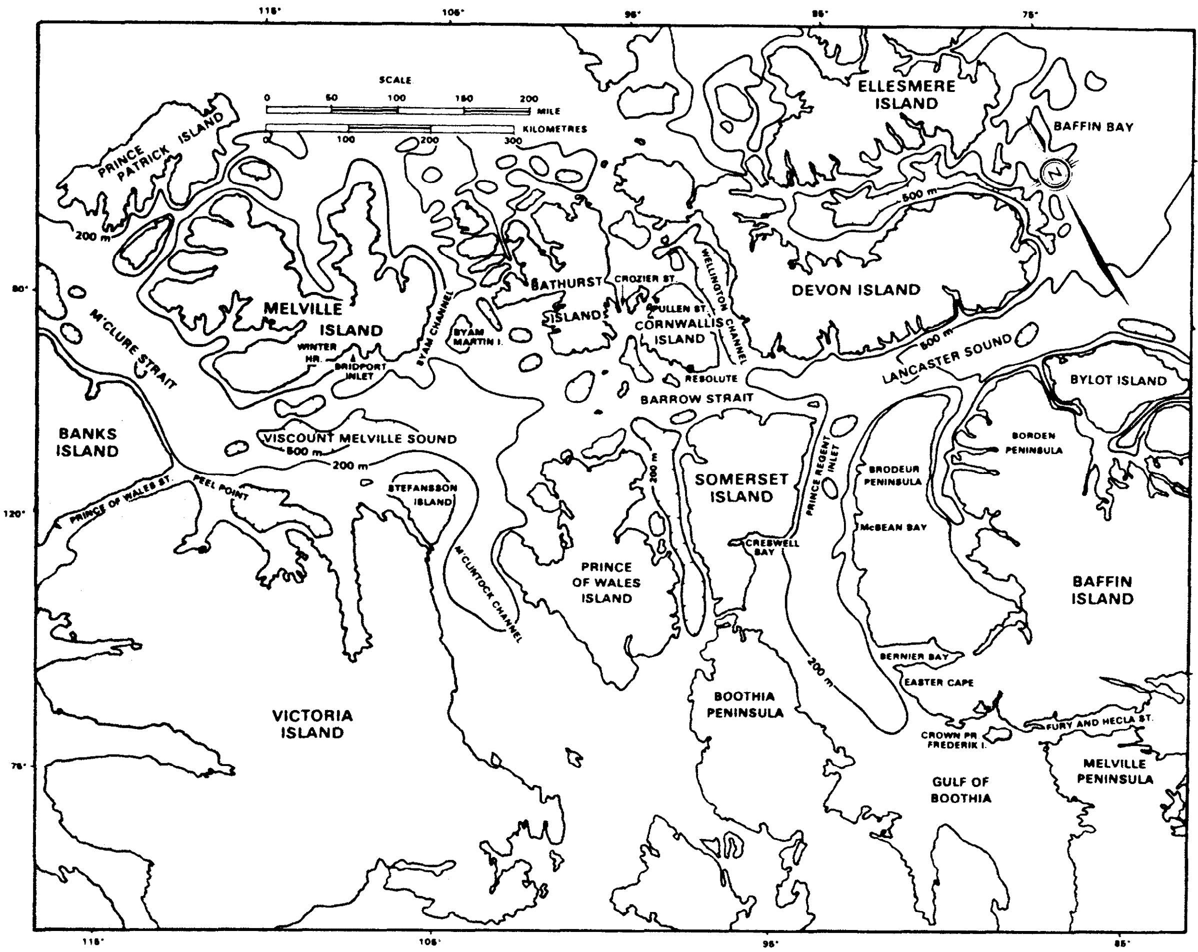

FIGURE 1.4-4 *The Northwest Passage part of the eastern tanker route. Most soundings in Viscount Melville Sound are along its northern part near Melville Island where most shipping has travelled. Use of central and southern Viscount Melville Sound, possible in some years, would require the sound to be surveyed to modern standards. In general, a northern route throughout the Northwest Passage has most favourable ice conditions. Ice conditions are less severe toward the eastern end of the Passage (Dickins, 1979). Least water depths occur in Barrow Strait but range between 100 to 200 m in navigable passages.*

of Melville Island most of the central and northern portions of the sound have depths ranging between 200 and 500 metres. The sparse soundings along the southern portion of the sound are generally less than 200 m.

The 50 m isobath is generally within 10 km of the Melville coastline. The 100 m isobath extends offshore from 20 to 25 km just east of Bridport Inlet towards the southeastern corner of Melville Island. Between the 50 and 100 m isobaths there are a number of shoals where depths range between 27 and 55 metres.

East of Melville and Stefansson Islands, the deep waters of the sound angle off to the southeast with depths ranging between 200 and 400 m, leaving the northern and central portions of the sound with depths between 100 and 200 metres. Interspersed within the southern portion of the sound are numerous shallow water areas where sparse soundings show depths less than 100 m.

To the east of Melville Island, the 100 m isobath extends 20 to 25 km off the southern coast of Byam Martin Island. To the north, in Austin Channel, a shoal exists between Byam Martin Island and southern Bathurst Island. Its size, to the 100 m isobath, is roughly 8 km long in an east-west direction, and 4 km wide in a north-south direction, and it has a minimum depth of 7 metres. Twenty km to the south is a deeper shoal area where water depths between 37 and 97 m are encountered.

Southwest of Bathurst Island, the 50 m isobath lies offshore to the south from 35 to 40 km. Shoals with depths around 30 m lie just to the north of this isobath at distances of 30 to 32 km from the island.

During winter, multi-year ice concentrations through most of the sound range from 7/10ths to 8/10ths. However concentrations decrease from 6/10ths to 1/10th as the southern coast of Melville Island is approached east of Winter Harbour (Dickins, 1979). In addition, it is usual for a band of predominantly first year ice several kilometres wide to exist off the Melville Island coast in the sound.

Between break-up and freeze-up, multi-year ice concentrations tend to be lower through the northern portion of the sound. However, in some years multi-year ice concentrations may be lowest through the central or southern regions. Studies have also shown that multi-year floes in the northern half of the sound are generally thinner than those in the southern half (Dickins, 1979).

Ice conditions, described more fully in Section 1.1, show that a northern route through Viscount Melville Sound would be favored in most years. However, a central or southern route would have encountered the least difficult ice in some years. Depths appear adequate for a northern route near the Melville Island coast, however a higher density of soundings is needed to identify and delineate possible shoals extending off this coast. Although waters generally appear deeper along a central and southern route, sounding densities remain inadequate for determining safe navigation, particularly along a southern route.

1.4.1.5 Barrow Strait

Barrow Strait lies in the eastern half of Parry Channel between Viscount Melville Sound to the west and Lancaster Sound to the east (Figures 1.4-4 and 1.4-5). Young, Lowther and Griffith Islands stretch across the western half of the strait from Russel Island in the south to Cornwallis Island in the north. To the north of these three relatively large islands lie the smaller Garrett, Brown and Sommerville Islands. In addition, the small Hamilton Island lies to the southeast of Young Island.

Water depths generally range between 100 and 200 m throughout much of the Strait. At its eastern end it deepens to between 200 and 300 metres.

Between these islands are various passages and channels: Kettle Passage between Young Island and Lowther Island; Intrepid Passage between Garrett and Bathurst Islands; Resolute Passage between Griffith and Cornwallis Islands; Hayes Channel between Garrett and Lowther Islands; and Fournier Channel between Sommerville and Griffith Islands.

All of these passages and channels have safe water depths, according to the charts, for the passage of Arctic tankers. However, ice conditions in Barrow Strait are most favorable in its central to northern portions, so that a route south of Young Island is unlikely to be used in most years. There are various shoals which limit the usable widths of these passages, particularly along a northern corridor. Although bathymetric surveys of Barrow Strait are more complete than those in Viscount Melville Sound, increased sounding densities are needed to

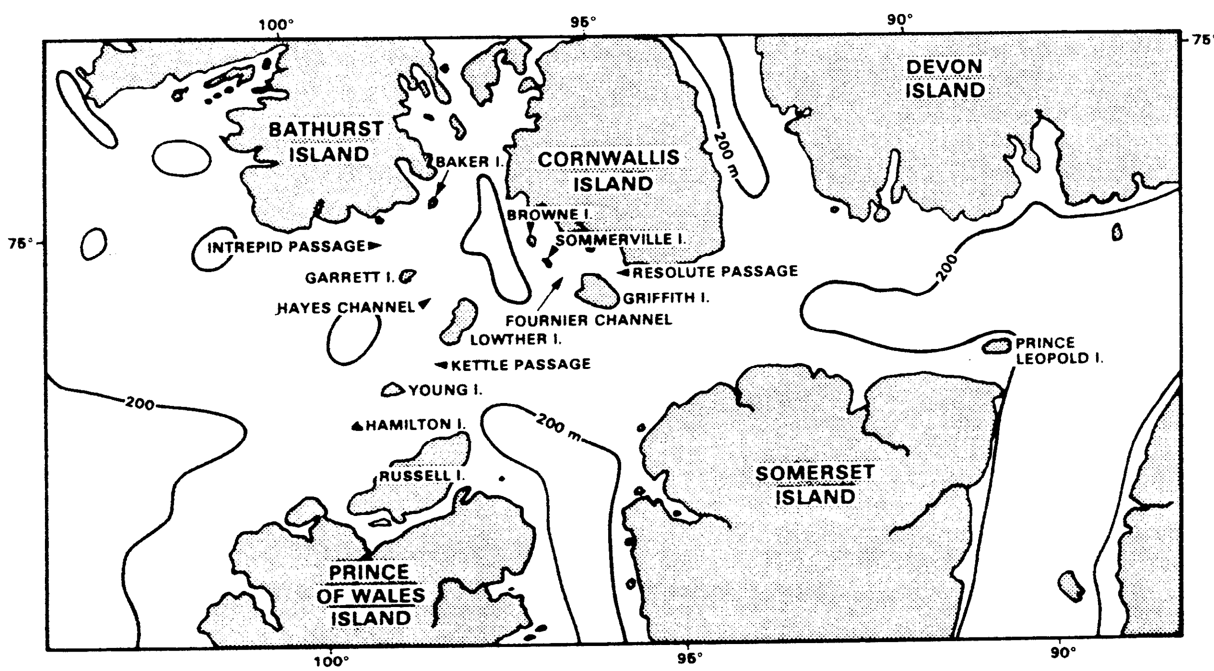

FIGURE 1.4-5 *The Barrow Strait section of the eastern tanker route. All of the passages and channels between the islands in the strait have water depths adequate for the safe passage of Arctic tankers, however those to the north will generally have the best ice conditions (Dickins, 1979).*

better delineate shoaling waters to provide more sea-room for deep-draft vessels.

Eastward of Griffith Island there are no apparent navigational hazards according to Chart 7503. The 100 m isobaths are generally within 5 km of the southern and northern coastlines. At its narrowest point the distance across the strait measures roughly 56 kilometres. Water depths tend to range between 113 and 180 m south of Cornwallis Island. These deepen to between 150 and 300 m south of western Devon Island. Depths between 110 and 150 m extend north of the sound into Wellington channel.

1.4.1.6 Lancaster Sound

Lancaster Sound, in eastern Parry Channel, connects the waters of Barrow Strait with those of Baffin Bay (Figure 1.4-6). Lancaster Sound is about 70 km wide at its western end and about 90 km wide at its eastern end. Prince Leopold Island projects into the southeast corner of the sound off the northeast corner of Somerset Island. The 100 m isobath, which encircles the island, is within a few kilometres of its coastline. The 100 m isobaths along the northern and southern coasts of the sound are no further than a few kilometres offshore. Depths throughout the sound generally increase from 200 to 400 m in its western end, to 650 to 800 m in its eastern end.

Modern surveys have been carried out throughout the sound except for in its eastern end. Lancaster Sound is the most heavily used section of the Parry Channel. Marine experience in the sound coupled, with its generally deep waters, make further survey requirements unlikely for the safe passage of deep-draft Arctic tankers.

The most favorable ice conditions are usually found in the northern portions of the sound, and the least

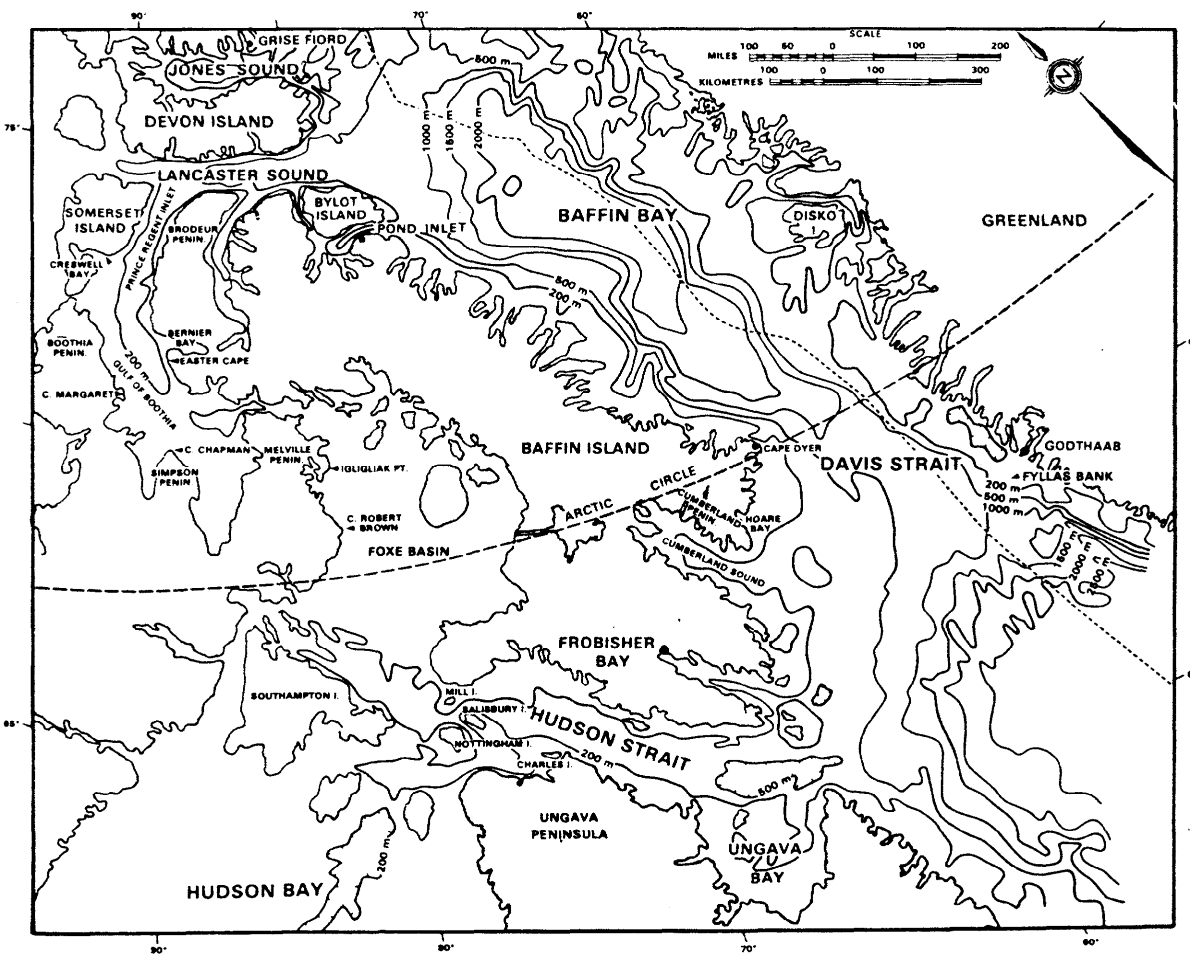

FIGURE 1.4-6 *General bathymetry along the eastern tanker route through Baffin Bay and Davis Strait. Although this region has only been partially surveyed, particularly near the Greenland coast, this would not affect Arctic tankers which would travel well off this coast in deep water. These waters are frequented in summer by large ships, including fuel tankers, servicing Canada's north and Greenland communities.*

favorable are generally present in the southern portion (Dickins, 1979). However, the proposed Arctic tankers would easily travel through the ice generally found within Lancaster Sound.

1.4.1.7 Baffin Bay

Baffin Bay, a wide body of deep water, lies between the west coast of Greenland and the east coast of Devon, Bylot and Baffin Islands (Figure 1.4-6). Smith Sound enters from the north, while Jones and Lancaster Sounds enter from the west into northern Baffin Bay. South of 70° N Baffin Bay joins with Davis Strait. An international demarcation line between Canada and Greenland runs through the centre of Baffin Bay and Davis Strait.

Although the waters of Baffin Bay are generally deep, individual soundings vary greatly across the ocean floor. The northwestern part of Baffin Bay, adjoining Smith and Jones sounds, has depths ranging from 180 to 450 metres. Further south a bank of shallow waters with soundings between 108 and 164 m lies 40 km southeast of Cape York, Greenland. This bank has a length of about 156 km and a maximum width of about 44 kilometres. To the west of this shallow bank, depths increase to over 900 m in Melville Bay.

The offshore distance of the 180 m isobath fluctuates considerably along the Greenland coast. In many places it extends as far west as 50 km from shore. Between this 180 m isobath and the demarcation line, depths vary between 198 and 2,200 m. Waters tend to be deepest towards the centre of the bay but also vary greatly along its length. There are a number of shoals lying to the west of the 180 m isobath south of Melville Bay. Depths there range from 36 to 100 metres. The shallowest water, 36 m deep, is located 200 km from the Greenland coast at 73° 1' N, 61° 7' W (Pilot of Arctic Canada, 1978). Depths are greatest west of the demarcation line, reaching over 2,000 m between 69° N and 74° N. To the west, the 180 m isobath is within 20 km of Bylot Island and from 20 to 80 km off Baffin Island.

The most favorable ice conditions are encountered through the eastern portions of Baffin Bay, becoming increasingly poorer toward the west. In northern Baffin Bay the North Water (see Section 1.1) has thin ice and open water in winter which can be exploited by Arctic tankers.

The bathymetry of Baffin Bay has only been partially surveyed, particularly near the Greenland coast. However, Arctic tankers will travel well off the Greenland coast so that no further delineation of the relatively shallow coastal banks will be necessary. Baffin Bay and Davis Strait are regularly and frequently navigated in summer by large vessels, including fuel oil tankers servicing Canada's north and communities in western Greenland.

1.4.1.8 Davis Strait

Davis Strait joins the waters of Baffin Bay to the north with those of the Labrador Sea to the south (Figure 1.4-6). To the west it is bordered by Baffin Island and the entrance to Hudson's Strait, while to the east it is bordered by Greenland. Davis Strait is approximately 325 km wide at its narrowest point off Cape Dyer on Baffin Island. Its deepest waters are largely to the west of the international demarcation line except south of 65° N, where they are further east.

The 180 m isobath is about 80 to 120 km off the Greenland coast from Disko Island to Godthaab, but reduces to 40 to 80 km off the coast from Godthaab south to Cape Farewell. Between this isobath and the Greenland coast, shallow soundings, ranging from 36 to 110 m are frequent. Along the Baffin coast, the offshore distance of the 180 m isobath fluctuates between 10 and 120 km, but is generally within 20 km of the shoreline. Several shoals with minimum depths between 117 and 180 m lie 70 to 100 km east of Hoare Bay near the southern tip of Cumberland Peninsula. However, these form no impediment to the passage of deep-draft vessels.

The most favorable ice conditions are found through the eastern and central portions of Davis Strait. With the exception of a few areas along the Baffin coast, the bathymetry of Davis Strait has not been surveyed to modern standards.

1.4.2 THE M'CLURE STRAIT ALTERNATE ROUTE

An alternate route for reaching Viscount Melville Sound from the southeastern Beaufort Sea is through the waters off the west coast of Banks Island and through M'Clure Strait. This route would increase the overall distance travelled by 150 km compared to that through Amundsen Gulf and Prince of Wales Strait. The advantage of this secondary route is that it may occasionally offer more favorable ice conditions. This can occur when multi-year ice concentrations fall below 6/10ths through M'Clure Strait and rise above 8/10ths across western Viscount Melville Sound from Prince of Wales Strait to Melville Island (Dickins, 1981).

1.4.2.1 Western Banks Island and M'Clure Strait

The distance of the 30 m isobath from the west coast of Banks Island ranges from 15 to 50 km, beyond which waters gradually deepen until the 200 m isobath is reached, at a maximum distance of about 110 km from the shore (see Figures 1.4-l and 1.4-2). The ocean floor drops nearer the shores off the southwestern and northwestern corners of Banks Island where the 200 m isobath comes within 20 km of Cape Kellet and 5 km of Cape Prince Alfred. No navigational hazards are identified between the 30 and 200 m isobaths according to Chart 7832 (Canadian Hydrographic Service). However, a few 50 m soundings are located about 58 km west of Worth Point between the 50 and 100 m isobaths. This, along with the relatively shallow waters off the west coast of Banks Island, indicate that potential hazards may be identified by a higher density of sounding.

Once past Cape Prince Alfred on northeastern Banks Island, the route enters M'Clure Strait where depths of more than 200 m exist a few kilometres off both its northern and southern coastlines. Throughout most of the strait depths range between 300 to 500 m.

From the southeastern Beaufort Sea to M'Clure Strait, a route close to the west coast of Banks Island will likely be followed which will minimize multi-year ice encounters, and take advantage of the leads and open water which develop off the coast between break-up and freeze-up.

The bathymetry along the west coast of Banks Island has not yet been surveyed to modern standards, although waters farther offshore have been partially surveyed. A relatively high density will likely be required along a shipping corridor through the relatively shallow waters off the coast.

After rounding the northwest corner of Banks Island, multi-year ice encounters may be minimized by routing vessels along the northern portion of M'Clure Strait, although generally, multi-year ice concentrations are expected to be higher than elsewhere in the Northwest Passage. The bathymetry of M'Clure Strait has been partially surveyed by the Canadian Hydrographic Service. However a sounding density higher than that indicated on published charts will likely be required for navigational purposes.

1.4.3 THE FURY AND HECLA ALTERNATE ROUTE

For smaller vessels, a secondary route for reaching the Labrador Sea from Barrow Strait is through Prince Regent Inlet, the Gulf of Boothia, Fury and Hecla Strait, Foxe Basin, Foxe Channel and Hudson Strait. The distance of this route is roughly the same as that through the Lancaster Sound Baffin Bay and Davis Strait route (Figure 1.4-1).

However, at present, there is no viable alternative deep-draft vessel route through Prince Regent Inlet, the Gulf of Boothia, Fury and Hecla Strait, Foxe Basin and Hudson Strait, primarily because of sparse bathymetric data and possibly insufficient water depths.

1.4.3.1 Prince Regent Inlet and the Gulf of Boothia

From Lancaster Sound south to the latitude of Creswell Bay in Somerset Island, mid-channel depths range from 200 to 450 m according to Chart 7503 (Canadian Hydrographic Service). Depths of 200 m occur within 8 km of both the eastern and western coastlines. A shoal with a sounding of 16 m is located 5 km northwest of McBean Bay on the Brodeur Peninsula. South of Creswell Bay, Prince Regent Inlet is shallower than further north, and depths do not increase as rapidly outward from the eastern and western coastlines.

Prince Regent Inlet has a predominantly first year ice cover during winter. Maximum multi-year ice concentrations are less than 4/10th along the preferred eastern side of the inlet. Slightly higher multi-year ice concentrations occur to the south.

The waters become shallower as one proceeds further south into the Gulf of Boothia. At the latitude of Bernier Bay, soundings generally range from 100 to 200 m across the gulf. South of Easter Cape on Baffin Island, the only chart soundings which exist are in a few narrow strips across the gulf. From Easter Cape southeast toward Crown Prince Patrick Island (see Figure 1.4-7), depths generally range between 90 and 180 metres. Waters over 90 m deep lie within a few kilometres of the southern shore of this island. From Crown Prince Patrick Island to the western entrance of Fury and Hecla Strait, depths range from 90 to 290 metres. South and west of Crown Prince Patrick Island, only a few strings of soundings exist across the gulf, to Cape Margaret on Boothia Peninsula and Cape Chapman on Simpson Peninsula, and these range in depth from 36 to 216 metres. These are too sparse for navigational purposes, particularly with regard to the avoidance of multi-year ice floes.

The Gulf of Boothia has the heaviest ice conditions along this alternative route. Multi-year ice concentrations during winter range from 1/10th to 3/10ths at the northern end, and from 7/10ths to 9/10ths at the southern end. Similarly, during summer, multi-year ice concentration range from 1/10th to 3/10ths, and from 4/10ths to 6/10ths, respectively. On average, summer clearing of the ice (less than 5/10 cover) in the Gulf of Boothia fails to occur in two of ten years. Multi-year ice encounters can be minimized by a routing across the northern end of the gulf along the Baffin coast. Concentrations below 6/10ths will

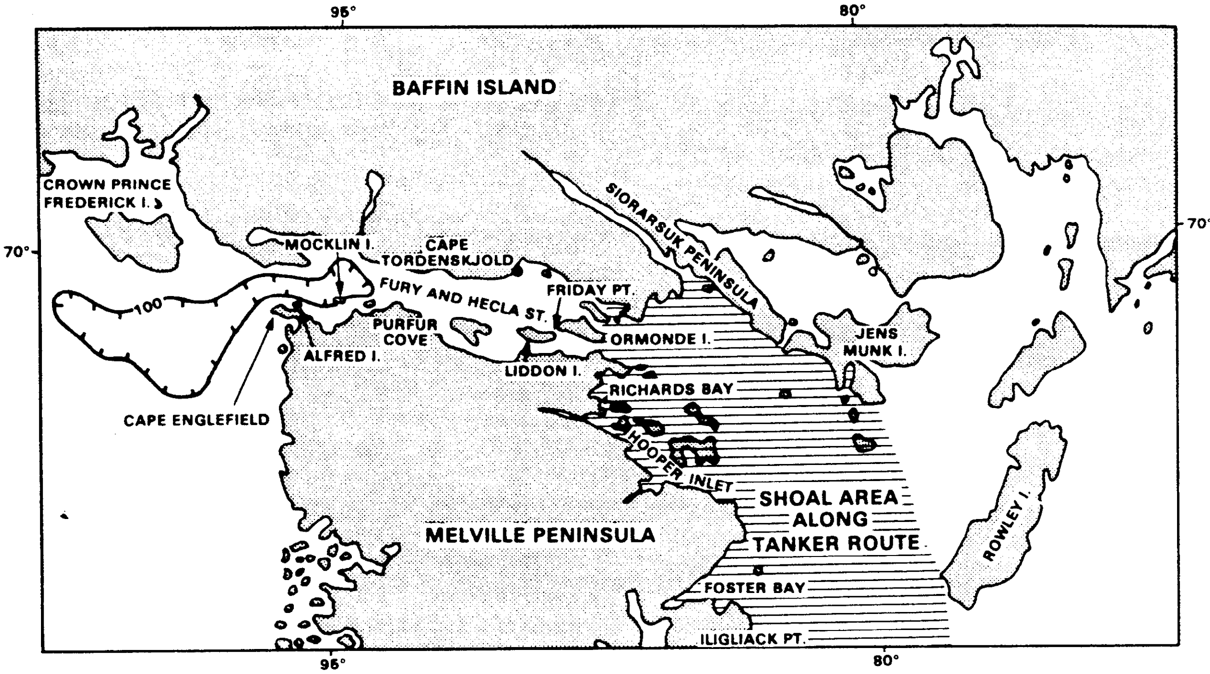

FIGURE 1.4-7 *Fury and Hecla Strait. Soundings have only been made through the centre of the strait and across a narrow section north of Purfur Cove. The strait is narrowest (1.95 km) between Ormonde Island and Melville Peninsula. During winter, the strait is mostly covered with first year landfast ice, however in summer, heavy ice can remain packed against the southern shore where water depths are greatest (Dickins, 1979).*

allow selective detouring around much of the multi-year ice (Dickins, 1979).

1.4.3.2 Fury and Hecla Strait

Soundings have only been made through the centre of Fury and Hecla Strait and were made in a strip passing between Alfred and Mocklin Islands at the strait's western end, and between Liddon and Ormonde Islands at its eastern end (Figure 1.4-8). The one exception to this occurs across a narrow section of the strait north of Purfer Cove on Melville Peninsula, where soundings extend from the northern to the southern shore.

The width of Fury and Hecla Strait tends to remain between 15 and 20 km along much of its length. However, the strait narrows to a distance of 3.75 km between Fruchen Point on Liddon Island and Friday Point on Ormonde Island. This distance decreases to 1.95 km at the narrowest point across the Labrador meadows, between Ormonde Island and Melville Peninsula.

At the strait's western end, north of Cape Englefeld, depths range between 270 and 360 metres. From Cape Englefelt to Purfer Cove, depths decrease to between 90 and 150 metres. At Purfer Cove the 50 m isobath occurs within a few kilometres of both the southern and northern coast. From Purfer Cove to Friday Point depths vary between 36 and 195 m through the centre of the strait. Minimum depths of 17 and 27 m are located 5 km off the western end of Liddon Island, and a sounding of 25 m occurs about 10 km south and west of Cape Tordenskjold on Baffin Island. Shallow waters are also located in the narrow passage between Liddon and Ormonde Islands. Depths here range from 11 to 27 m at distances ranging from 0.4 to 2.25 km off the point's southern coast. Elsewhere depths range between 40 and 214 m until the Labrador Narrows is reached. Soundings through the centre of the Narrows range from 40 to 214 metres.

During winter, Fury and Hecla Strait is predominantly covered with first year landfast ice. Multi-year ice concentrations range from 1/10th to 3/10th. A polynya occurs every winter in the Labrador Narrows at Ormonde Island (Dickins, 1979).

During spring break-up the weaker ice of the strait is flushed out by a strong tidal current. Heavier ice, including multi-year floes from the Gulf of Boothia and Prince Regent Inlet, can then pass through the strait during summer. There is a tendency for heavy ice to remain packed against the southern shore, thus reducing ice concentrations through the centre of the strait where water depths are greater.

The Pilot of Arctic Canada (1978) mentions the possibility of severe ice jams in the narrows which can back up to the west. The narrowness of the strait combined with tidal currents could make it difficult for icebreaking tankers to turn around under extraordinary circumstances.

1.4.3.3 Foxe Basin, Foxe Channel and Hudson Strait

Once east of Fury and Hecla Strait, the route enters the northwestern corner of Foxe Basin. A southerly direction is assumed with Siorarsuk Peninsula, Jens Munk Island and Rowley Island to the east, and Richards Bay, Hooper Inlet and Foster Bay on Melville Peninsula to the west (Figure 1.4-7). This section of the route through Foxe Basin is characterized by extensive shoals.

Depths gradually increase in southern Foxe Basin. Between Igligliak Point and Cape Robert Brown depths range from 35 to 110 metres (Figure 1.4-6). South of Cape Robert Brown to Foxe Channel, depths range between 90 and 150 m and waters tend to deepen towards Melville Peninsula.

During winter Foxe Basin is normally covered with first year ice. Some old floes from Fury and Hecla Strait may be scattered around the basin. An important area of open water and thin ice usually occurs in northwest Foxe Basin. This polynya extends west of Rowley Island across the alternative tanker route along Melville Peninsula. A shore lead also tends to run about 10 km off the Melville Peninsula coast, but water depths are likely to be inadequate for icebreaking tankers to take advantage of this lead unless it extends south of Cape Robert Brown.

Ice thickness generally increases towards the centre of the Basin, favoring a route along Melville Peninsula. The western half of Foxe Basin also tends to have lighter summer ice conditions, which is due to a northeast current along the shore of Foxe Peninsula (Dickins, 1979).

Foxe Channel leads from the southwest corner of Foxe Basin to Hudson Strait, and passes between Foxe Peninsula to the west, and Southampton Island to the east. Mill, Salisbury and Nottingham Islands lie at the eastern end of the channel.

Depths in Foxe Channel generally range between 50 to 400 m, with the deepest waters occurring in the western half of the channel. A shoal peaking at a depth of 13 m lies in the middle of the channel, about 100 km east of Cape Donovan on Southampton Island.

In Hudson Strait, a route along the northern side will avoid the heavier ice concentrations which accumulate on the southern side. Water depths increase rapidly from the northern and southern coasts of the Strait and depths generally range between 180 and 360 m, except at its eastern end where depths well over 360 m are encountered. A shallow bank where depths are under 180 m lies to the northwest of Charles Island off Ungava Peninsula. At the end of this bank, about halfway between Charles and Salisbury Islands, is a shoal with a minimum depth of 29 metres. Occasional soundings between 126 and 180 m are found at the eastern end of the strait.

The bathymetry between Prince Regent Inlet and Hudson's Strait is the least surveyed area of the waters being considered for icebreaking tanker routes. Most of the area has not been surveyed to modern standards and existing charts are characterized by a sparsity of soundings. To use this route, a high density of soundings will be required through Fury and Hecla Strait and Foxe Basin, given the shallowness of these waters. Dredging would also likely be required at several points to maximize navigational safety.

During the summer of 1981, the Canadian Hydrographic Service conducted a new series of soundings in Foxe Basin and Fury and Hecla Strait. Provisional results, not yet published, show a number of critical shoals not indicated on current charts.

1.5 THE SHORES

This section summarizes the physical character of shorelines in the Northwest Passage, between Amundsen Gulf and Davis Strait, as well as active processes which affect these shores. A more comprehensive treatment of the subject is provided in Woodward-Clyde (1981), a supporting document to the Environmental Impact Statement.

On a regional basis the coasts of Lancaster Sound and of northwest Baffin Bay are better understood than those between Amundsen Gulf and Barrow Strait. The coasts of western Lancaster Sound are probably the best known of those studied within the Canadian Arctic (Woodward-Clyde, 1981). Elsewhere there is a paucity of data and, in many sections, there is no ground-truth information available to determine either the sediment characteristics or the beach morphology.

The coasts of the Northwest Passage between Amundsen Gulf and Davis Strait are relatively stable in terms of shoreline changes, despite considerable variability in the characteristics of the coastal processes. The shoreline throughout is geologically controlled and relief is high with bedrock outcrops along the shore particularly in eastern sections, to the east of Barrow Strait. The coasts around Viscount Melville Sound have lower relief and are underlain by near-surface bedrock in most sections. Barrier beaches are generally restricted in length and primarily associated with deltas; in contrast to shores of the Beaufort Sea, there are no sections of coast with ice-rich tundra cliffs.

1.5.1 VISCOUNT MELVILLE SOUND AND LANCASTER SOUND

In Viscount Melville Sound, and generally between Amundsen Gulf and Barrow Strait, the bedrock outcrops are predominantly sedimentary sequences and relief is low everywhere, except along northeast Banks Island and Dundas Peninsula on Melville Island. Examples of shoreline types are shown in Plates 1.5-1 to 1.5-8 for Parry Channel. The physiography of the coastal zone in most sections is characterized by a low plain with a veneer of surficial materials. The shore zone character is one of predominantly continuous sand or gravel beaches (Area A in Figure 1.5-1). Sequences of raised beaches are a common occurrence on coasts where backshore relief is low. There are few large deltas in this section and rivers generally exit into the sea through braided lobate deltas. The shorelines are essentially very stable; beach changes are infrequent and of low magnitude. Despite this overall stability, the intertidal sediments are subject to reworking and to redistribution by normal wave processes during the open water season.

The coasts of the Viscount Melville Sound area are in an ice-dominated environment. Ice push is common on all exposed coasts and storms are an important but infrequent event in terms of coastal sediment reworking (Woodward-Clyde, 1981). Where rivers reach the coast, fluvial processes play an important role in determining shore zone character. The open water season ranges between 30 and 70 days in eastern and southwestern areas but can be as little as 0 to 40 days in M'Clure Strait. Fetch distances are limited in all areas by ice and by the coastal configuration of the Arctic Archipelago. As a result of the fetch and ice limitations, wave energy levels are extremely low except during periods of infrequent open water storm wave activity.

PLATE 1.5-1 *Barrier beach north of Deans Dundas Bay, west Victoria Island. Hummocky ice-push terrain characterizes the beach berm (Courtesy: Woodward-Clyde).*

PLATE 1.5-2 *High relief coast characterized by cliff faces buried with talus and by incised rivers with braided lobate deltas at Cape Vesey Hamilton, northeast Banks Island (Courtesy: Woodward-Clyde).*

PLATE 1.5-3 *Continuous pebble-cobble beach at the base of a large talus slope, Cape Ricketts, southwest Devon Island. The person is standing at the mean high-water mark; photograph was take at low tide (Courtesy: Woodward-Clyde).*

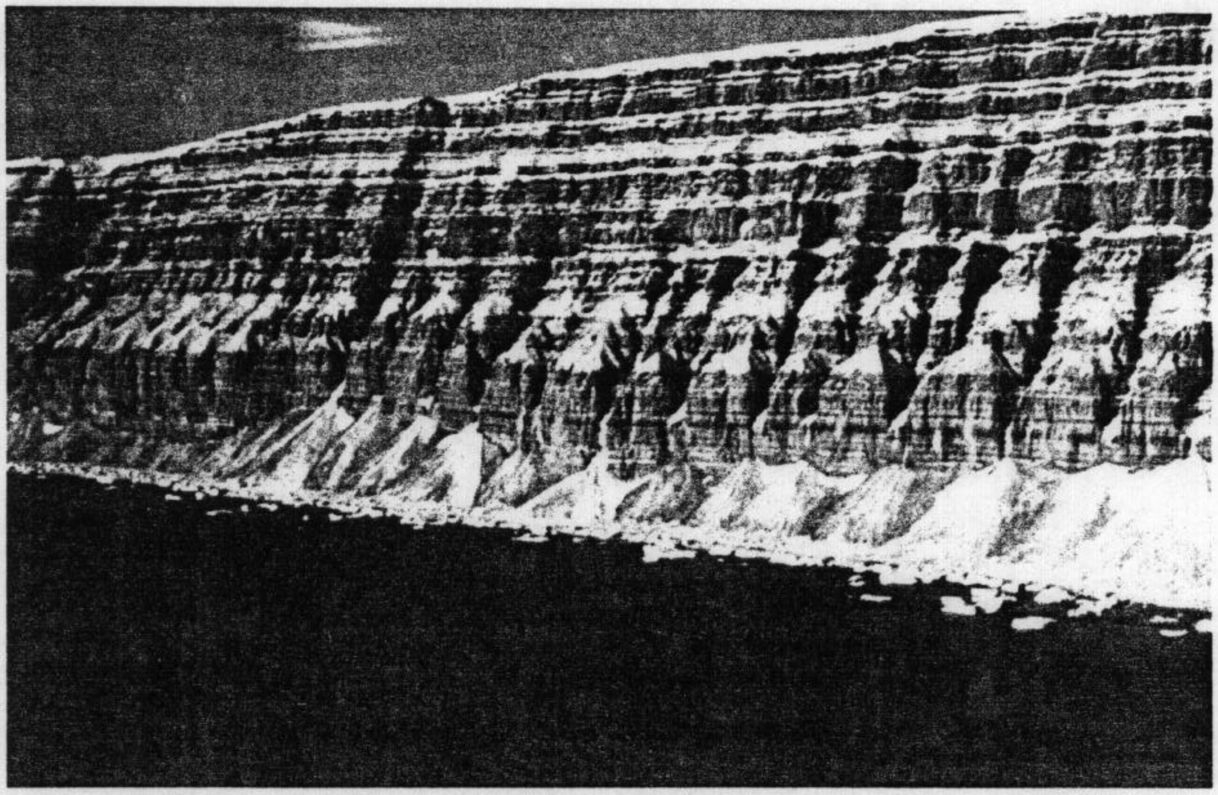

PLATE 1.5-4 *Upland plateau and a cliff face buried by talus: southern Devon Island (Courtesy: Woodward-Clyde).*

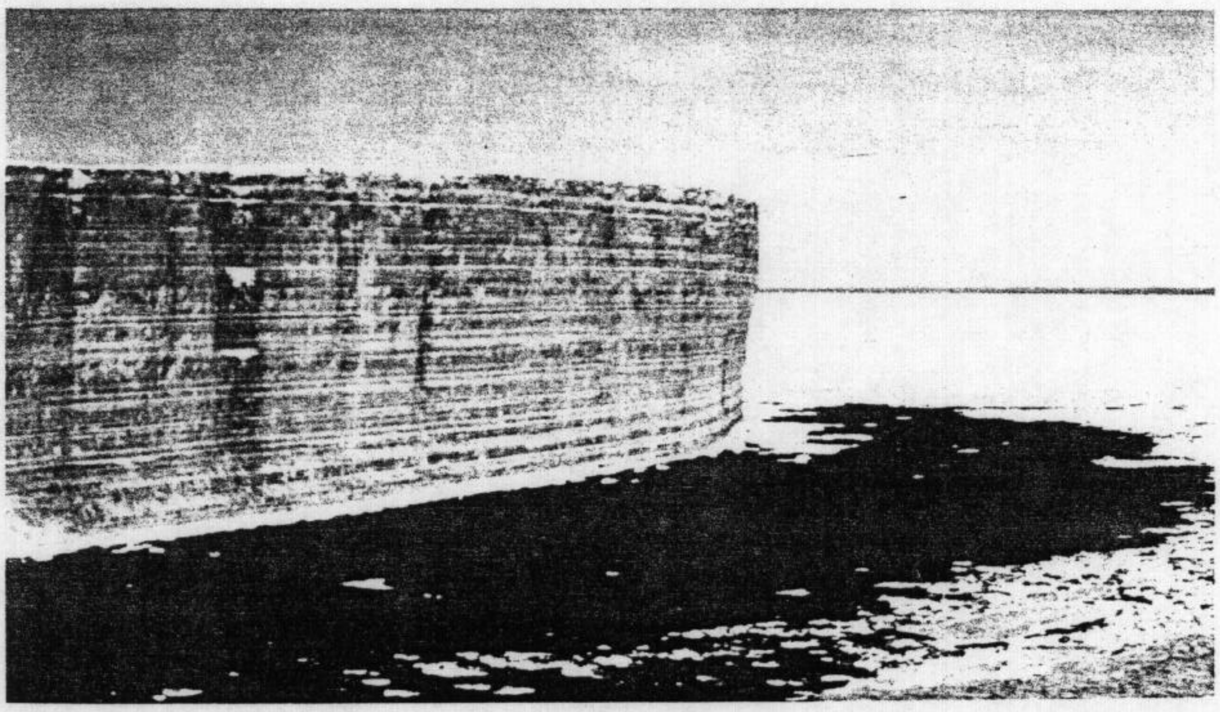

PLATE 1.5-5 *Horizontally bedded sedimentary rocks forming near vertical cliffs up to 300 m in height: Prince Leopold Island (Courtesy: Woodward-Clyde).*

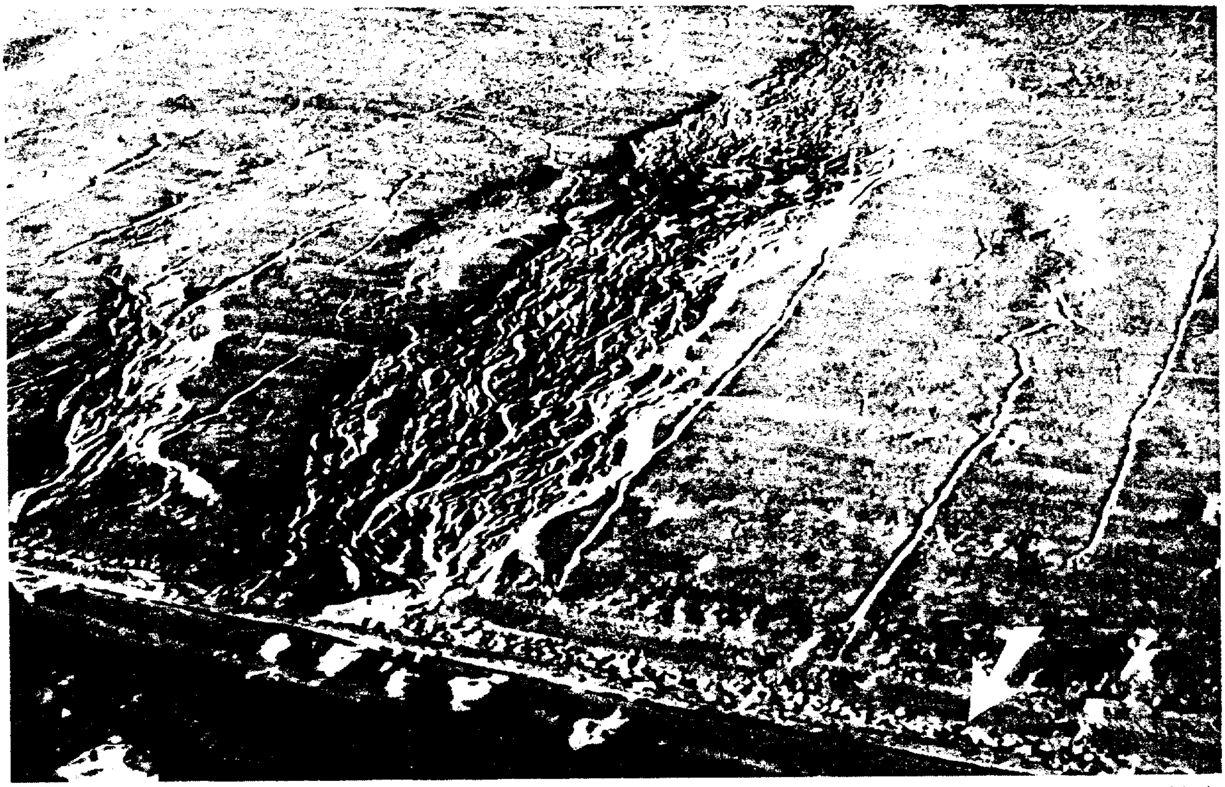

PLATE 1.5-6 *Coastal plain of northern Somerset Island between Cape M'Clintock and Cape Clarence showing braided streams, raised beach ridges, frost cracks, ice-push ridges (indicated by arrow), and ice floes stranded in the intertidal zone (photo at low tide). (Courtesy: Woodward-Clyde).*

PLATE 1.5-7 *Calving tidewater glacier (East Cunningham glacier) and outwash plain on southeast Devon Island, west of Cape Sherard (Courtesy: Woodward-Clyde).*

PLATE 1.5-8 *Coastal plain with a continuous beach ridge and wide supratidal flats north of Clyde, northeast Baffin Island. (Courtesy: Woodward-Clyde).*

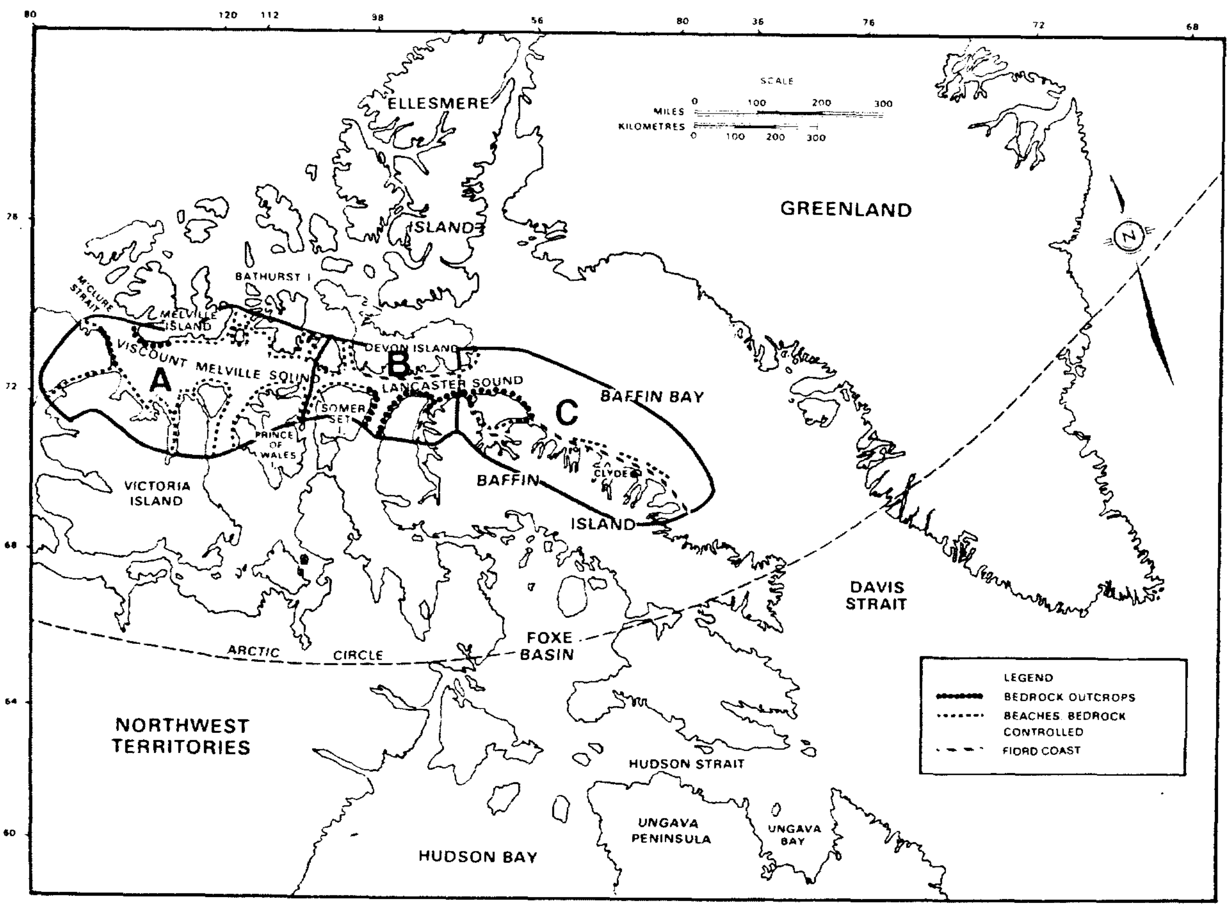

FIGURE 1.5-1 *Simplified shore zone character along the eastern tanker corridor between Amundsen Gulf and Davis Strait. Shorelines are relatively stable. There are no sections of coast with ice-rich tundra cliffs. Barrier beaches are short and primarily associated with deltas (Source: Woodward-Clyde, 1981).*

Lancaster Sound (Area B in Figure 1.5-1), between Barrow Strait and Baffin Bay, is characterized by horizontally bedded sedimentary rock outcrops. This upland plateau region, with high (500 m) relief in most sections is interrupted by several low coastal plains, such as northern Somerset Island, and is frequently incised by river valleys that cross the shore zone. Some Precambrian bedrock is exposed on western Somerset Island; this is also an area of low relief. The shore zone character is typically that of fjord coasts, except where low coastal plains occur. The coastal cliffs are usually buried by basal talus so that the intertidal zones are predominantly continuous coarse-sediment beaches. On the few shoreline sections where a low coastal plain is present, the backshore is characterized by relict raised beaches and the shore zones are sand or gravel beaches. These coasts are very stable due to the bedrock control; major shoreline changes are rare. The intertidal sediments are subject to reworking by normal wave activity.

The coastal processes that operate in Lancaster Sound can be characterized as those of a micro-tidal, low energy, wave-dominated environment. Ice push is common on most exposed coasts but, unlike coasts further to the north and west, ice is not a dominant coastal process. The open water season ranges between 40 and 100 days and fetch distances are limited by the coastal configuration. The fetch areas are generally less than 500 km, but infrequent storms can produce high wave energy levels on exposed coasts during the open water season.

1.5.2 BAFFIN BAY AND DAVIS STRAIT

The coasts of northwest Baffin Bay (Area C in Figure 1.5-1) are predominantly Precambrian bedrock outcrops. This is a mountainous coast with high relief (up to 2,000 m) and permanent ice caps in backshore environments. A low coastal plain characterizes eastern Devon Island, southwest Bylot Island, and parts of the Baffin Island coast (Plate 1.5-8). The shore zone character is that of fjords with tidewater glaciers and, on eastern Devon Island, tidewater ice sheets. Coastal relief is generally high but the cliff faces are usually buried by talus deposits. Continuous gravel or sand beaches are common on the low coastal plains but elsewhere coarse sediments (cobbles and boulders) cover the intertidal zone. Deltas are a common feature at the heads of ice free fiords. These coasts are very stable; major shoreline changes are rare due to bedrock control of the shore zones. The beaches are actively reworked during open water conditions for a few months each summer. In areas where glaciers and ice sheets break off directly into the sea, the shoreline is unstable.

The coasts of northwest Baffin Bay are a storm-wave environment. Wave energy levels are relatively high for Arctic coasts; wave heights greater than 1 m are common. The open water season is generally 100 days or more each year and fetch areas during the open water season are greater than 500 kilometres.

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CHAPTER 2
MARINE PLANTS AND ANIMALS

This part of Volume 3B summarizes existing information on the marine plants and animals frequenting the Northwest Passage region, generally illustrated in Figure 2-1. For certain key species which may migrate into and out of the region (e.g. Beluga Whales) the area covered is extended. Separate sections provide the most relevant information on the mammals, marine birds, fish, and lower trophic levels of the region. Section 2.5 reviews the resource harvesting activities of people living in the region, while Section 2.6 identifies special areas.

For information on the Beaufort Sea portion of the eastern shipping corridor and the western corridor, the reader is referred to Volume 3A. Additional information is available in various supporting documents to the Environmental Impact Statement as well as the literature cited in the text. To assist the reader, Table 2-1 is provided; it defines many of the more important biological terms used throughout this chapter.

2.1 MAMMALS

About 22 species of marine mammals occur along the primary eastern shipping corridor between Prince of Wales Strait and Davis Strait. Twelve species are whales that occur primarily in Davis Strait during summer. Of the remaining 10 species, only the ringed seal and polar bear are permanent residents throughout the area. During summer, bearded seals range along the entire route, while white whales, narwhals, bowheads, walruses and harp seals, all of which winter in the eastern Arctic or off the Atlantic coast rarely range farther west than western Barrow Strait. Harbour seals and hooded seals rarely occur west of eastern Lancaster Sound. The white and bowhead whales that frequent the Beaufort Sea during summer (Volume 3A, Section 3.2.1) rarely move farther east than southern Prince of Wales Strait.

Information on the distribution and abundance of marine mammals along the eastern shipping corridor, particularly in summer, has increased greatly over the past decade. Aerial survey programs (Finley *et al.*, 1974; Finley, 1976; Johnson *et al.*, 1976; Finley and Johnston, 1977; RRCS, 1977; Davis *et al.*, 1978

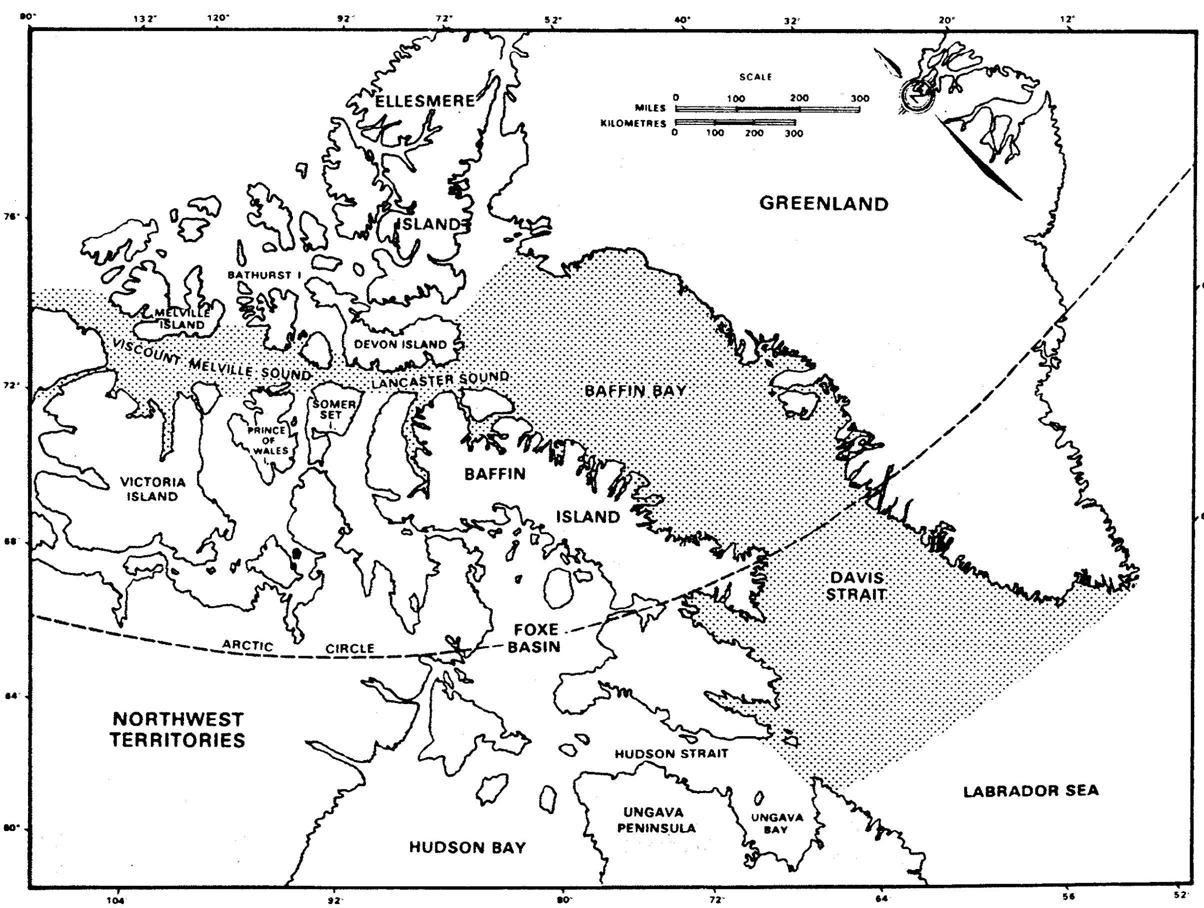


FIGURE 2-1 *Approximate boundary of the Northwest Passage region. This chapter summarizes existing information on the marine plants and animals of this large region.*

TABLE 2-1

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.

a,b; Koski and Davis, 1979, 1980; MMI 1979 a,b; Stirling *et al.*, 1981) have provided much new information on the distribution and numbers of most species over much of the route, while studies of reproductive biology and behavior (e.g., McLaren, 1958, a,b,c, 1962; Brodie, 1971; Smith, 1973a; Sergeant and Brodie, 1975; Schweinsburg *et al.*, 1977; Stirling and Archibald, 1977; Finley, 1979; Smith *et al.*, 1979; Smith and Hamill, 1981; Stirling *et al.*, 1978, 1980) have provided much useful information required for management purposes. However, for many species the wintering areas and migration routes especially in Baffin Bay and Davis Strait, are not well known.

2.1.1 WHALES

2.1.1.1 White Whale (Beluga)

The white whale *(Delphinapterus leucas)* is a small, toothed whale that may reach 4 to 5 m in length. It is a very social species and large herds often occur in shallow coastal waters. White whales are highly vocal, and have a well-developed capacity for echolocation (Ford, 1977; Morgan, 1979). White whales occur primarily in Arctic and subarctic waters of North America and Eurasia, although a small isolated population inhabits the Gulf of St. Lawrence. Sergeant and Brodie (1975) estimated that about 30,000 white whales inhabit North American waters. During certain times of the year, substantial proportions of the North American population are found in very restricted areas.

The two principal regions along the eastern shipping corridor where white whales are known to summer are the eastern High Arctic and along the southeast coast of Baffin Island. The size of the 'High Arctic' population has been estimated at 10,000 to 14,000 individuals (Davis and Finley, 1979), whereas the eastern Baffin population (the 'Cumberland Sound stock') has an estimated 500 to 700 animals (Brodie *et al.*, 1980). The estimated annual harvest of white whales along the eastern shipping corridor is about 600 to 1,200 (Section 2.5.1.3).

The reproductive potential of white whales is not well understood because there is uncertainty about the validity of the ageing method. It was originally believed that two dentinal layers were laid down per year (Brodie, 1971; Sergeant, 1973a), while more recent opinion (Sergeant, 1979) based on the same data and a study by Ohsumi (1979) suggests that only one layer is added per year. The question is unresolved at present.

Depending upon which ageing criterion is correct, the age of first breeding in female white whales is either 5 or 10 years and the average life span is either 25 or 50 years. Calving occurs during the summer in the eastern Arctic, and females produce a single calf every third year (Brodie, 1971). The reproductive potential of this species is low.

White whales feed on a wide variety of fish and invertebrates of benthic and pelagic origin (Kleinenberg *et al.*, 1964). In Arctic waters, the Arctic cod appears to be the major prey (Vibe, 1950; Freeman, 1968; Finley, 1976; Davis and Finley, 1979).

Although a small number (estimated at 500 to 1,000 individuals in March 1978) of white whales from the 'High Arctic' population winter in areas of open water along southeastern Devon Island and in eastern Jones and Smith sounds (Finley and Renaud, 1980), most of this population is believed to winter off the west Greenland coast between Disko Bay and 63°N latitude (Figure 2.1-1) (Vibe, 1967; Kapel, 1977; Davis and Finley, 1979). However, data on the winter distribution of whales in this area are not available. No white whales were recorded along the pack ice edge in western Davis Strait in March, 1978 (MMI, 1979a).

Migration of white whales from wintering areas in Greenland to the summering areas in the central Canadian Arctic begins in April and follows the landfast ice edge on the west coast of Greenland (Figure 2.1-1). Most individuals continue across northern Baffin Bay north of 76°N, although an unknown number of white whales summer in the Thule District of Greenland. Only a few white whales were observed in offshore areas of Baffin Bay south of 76°N during aerial surveys conducted in spring, 1978 and 1979 (Koski and Davis, 1979; Koski, 1980a). After crossing northern Baffin Bay, the whales move in a southerly direction along the ice edge across Jones Sound and along the east coast of Devon Island to Lancaster Sound.

The few white whales that may be present in eastern Lancaster Sound during April are presumably animals that winter in northern Baffin Bay. The number of migrants moving through Lancaster Sound increases through May and early June, and peaks during late June and July. However, migration can be delayed until mid to late July in years when fast ice persists across eastern Lancaster Sound. For example, persistent fast ice in 1978 and 1979 resulted in considerable movement of whales back and forth along the south coast of Devon Island, the edge of the fast ice, and the north coast of Bylot Island. Large concentrations may occur at this time. For example, 1,800 individuals were found along a 60 km portion of the ice edge on July 11, 1978 (Koski and Davis, 1979).

The migration through Lancaster Sound occurs primarily along the south coast of Devon Island

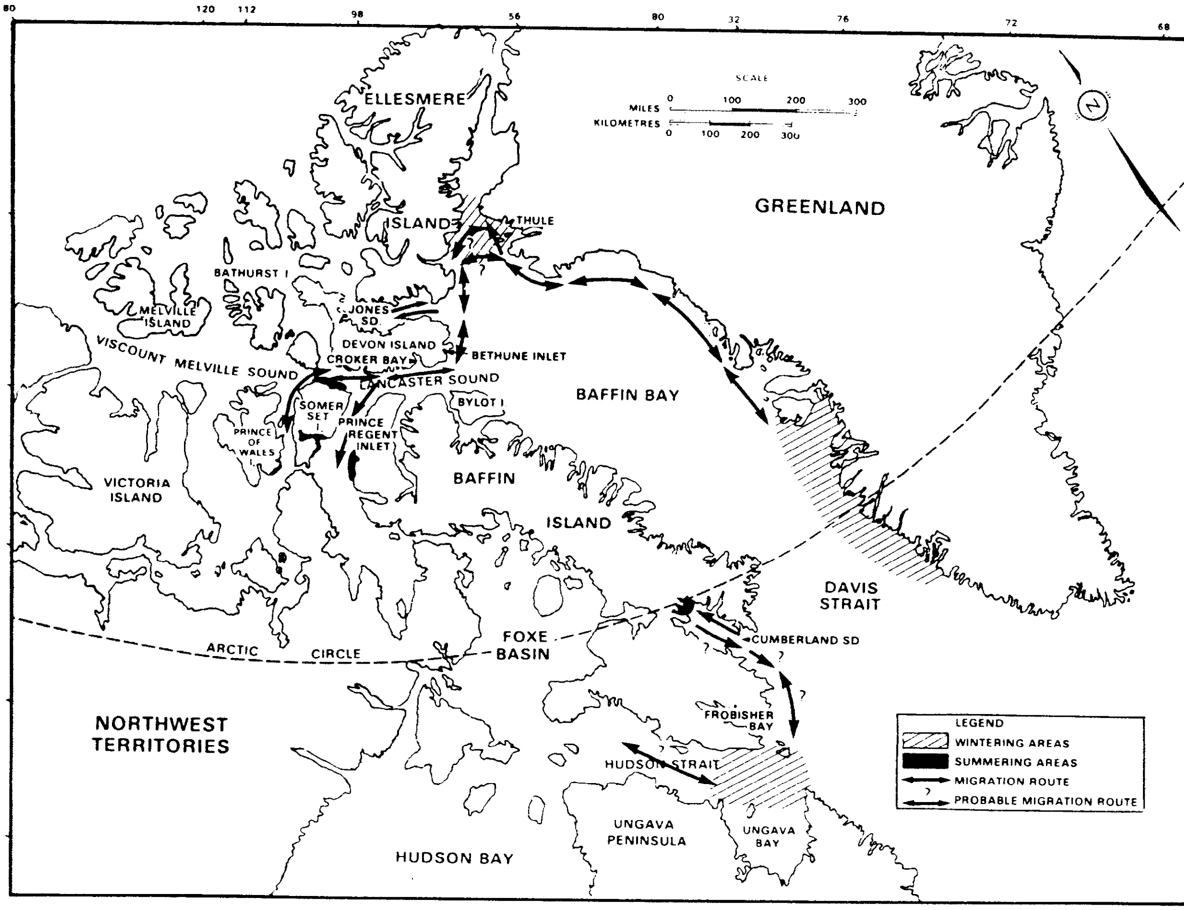


FIGURE 2.1-1 *White whale migration routes, wintering areas and summer concentration areas in the High Arctic and Cumberland Sound. The migration of white whales through Lancaster Sound occurs mainly along the south coast of Devon Island.*

(Figure 2.1-1) rather than in the middle of the sound or along Bylot and Baffin islands. For example, during weekly surveys of the north and south shores of Lancaster Sound during the westward migration in 1976, 86% of more than 1,800 animals seen along the coasts and ice edges were within 1.5 km of the shore or ice edge along Devon Island. During the peak migration in late June and July, 94% of the migrants were observed in these areas (Johnson *et al.*, 1976; Davis and Finley, 1979). By the end of July, virtually all migrants have moved west to Barrow Strait.

White whales move into shallow estuaries from mid July to mid August (Plate 2.1-1). Major concentration areas occur along the south side of Barrow Strait, especially in bays such as Cunningham Inlet and Garnier Bay in Somerset Island. In addition, several thousand white whales move south to summering areas in Prince Regent Inlet (Figure 2.1-1). The small number of white whales recorded in offshore waters of Barrow Strait in July are presumably crossing the strait to the summering areas. White whales have not been observed offshore during August (Finley, 1976), and they are not known to move farther west than about 98°W (Finley, 1976).

Eastward fall migration is rapid and involves large compact herds. Migration through Lancaster Sound occurs almost exclusively along the southern coast of Devon Island within 200 m of the shore. In 1976, 1978 and 1979, the whales passed through Lancaster Sound mainly during the third week of September (Davis and Finley, 1979; Koski and Davis, 1979, 1980). Bethune Inlet and Croker Bay, both in south Devon Island, may be important feeding areas during fall migration (Koski and Davis, 1979).

After leaving Lancaster Sound, virtually all white whales travel north along the east coast of Devon Island toward the entrance of Jones Sound and presumably retrace the spring migration route. Migrants are generally found moving southward past Thule by late October (Vibe, 1950). Harvest statistics indicate that whale numbers along the coast of Greenland from 75°N to 72°N peak in October and November (Kapel, 1977).

The 'Cumberland Sound Stock' of white whales

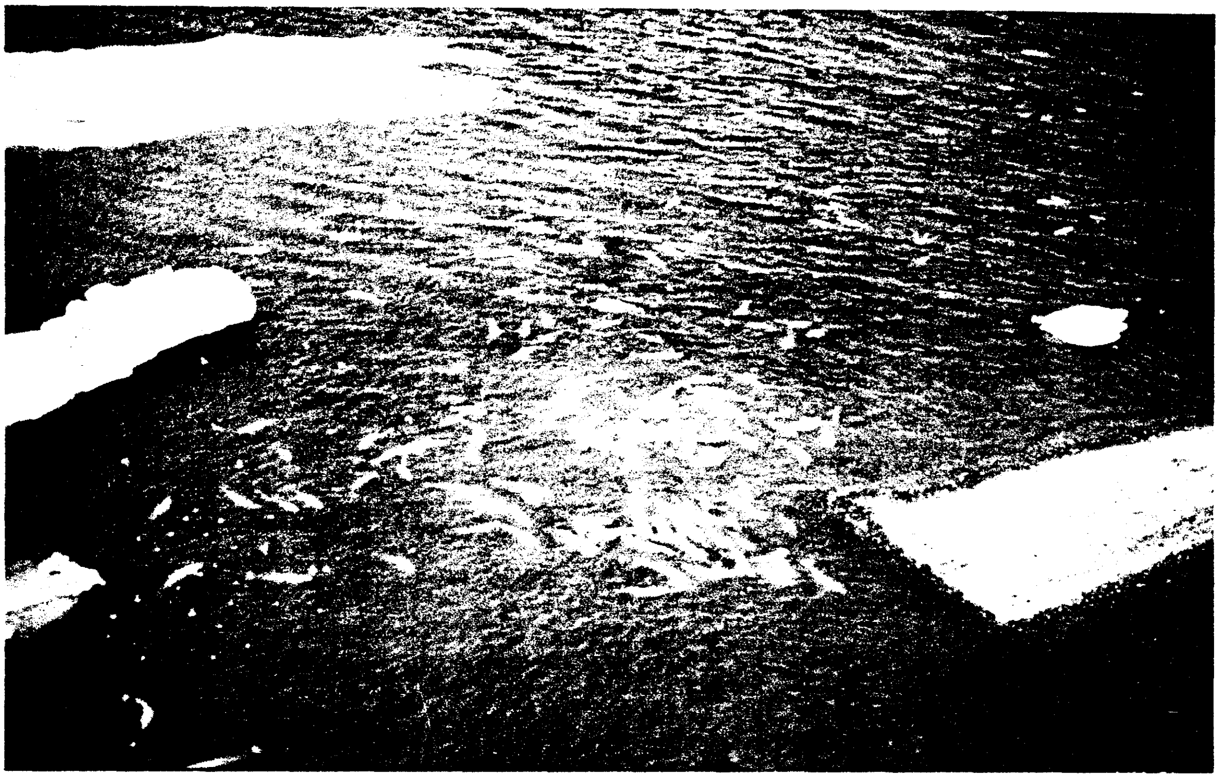


PLATE 2.1.1 *White whales, such as those shown here, move into shallow estuaries along the south side of Barrow Strait and in Prince Regent Inlet from mid July to mid August. (Courtesy, Petro-Canada).*

numbers about 500 to 700 (Brodie *et al.*, 1980) and is believed to be genetically isolated from the 'High Arctic' population (Davis and Finley, 1979). These whales summer in Cumberland Sound along southeast Baffin Island, and probably winter in Hudson Strait although migration routes between these two areas are unknown (Figure 2.1-1). A few white whales are present in Cumberland Sound by May, and their numbers generally peak in August. White whales have been observed in Cumberland Sound as late as November (MAL, 1978; MMI, 1979b). An estimated 300 white whales were also observed in Frobisher Bay in late August, 1979 (MAL, 1978), but the stock affinity and migration routes of these whales are unknown.

A major wintering area for white whales is located in the pack ice of eastern Hudson Strait and in adjacent areas of Davis Strait (Figure 2.1-1). MMI (1979a) recorded about 400 individuals in this area in March, 1978, although survey techniques and design did not permit the authors to estimate the total number present. White whales wintering in this area include animals from populations that summer in Hudson Bay and Ungava Bay and possibly Cumberland Sound (Finley *et al.*, in press). White whales have also been recorded in Frobisher Bay during March (MMI, 1979a).

2.1.1.2 Narwhal

The narwhal *(Monodon monoceros)* is a small, toothed whale that is found primarily in Arctic waters off eastern Canada and Greenland. Along the eastern shipping route, this species occurs in Barrow Strait, Lancaster Sound, Baffin Bay and Davis Strait. The size of this population is uncertain, but has been estimated to be at least 20,000 individuals (Davis *et al.*, 1978a; Koski, 1980a). Narwhals occur in deep water areas (Mansfield *et al.*, 1975) and for most of the year are closely associated with pack ice (Finley and Johnston, 1977; Koski and Davis, 1979; Koski, 1980a). The estimated annual harvest of narwhals by residents along the shipping corridor ranges from 500 to 1,200 animals (Section 2.5.1.4).

During most of the year, narwhals occur in small, widely scattered herds (Plate 2.1-2). However, groups ranging from several hundred to a few thousand may occur in relatively small areas during summer. In addition, they are also concentrated during migration when several thousand may move past a particular point during a two or three day period (Greendale and Brousseau-Greendale, 1976; Koski and Davis, 1979, 1980).

The population dynamics of the narwhal are not well

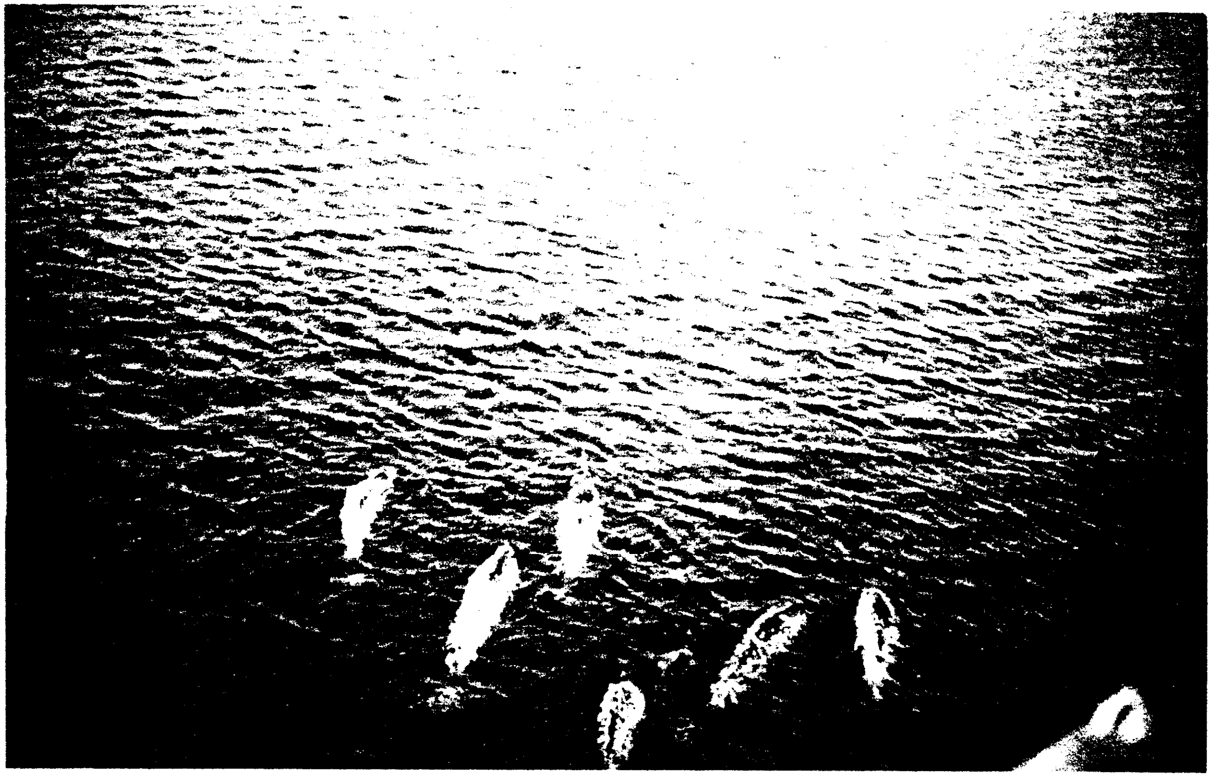


PLATE 2.1-2 *A small herd of narwhal moving through open water. Narwhal occur in deep water areas and for most of the year are closely associated with pack ice. (Courtesy, Petro-Canada).*

known (see Davis *et al.*, 1980 for review) but may be similar to those of the closely related white whale (Mansfield *et al.*, 1975). The information available suggests that this species reproduces slowly.

Narwhals often feed in areas associated with pan ice (Finley and Johnston, 1977) and in deep water. Their major foods include Arctic cod, squid, decapod crustaceans and Greenland halibut. Several sources indicate that Arctic cod are particularly important in the diet of narwhals in Arctic waters (Degerbøl and Freuchen, 1935; Vibe, 1950; Mansfield *et al.*, 1975; K. Hay, pers. comm; H. Silverman, pers. comm.; K.J. Finley, pers. comm.).

Although the winter distribution of this species has not been well documented, the few available observations suggest that narwhals winter in the pack ice of Davis Strait and eastern Hudson Strait (M'Clintock, 1859; Davis, 1876; Turl, 1977; MMI, 1979b). Wintering also occurs in the Disko Bay area of west Greenland during the period from January to May (Kapel, 1977).

Narwhals begin their northward spring migration during March. They generally appear to travel along the receding ice edge off the west coast of Greenland, north to Melville Bay and Thule. Narwhals first appear near Thule at the end of May or in early June (Vibe, 1950). There is also a major movement of narwhals in May and June through offshore Baffin Bay towards Lancaster Sound (Koski and Davis, 1979; Koski, 1980a). During these months, animals are widely distributed throughout much of Baffin Bay. In late June, some move to the fast ice edge along the east side of Baffin Island, and then proceed northwest along the ice edge towards Bylot Island (Figure 2.1-2).

The peak movement of narwhals into Lancaster Sound usually occurs in late June and July, although some may be widely distributed throughout the sound by as early as May. For example, several thousand narwhals entered the sound between June 24 and July 14 (1976), and smaller numbers continued to enter until the end of July in 1976, a year when there was no fast ice edge. During this migration, 21% of the narwhals entered along the north coast of the sound, 22% were along the south coast and 57% were offshore, more than 7 km from the coastline (Johnson *et al.*, 1976; Davis *et al.*, 1978a). A total of over 20,000 animals were estimated to have entered Lancaster Sound during this period (Davis *et al.*, 1978a).

In years when a fast ice edge blocks the entrance to Lancaster Sound, several hundred narwhals may collect along the ice edge and move back and forth

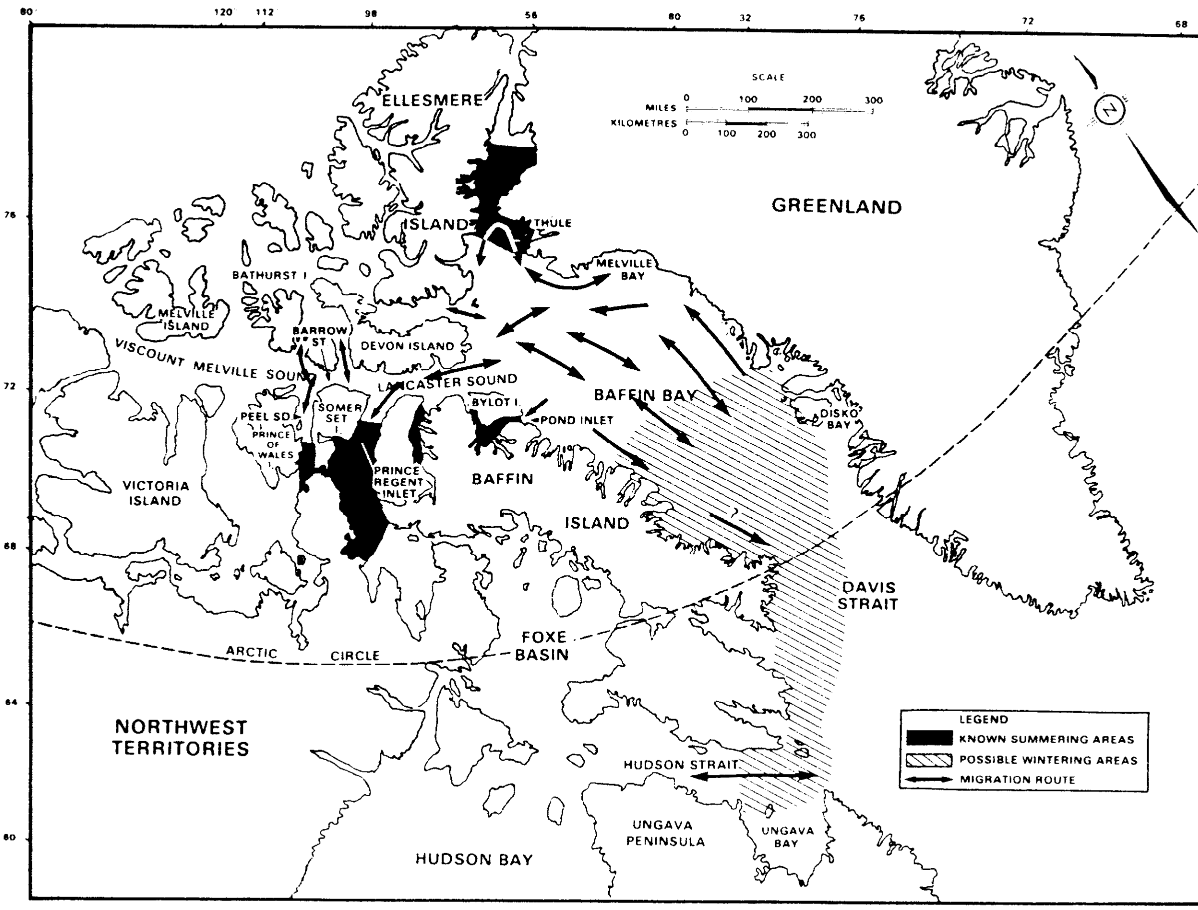


FIGURE 2.1-2 *Narwhal migration routes, wintering areas and summer concentration areas in Parry Channel, Baffin Bay and Davis Strait. Approximately 20,000 narwhals are estimated to inhabit the area of the shipping corridor.*

between the coasts of Devon and Bylot islands until break-up (Koski and Davis, 1979). The presence of fast ice during June can delay narwhal movements into Lancaster Sound by as much as a month. For example, narwhals were observed moving into Lancaster Sound as late as August 9 in 1978 (Koski and Davis, 1979).

Relatively few narwhals move as far west as Barrow Strait. For example, Finley (1976) estimated that 200 to 400 animals were in the strait in late July, 1975. A few move north into McDougall Sound and Wellington Channel, while larger numbers move south into Prince Regent Inlet (Koski, 1980b) and Peel Sound (about 1,000 in 1976: Finley and Johnston, 1977). Between mid August and mid September, narwhals are present in many of the deep water fiords and channels off Parry Channel and Baffin Bay (Figure 2.1-2).

The eastward migration from the summering areas usually begins during mid September, and by the end of September, large numbers of narwhals are present along both coasts and offshore in Lancaster Sound. An estimated 7,000 animals were in the sound on September 25 and 26, 1976 (Johnson *et al.*, 1976). Although several hundred migrants have been observed along the south coast of Devon Island during mid September, numbers and densities are generally higher along the southern side of Lancaster Sound. A major migration route follows the north and east coasts of Bylot Island and the northeast coast of Baffin Island (Figure 2.1-2). Over 4,000 narwhals were observed east of Pond Inlet on October 1, 1979 (Koski and Davis, 1980), while approximately 5,000 were observed moving south past Cape Adair on the northeast coast of Baffin Island between September 29 and October 2, 1978 (Koski and Davis, 1979). In addition to movements along the northeast coast of Baffin Island, substantial numbers of narwhals are believed to migrate through open water offshore in Baffin Bay (Koski and Davis, 1980), although the route of this migration has not been well documented. An unknown number of narwhals that summer in north Baffin Bay and Smith Sound are believed to migrate south along the west coast of Greenland (Vibe, 1950; Kapel, 1977).

Most narwhals have left Lancaster Sound and northwest Baffin Bay by mid October, but the routes of the late fall migration to the wintering areas have not been documented. No narwhals were recorded during aerial surveys in western Davis Strait during October and November, 1978, but a few were present in Hudson Strait in December (MMI, 1979b).

2.1.1.3 Bowhead Whale

The bowhead or Greenland right whale *(Balaena mysticetus)* is an Arctic baleen whale that may reach a maximum length of 20 metres. The bowhead whale is designated as an endangered species under U.S. legislation and by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In addition, this species is considered endangered by the International Union for Conservation of Nature and Natural Resources (IUCN) and by the International Whaling Commission (IWC).

Historically, five separate bowhead populations were present in the Sea of Okhotsk, the western Arctic, Hudson Bay, Davis Strait-Baffin Bay and near Spitsbergen west to eastern Greenland (Mitchell, 1977). In the last century bowhead whales were subjected to an intense commercial harvest resulting in their present endangered status.

The estimated 300 bowhead whales that frequent the eastern shipping corridor belong to the eastern Arctic population (Plate 2.1-3). This stock winters in Davis Strait, and ranges to Baffin Bay and Parry Channel during spring, summer and fall. Ross (1979) estimated that commercial whalers harvested 36,000 bowheads (includes 20% killed but lost) from this population between the years 1819 to 1915. Bowhead whales from the western Arctic population rarely range as far east and north as Viscount Melville Sound (Section 3.2.2.1, Volume 3A).

The population dynamics of bowhead whales have not been documented, but the low fraction of calves (2 to 3.8%) in both the western and eastern Arctic populations suggests that this species has a low reproductive rate (Braham *et al.*, 1979; Davis and Koski, 1980; Renaud and Davis, 1981). This is supported by the apparent slow recovery of the Davis Strait population during the 65 years since intensive whaling ceased.

The bowhead is a skimming-type baleen whale adapted to strain small prey from large volumes of water (Nemoto, 1970). Brown (1868) reported that zooplankton, mainly copepods and to a lesser degree pteropods, were important food for bowheads in the

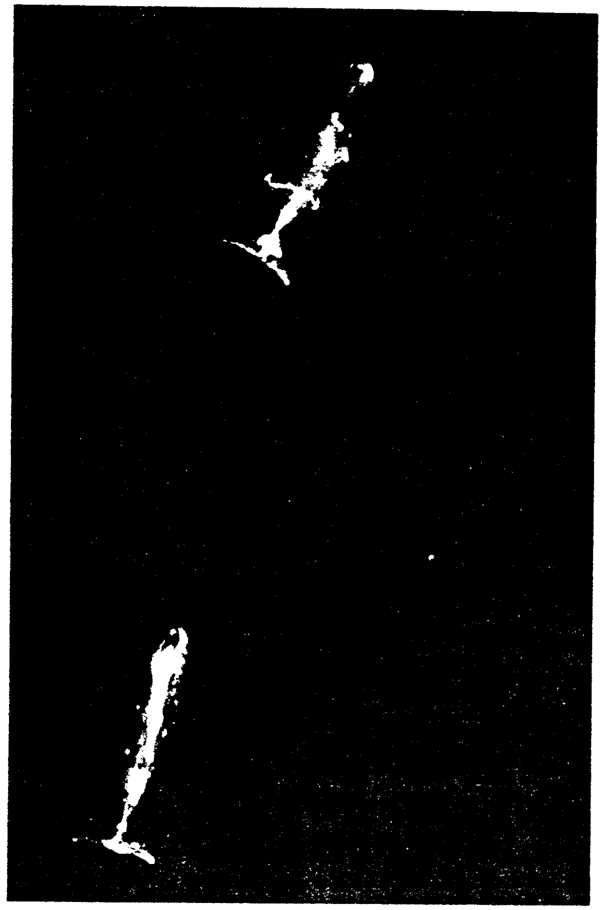


PLATE 2.1-3 *The bowhead whale is a skimming type baleen whale adapted to strain plankton from the sea. An estimated 300 bowhead whales frequent the eastern shipping corridor. They winter in Davis Strait and range to Baffin Bay and Parry channel during spring, summer and fall. (Courtesy, LGL Ltd.).*

Davis Strait and Baffin Bay areas. Bowheads of the western Arctic population are known to feed on euphausiids (90.3% of subsample volume in two specimens), amphipods, copepods, and, occasionally, small sculpins (Durham, cited by Marquette, 1978; Lowry *et al.*, 1978; Lowry and Burns, 1980). The presence of gammarid amphipods and sculpins, plus polychaetes, gastropods, echinoideans, reptantian decapods, sand and gravel in one bowhead from the Chukchi Sea (Johnston *et al.*, 1966), suggests that bowheads sometimes feed near or on the bottom, at least in nearshore waters. Würsig *et al.* (1981) observed bowheads in the southeastern Beaufort Sea actively feeding on the bottom but the importance of the infaunal and benthic organisms to the total diet is unknown.

The wintering areas of the Davis Strait bowhead stock are not well known. They formerly wintered along the edge of the pack ice in Davis Strait, off the entrances to Hudson Strait and Cumberland Sound, and off the west coast of Greenland from Disko Bay south to 63°N (Figure 2.1-3) (Brown, 1868; Low,

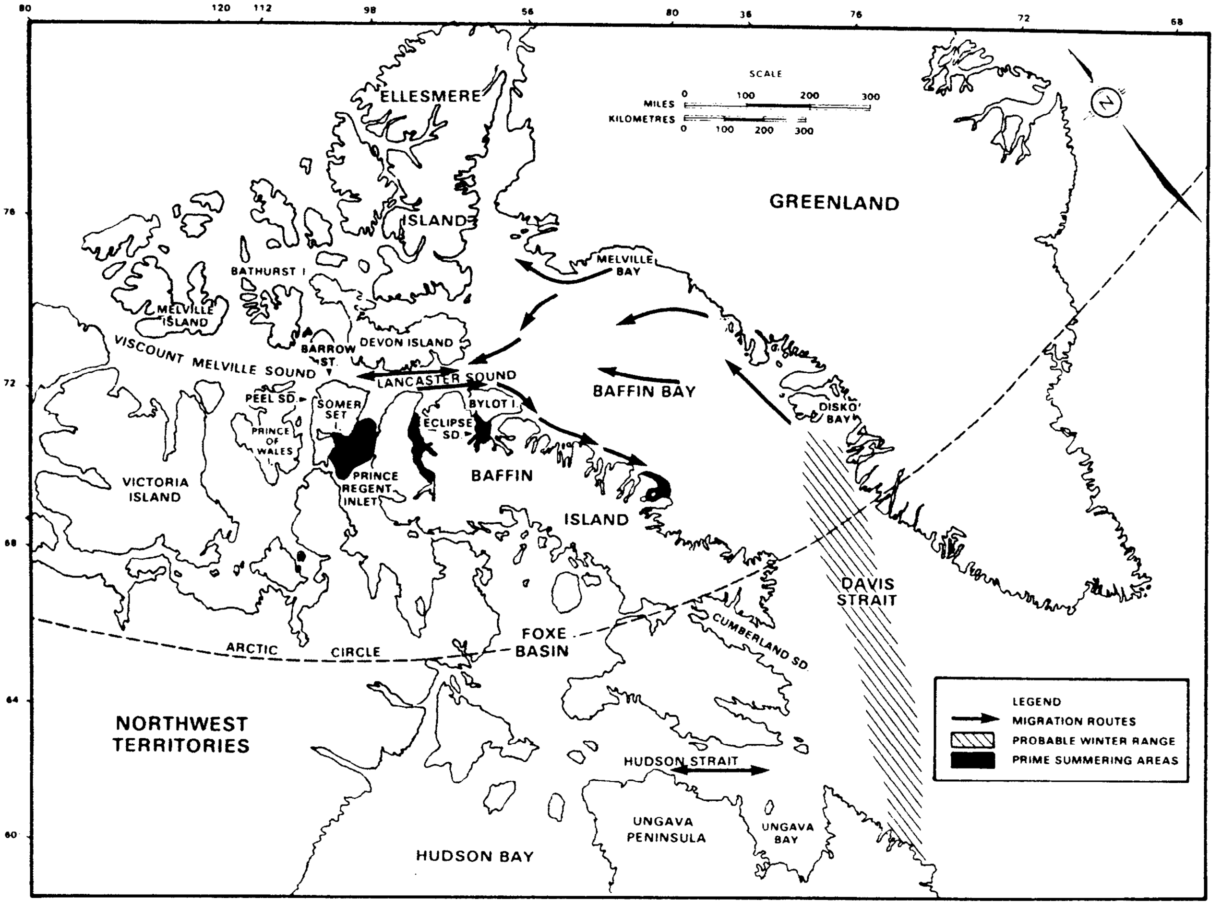


FIGURE 2.1-3 *Bowhead whale migration routes, probable winter range and known summer coastal concentration areas in Parry Channel, Baffin Bay and Davis Strait.*

1906; Marin ID, 1980). Turl (1977) observed a single bowhead at approximately 68°N, 55°W during 27 days of icebreaking operations in the Davis Strait pack ice in February and March, 1976.

The northward migration of bowheads is thought to begin by April. During May and early June early migrants follow the edge of the landfast ice north past Melville Bay and across northern Baffin Bay (north of 76°N), arriving in Lancaster Sound from the north and east. However, later migrants (late June to early August) apparently move through the offshore pack ice in central Baffin Bay and arrive in Lancaster Sound from the southeast (Koski and Davis, 1979; Koski, 1980a; Figure 2.1-3). The movement of whales into Lancaster Sound peaks in late June and July, but continues until early August. Bowheads may move as far west as Barrow Strait and one has been recorded in Peel Sound (Finley, 1976; Finley and Johnston, 1977). In August, bowheads move from Parry Channel into the adjacent summering areas which include Prince Regent Inlet, Admiralty Inlet and Eclipse Sound. In addition, bowheads summer in some of the bays along northeast Baffin Island (Figure 2.1-3) (Koski and Davis, 1980) and a few have been observed along southeast Baffin Island in September (MAL, 1978; MMI, 1979b).

The southward migration of bowheads begins during mid September, and most have left northern Baffin Bay by early October. The migration is almost exclusively coastal, and occurs along the southern shore of Lancaster Sound and the east coasts of Bylot and Baffin islands (Koski and Davis, 1979, 1980). Bowheads migrate singly or in small groups, probably reaching Cumberland Sound by October and remaining there until December before moving to wintering areas (see Davis *et al.*, 1980, for review).

2.1.1.4 Other Cetaceans (Whales)

During the summer, at least 12 other species of cetaceans frequent Davis Strait (Table 2.1-1). In general, the distributions of these species are not as well known as those of narwhals, belugas and bowheads. The killer whale, northern bottlenosed whale, pilot whale, fin whale, and blue whale may also occur in

TABLE 2.1-1 Cetaceans Ranging to Davis Strait During Summer.	
Fin Whale	Balaenoptera physalus
Sei Whale	Balaenoptera borealis
Minke Whale	Balaenoptera acutorostrata
Blue Whale	Balaenoptera musculus
Humpback Whale	Megaptera novaeangliae
Northern Bottlenosed Whale	Hyperoodon ampullatus
Sperm Whale	Physeter catodon
Killer Whale	Orcinus orca
Pilot Whale	Globicephala melaena
Harbour Porpoise	Phocoena phocoena
White-Beaked Dolphin	Lagenorhynchus albirostris
Atlantic White-sided Dolphin	Lagenorhynchus acutus

small numbers in Baffin Bay, but only the killer whale ranges as far north as Lancaster Sound and then only rarely (RRCS, 1977; IOL *et al.*, 1978; Koski and Davis, 1979; Marin ID, 1980).

The distribution and abundance of species listed in Table 2.1-1 are not well documented. Their summer range is mostly on the offshore fishing banks in Davis Strait, although humpback and sperm whales are also known to appear near the coast, and harbour porpoises almost always frequent coastal waters. Most species have left Davis Strait by late fall, but northern bottlenosed whales have been seen along the pack ice edge in winter (MAL, 1977; MMI, 1979a) and small numbers of minke whales may remain off south Greenland all winter (Mitchell, 1974). The annual harvest of whales by residents along the west coast of Greenland is discussed in Section 2.5.1.5.

2.1.2 WALRUS AND SEALS

2.1.2.1 Walrus

The walrus is a large pinniped with a discontinuous circumpolar range. The Atlantic race *(Obodenus r. rosmarus)* is found along eastern portions of the primary eastern shipping route as well as in Foxe Basin and Hudson Bay (Mansfield, 1958; Loughrey, 1959). Atlantic walrus populations in Baffin Bay and Davis Strait were heavily exploited in the late 19th and first half of the 20th centuries, but it is not known if the present population levels are lower than historic levels as a result of this commercial harvesting (reviews in Reeves, 1978 and Davis *et al.*, 1980). The status and size of the Atlantic walrus population has not been documented, although at least 1,000 animals were recorded in the central Canadian High Arctic during the summer of 1977 (Davis *et al.*, 1978b).

The estimated annual harvest of walruses by residents of communities along the eastern shipping corridor ranges from 250 to 400 animals (Section 2.5.1.2).

Walruses are associated with pack ice throughout most of the year, but they come ashore to traditional haul-out sites during the late summer moulting period (Vibe, 1950; Mansfield, 1958; Burns, 1965; Salter, 1979, 1980). Herds of up to several thousand walruses (Miller, 1975; S.R. Johnson, pers. comm.) may occur at terrestrial haul-out sites or on offshore pack ice in some areas, although such large groups are not known to exist along the eastern shipping corridor (Plate 2.1-4).

Walruses feed primarily on infaunal invertebrates, particularly bivalve molluscs (Fay *et al.*, 1977). Consequently, this species usually lives in relatively shallow waters where they are able to dive to the bottom. Although the maximum depth to which walruses can dive has not been documented, Vibe (1950) suggested they are limited to foraging depths of less than 80 to 90 metres. Nevertheless, walruses have been observed overwintering over deep water in northern Baffin Bay (Finley and Renaud, 1980).

There are few records on the winter distribution of walruses along the eastern shipping corridor. Davis *et al.* (1978b) observed a few hundred overwintering in polynyas in Queens Channel, Penny Strait and at the west end of Jones Sound, and Finley and Renaud (1980) recorded about 700 on pack ice off southeast Ellesmere Island in March, 1979. In addition, an unknown number winter in the Thule District of Greenland (Vibe, 1950). Loughrey (1959) reported that major wintering areas included the coast of Greenland south of 69°N and the southern edge of the Davis Strait pack ice but there are no recent estimates of numbers in these areas. MMI (1979a) observed walruses on pack ice in Frobisher Bay in March, 1978.

During May and June, small numbers of walruses, that may be migrants from wintering areas off southern Ellesmere Island, begin to move into eastern Lancaster Sound. The number of migrants in Lancaster Sound peaks in July (Koski and Davis, 1979; Koski, 1980a), but the wintering areas of the later migrants are unknown. They may arrive from the coast of west Greenland and cross northern Baffin Bay or Smith Sound before moving into Lancaster Sound. Walruses are not known to migrate along the northeast coast of Baffin Island or through offshore waters (Koski and Davis, 1979; Koski, 1980a).

The migration through Lancaster Sound and Barrow Strait occurs primarily along the south coast of Devon and Cornwallis islands (Degerbøl and Freu-

PLATE 2.1-4 *Walruses usually live in relatively shallow waters where they are able to dive to the bottom to obtain the invertebrates they feed on. (Courtesy, Northwest Territories Wildlife Service).*

chen, 1935; Bissett, 1967; Finley 1976; Johnson *et al.*, 1976). Relatively few walruses are present along the south side of Parry Channel.

Most walruses have arrived at their summering areas by late July or early August (Figure 2.1-4). Summering areas in Parry Channel include several sites along the south coast of Devon Island (Gunn, 1949; Lawrie, 1950; Finley *et al.*, 1974; Johnson *et al.*, 1976; Davis *et al.*, 1978b). In addition, a substantial but unknown number of walruses summer along the west coast of Greenland. These walruses occur mainly in the Thule area, but may also range south to about 64°N during summer (Vibe, 1967; Mansfield, 1973). Walruses are absent from areas south of 64°N during the summer months (Mansfield, 1973). In western Davis Strait, summering areas are located off the coast of the Cumberland, Hall and Meta Incognita peninsulas on southern Baffin Island (MMI, 1979b).

Walruses probably do not leave the summering areas until freeze-up. The routes and timing of the fall migration retrace spring routes in Parry Channel. Routes in other areas are not known.

2.1.2.2 Harbour Seal

The harbour seal *(Phoca vitulina)* is a widely distributed and relatively sedentary species that occurs primarily in temperate waters. The present abundance and distribution of this species along the eastern shipping corridor is poorly known. There are summer records of harbour seal sightings along the coast of southwest Greenland south of 67°N (Kapel, 1975); in the Canadian Arctic from Hudson Strait north along the east coast of Baffin Island to Pond Inlet (Tuck, 1957; Bissett, 1967); at Arctic Bay (Mansfield, 1967b) and at Alexandra Fjord, eastern Ellesmere Island (Mansfield, 1967a). In addition, there is also a questionable record of harbour seals in the Thule District of northwest Greenland (Vibe, 1950). Winter records for this species in the eastern Arctic are few. In the Arctic, harbour seals generally overwinter at locations where currents maintain open water through the winter (Mansfield, 1967a). This species is believed to be uncommon throughout the eastern shipping corridor. Harvesting has eliminated them from southern Baffin Island, parts of Ungava Bay and southern Southampton Island (Mansfield, 1967a). The majority of the 100 to 120 harbour seals harvested annually in the region are taken from southwest Greenland, although a few are also taken at Frobisher Bay (Section 2.5.1.1)

2.1.2.3 Harp Seal

Three largely distinct stocks of harp seals *(Phoca*

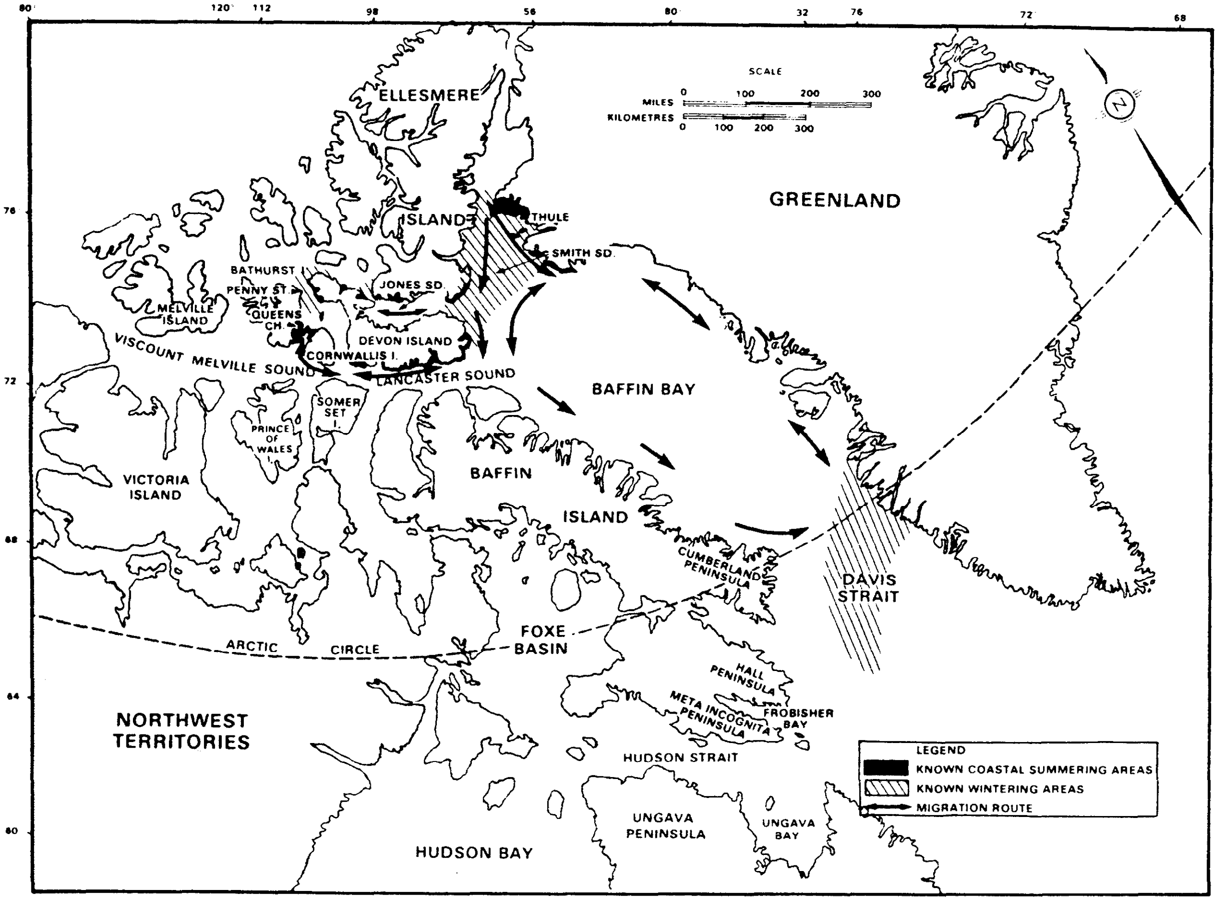


FIGURE 2.1-4 *Walrus migration routes, wintering areas and known coastal summering areas in Parry Channel, Baffin Bay and Davis Strait. Walruses are associated with pack ice for most of the year, but they come ashore to traditional haul-out sites during the late summer moulting period.*

groenlandica) whelp and moult during late winter and early spring on pack ice near Newfoundland, near Jan Mayen Island (north of Iceland), and in the White Sea. The first of these, the 'Western Atlantic Stock,' is the only stock that occurs in this region (Mansfield, 1967a). These seals whelp and moult in the Gulf of St. Lawrence and on the ice front off southern Labrador and northern Newfoundland. They then migrate north to summer in Arctic waters. The current size of the western Atlantic population is approximately 1,250,000 (excluding pups), and about 300,000 to 350,000 pups are produced each year. The exact numbers and current trends in population size continue to be the subject of considerable controversy (Allen, 1975; Sergeant, 1975, 1976 a,b; Lett and Benjaminsen, 1977; Winters, 1978). Harp seals are taken regularly only by residents of Pangnirtung in the Canadian Arctic but 5,000 to 10,000 are taken annually in western Greenland (Section 2.5.1.1).

Harp seals feed actively while in the Arctic. Arctic cod are important prey in Davis Strait, Cumberland Sound (Haller *et al.*, 1967; Templeman and Hunter, in Blacker, 1968) and Jones Sound (Finley and Gibb, in press). Capelin and Arctic cod are particularly important off the west coast of Greenland (Dunbar, 1949; Sergeant, 1973b).

The northward migration of harp seals from the whelping and moulting areas off Newfoundland occurs along the coast of Labrador and probably along the pack ice edge across Davis Strait to Greenland (Sergeant, 1965; Figure 2.1-5). Some migrants continue on to the eastern Canadian Arctic, where they are widely distributed. Recurring site specific concentrations have not been identified. Adults arrive along the southwest coast of Greenland during late May and June, and juveniles arrive about two weeks later. Most young-of-the-year and immatures spend the summer in nearshore areas between Disko Bay and Upernavik (Sergeant, 1976a). Many adults may continue northward along the west coast of Greenland and reach the Thule District during June and July, but few move farther north (Vibe, 1950).

A substantial number of harp seals enter Lancaster Sound in July and August (Tuck, 1957; Greendale and Brousseau-Greendale, 1976; Johnson *et al.*,

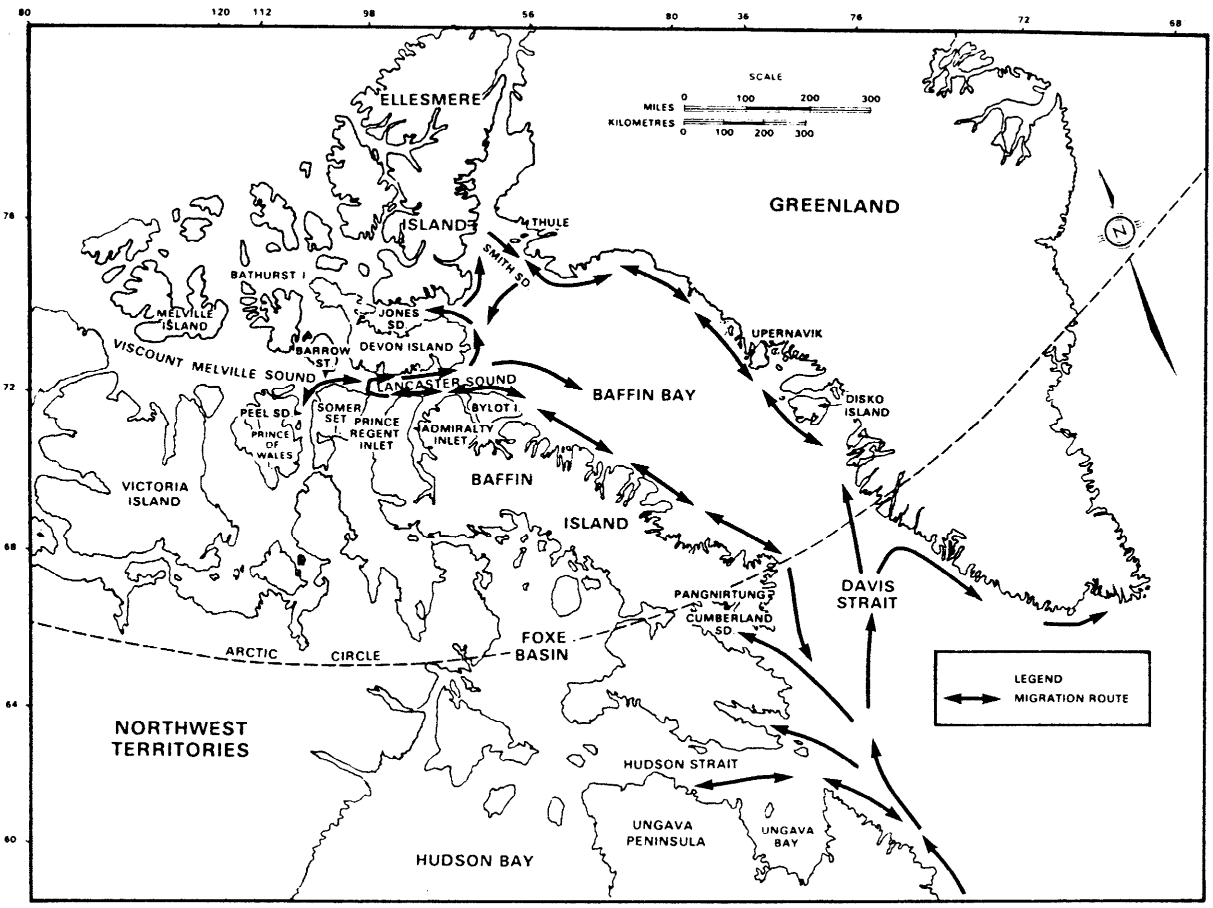


FIGURE 2.1-5 *Harp seal migration routes. Three largely distinct stocks of harp seals occur in the North American Atlantic, of which only the 'western Atlantic stock' migrates to Parry Channel.*

1976). Most migrants probably travel along the fast ice edge off east Baffin Island to eastern Lancaster Sound (Koski and Davis, 1979), although a route across northern Baffin Bay from Greenland has also been suggested (Degerbøl and Freuchen, 1935; Sergeant, 1965).

Harp seals entering Lancaster Sound are believed to be primarily adults (Tuck, 1957; Greendale and Brousseau-Greendale, 1976). They usually occur in small herds of fewer than 20 animals (Johnson *et al.*, 1976; Koski and Davis, 1979), although they occasionally gather in herds of up to several thousand individuals (Sergeant, 1965; Johnson *et al.*, 1976). The numbers of harp seals entering Lancaster Sound may vary substantially from year to year. For example, Tuck (1957) estimated 150,000 harp seals moved west past Cape Hay, Bylot Island, in late June to early August, 1957, while Greendale and Brousseau-Greendale (1976) estimated that only 16,000 passed the same point from mid June to late July, 1976. Relatively few harp seals pass through Lancaster Sound to areas as far west as Barrow Strait (Finley, 1976). During late August and early September 1979, Koski (1980b) estimated only 4,000 animals in offshore areas of Barrow Strait east of 94°W. In September, 1976 Finley and Johnston (1977) reported about 800 in Peel Sound. Over 3,500 harp seals were observed in Admiralty Inlet on August 24, 1978 (Koski and Davis, 1979).

Many of the harp seals that enter Lancaster Sound along the south shore leave by travelling across the sound and eastward along the north side (Koski and Davis, 1979). The fall migration beginning during September, heads north along the east coasts of Devon and Ellesmere islands, and presumably across Smith Sound to Greenland. An alternate route from Lancaster Sound occurs along the east coast of Baffin Island within about 60 km from the shore (Koski and Davis, 1979). Most harp seals have left Greenland and the Canadian High Arctic by October, although a few may winter near the southwest coast of Greenland until March (Kapel, 1975). In addition, some harp seals remain in Cumberland Sound on eastern Baffin Island until mid January, and a few may overwinter there (Haller *et al.*, 1967). A small number of young and immature seals also overwinter in Davis Strait (Fisher, 1955; Sergeant, 1965). MMI (1979a) observed a few adults wintering in Davis Strait and suggested that a small number may whelp along the pack ice edge.

The summer distribution of harp seals in the Arctic may be correlated with climatic conditions since harp seals in western Greenland tended to move farther north prior to 1810 and after 1910 than in the colder intervening years (Vibe, 1967). Consequently, future climatic changes may also affect harp seal populations in the Arctic.

2.1.2.4 Hooded Seal

The hooded seal *(Cystophora cristata)* is a large seal closely associated with heavy pack or drift ice. Males may attain an adult weight of 318 kg (Mansfield, 1967a). During March, hooded seals concentrate in relatively restricted areas of heavy pack ice at the main whelping areas near Jan Mayen Island north of Iceland, near the edge of the pack ice in Davis Strait (Figure 2.1-6), and on the ice front east of southern Labrador and northern Newfoundland. A few also whelp in the Gulf of St. Lawrence. The population of hooded seals that whelps in Davis Strait has been recently observed from aircraft, but studies of their population biology have not been done. Photo surveys of this population during whelping indicated that 34,000 and 42,000 seals (including pups) were present in 1978 and 1977, respectively (MMI, 1979a), while Sergeant (1974) observed an estimated 50,000 in 1974.

Females give birth to a single pup which is nursed for less than two weeks and then abandoned. Adult males also occupy the whelping areas and copulation occurs at the end of the lactaction period (Rasmussen, 1957; Mansfield, 1967a; Sergeant, 1976a).

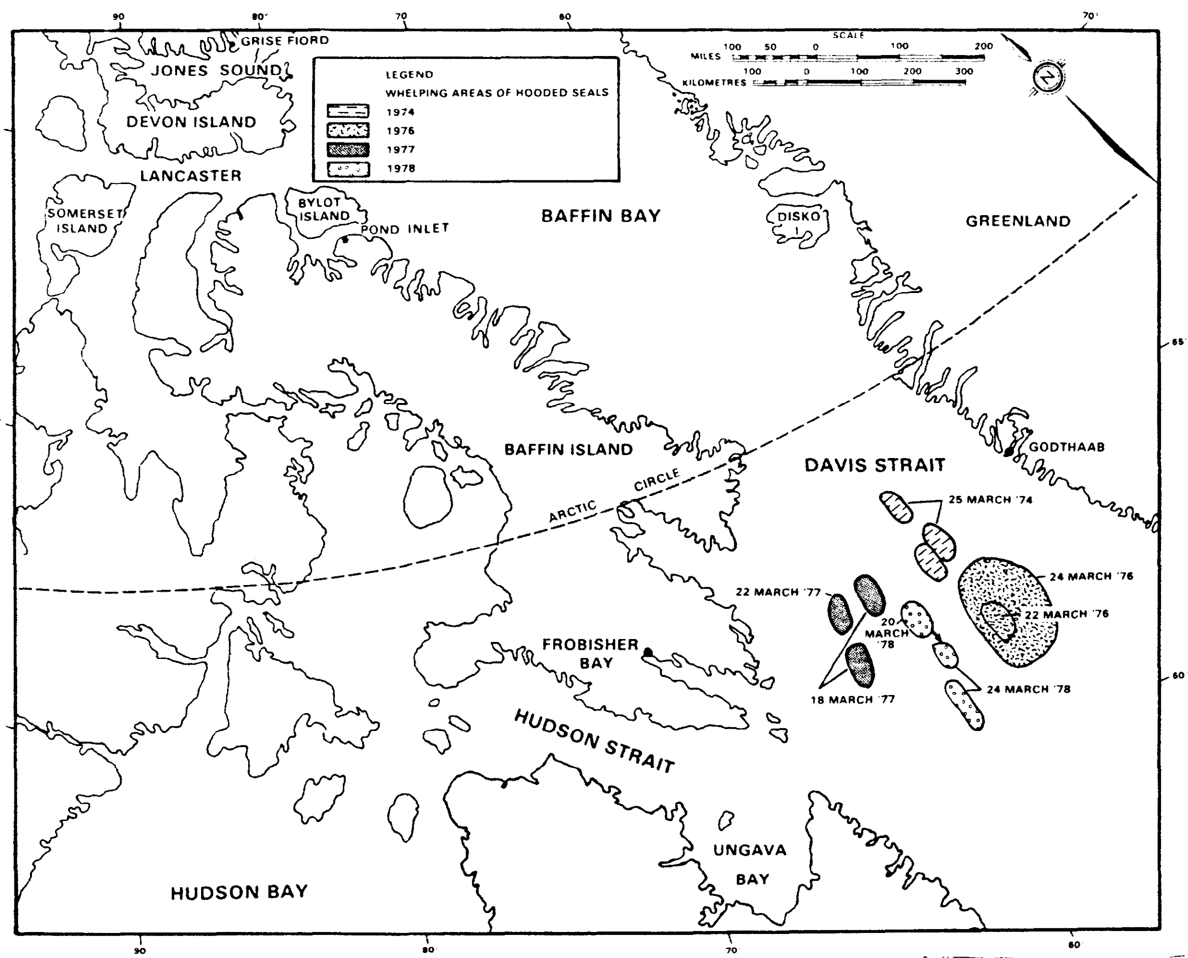


FIGURE 2.1-6 *Hooded seal whelping areas in Davis Strait, the southeastern portion of the shipping corridor. The hooded seal is a large seal closely associated with heavy pack or drift ice.*

The distribution of non-breeding subadults during this period has not been well documented, but a few occur at the periphery of the whelping patches (Rasmussen, 1960). The subadult component of the population is relatively large since females (at least those from the Newfoundland population) do not breed until three years of age (Oritsland and Benjaminsen, 1975) and males not until ten years of age (Sergeant, 1976c).

After whelping and breeding in April, hooded seals from the Newfoundland area begin to migrate northward through Davis Strait to southwest Greenland. The migration routes are unknown, but are believed to follow the edge of the offshore pack (IOL *et al.*, 1978). Hooded seals arrive in coastal waters off southwest Greenland (south of 63°N) by late April and most arrive in mid May (Rasmussen, 1960; Kapel, 1975). Early arrivals probably come from the Davis Strait whelping patches. Although a few hooded seals continue to move north along the west coast of Greenland, most are believed to move south around Cape Farewell to moulting grounds on the pack ice in Denmark Strait beteen the east coast of Greenland and Iceland (Rasmussen, 1960). Some hooded seals may remain off southern or southwestern Greenland during the moulting period, especially during heavy ice years. Seals from moulting areas in Denmark Strait begin a return migration to Davis Strait in late July (Rasmussen, 1960; Kapel, 1975), but their distribution during late summer and fall has not been recorded.

The numbers of hooded seals that move north along the west coast of Greenland instead of moving to Denmark Strait are unknown. Small numbers regularly occur on the Canadian side of Baffin Bay (see Koski, 1980a for review), and one individual was observed as far west as Radstock Bay on southwest Devon Island (Stirling and Archibald, 1977). The routes and timing of the southward fall migration through Baffin Bay and the fall distribution in Davis Strait have not been documented. However, hooded seals moving south are presumed to retrace the routes taken during the northward movement in spring (Mansfield, 1967a).

This species is the most numerous seal hunted by residents from southern Greenland who harvest 2,200 annually, but few are harvested by Canadian Inuit (Section 2.5.1.1).

2.1.2.5 Ringed Seal

The ringed seal *(Phoca hispida)* is the most abundant and widespread marine mammal in the North American Arctic. It occurs throughout marine areas north from James Bay and northern Newfoundland to the Arctic Ocean (Dunbar, 1949; Mansfield, 1967a). The ringed seal is the smallest pinniped, attaining an average adult length of about 125 to 135 cm (Mansfield, 1967a).

Ringed seals are permanent residents throughout most of their range. They overwinter under the sea ice through which they maintain breathing holes (Plate 2.1-5) (Degerbøl and Freuchen, 1935; Vibe, 1950; McLaren, 1958a; Mansfield, 1967a; Smith, 1973a; Finley, 1979). In general, ringed seals are widely distributed and rarely occur in large or dense aggregations. Throughout most of the eastern and central Canadian Arctic, the ringed seal is thought to be sedentary, moving only in response to changing ice conditions. This species is the most frequently harvested marine mammal along the eastern shipping corridor, where the annual harvest ranges from 75,000 to 85,000 animals (Section 2.5.1.1).

During the breeding period, ringed seals occur in the highest densities on stable fast ice. Females hollow out birth lairs in snow drifts in the lee of pressure ridges and hummocks (Degerbøl and Freuchen, 1935; McLaren, 1958a; Smith and Stirling, 1975). Consequently ringed seals have a predominately coastal distribution, with lower densities occurring in zones of moving pack ice.

Females produce a single pup generally between mid March and mid April (Vibe, 1950; McLaren, 1958a; Fedoseev, 1965; Johnson *et al.*, 1966; Smith, 1973a; Smith and Stirling, 1975). Lactation usually lasts for 1.5 to 2 months, after which time the pups are abandoned (McLaren, 1958; Smith, 1973a). However, the duration of the lactation period is partly a function of ice stability. For example, Fedoseev (1975) reported that ringed seals on drift ice in the Sea of Okhotsk nursed their pups for only three weeks. The lactation period for ringed seals inhabiting the pack ice in Baffin Bay has not been documented (K.J. Finley and W.G. Koski, pers. comm.). Ringed seal pups in subnivean birth lairs are particularly vulnerable to predation by polar bears and Arctic foxes during the lactation period.

The ringed seal is a particularly important element of Arctic marine ecosystems since it is the species taken in greatest numbers by Canadian Inuit (Section 2.5.1.1) and is the main prey of polar bears (Section 2.1.3). The abundance and distribution of polar bears is believed to depend on the abundance, distribution and availability of ringed seals (Stirling and McEwan, 1975; Stirling and Archibald, 1977; Stirling and Smith, 1977; Stirling, 1978). In addition, Arctic foxes are important predators of ringed seal pups in some areas (Smith, 1976), although the relationship between the abundance and distribution of these two species has not been determined.

PLATE 2.1-5 *Seal breathing holes in new ice in a lead in Viscount Melville Sound. Ringed seals overwinter under the sea ice by keeping breathing holes open. They are permanent residents throughout most of their range.*

The primary food of ringed seals includes fish (mainly Arctic cod), gammarid and hyperiid amphipods, mysids, euphausiids, and shrimp. However, the specific diet varies with time of year, habitat and geographic location (Kumlien, 1879; Dunbar, 1941, 1949; Vibe, 1950; McLaren, 1958a; Smith, 1973b; Lowry *et al.*, 1978, 1980; 1981; Eley and Lowry, 1978; Finley, 1978, unpubl. data).

Ringed seals are common residents throughout most of Parry Channel. The mean densities of ringed seals are relatively high in areas of stable first year ice (eg. Barrow Strait, Peel Sound, Navy Board Inlet, Eclipse Sound, Pond Inlet), and lower in areas of multi-year ice (eg. Viscount Melville Sound) and unstable ice (eg. Lancaster Sound) (Figure 2.1-7; Finley, 1976; Koski and Davis, 1979; Smith and Hammill, 1981; Stirling *et al.*, 1981). Birth lairs are probably also widely distributed throughout Parry Channel, but highest densities tend to occur in Barrow Strait (Smith *et al.*, 1979). During the winter months indications are that immature ringed seals concentrate along refrozen leads in the fast ice of Barrow Strait (K.J. Finley, pers. comm.). Ringed seals are also common throughout Baffin Bay. An estimated 50,000 seals inhabit the fast ice along the east side of Baffin Island north of 70°N and an estimated 150,000 to 200,000 occupy the pack ice in Baffin Bay (Koski, 1980a). These estimates have not been corrected for animals under the ice at the time of the survey. Ringed seals are common along the entire west coast of Greenland, particularly in Melville Bay (Vibe, 1950). This species is also common on the landfast ice along southeast Baffin Island, but relatively uncommon on the shifting pack ice in Davis Strait (MMI, 1979b).

The distribution of ringed seals along the eastern shipping corridor during the open water season is unknown. However, ringed seals tend to occur in coastal areas and there is a general movement from offshore to nearshore areas as break-up proceeds (McLaren, 1958a; Smith, 1973a; Finley, 1979).

2.1.2.6 Bearded Seal

The bearded seal *(Erignathus barbatus)* a large, solitary seal occurs throughout Arctic waters in close association with moving pack ice (Burns, 1967; Mansfield, 1967a; Benjaminsen, 1973). Adults weigh about 340 kg and are about 2 m long. Although bearded seals are able to maintain breathing holes in

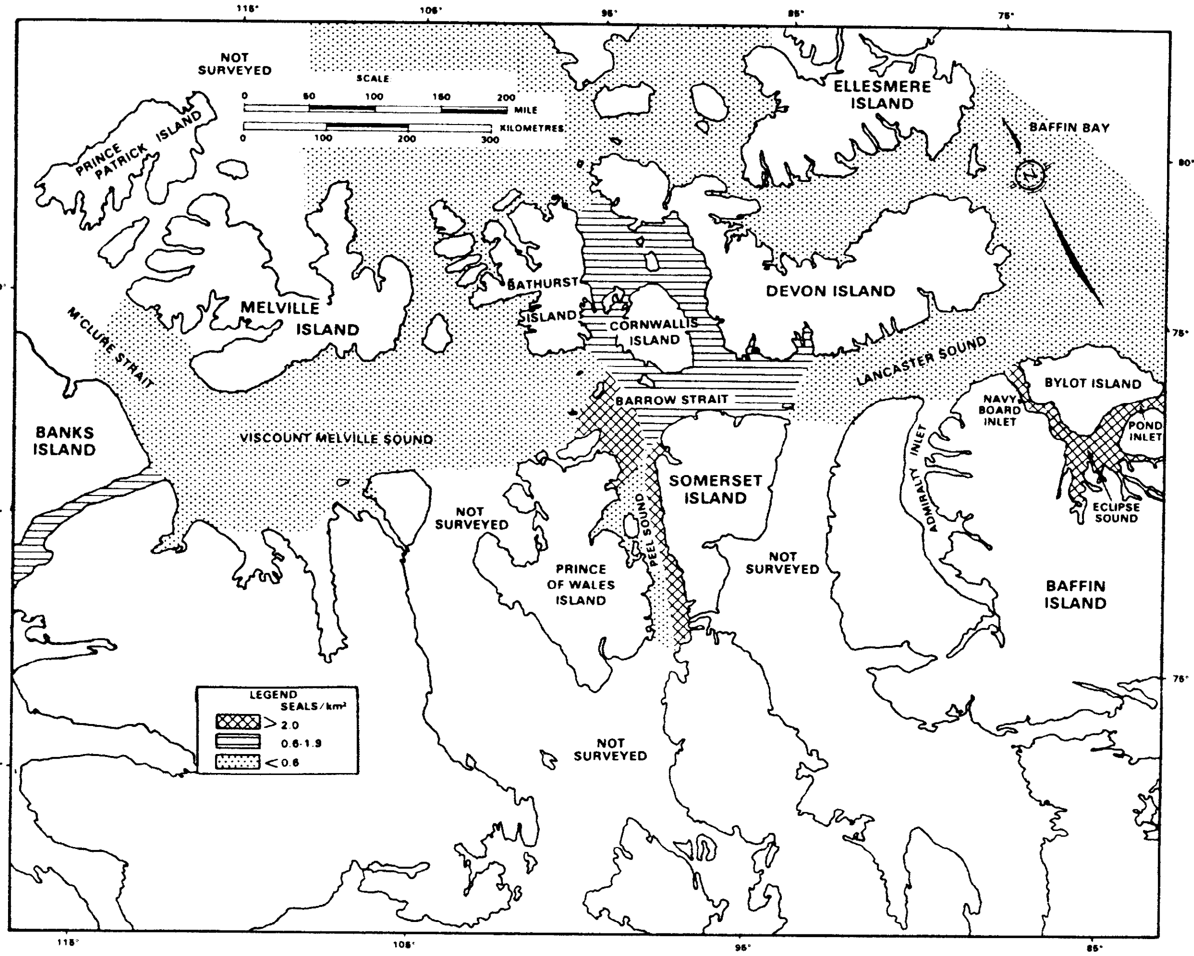


FIGURE 2.1-7 *Ringed seal densities in the Northwest Passage region. The Canadian Wildlife Service, with support from the industry, is carrying out annual aerial surveys of the Northwest Passage region to improve the ringed seal distribution data base.*

fast ice, they usually avoid both landfast and closed pack ice (Burns and Frost, 1979). In general, bearded seals are widely distributed and are not known to occur in large concentrations. The estimated annual harvest of bearded seals by residents along the eastern shipping corridor ranges from 800 to 1,400 animals (Section 2.5.1.1).

In some areas, bearded seals are sedentary and only move locally as ice conditions change (Vibe, 1950; McLaren, 1962; Fedoseev, 1973). In contrast, bearded seals in other areas are known to make regular long distance movements (Burns, 1967; Benjaminsen, 1973; Stirling *et al.*, 1975a, 1977, 1979). There is some evidence to suggest that different age classes move and are distributed differently (Benjaminsen, 1973; Potelov, 1975).

Bearded seals give birth to a single pup on moving pack ice during late April or early May. Lactation lasts for about 12 to 18 days before the pup is abandoned. Most seals mate in May, usually after the female has abandoned the pup (Burns and Frost, 1979).

Bearded seals feed mainly on benthic and epibenthic organisms (Chapskii 1938; Vibe, 1950; Burns and Frost, 1979) and therefore are usually restricted to the shallower waters of the continental shelf. However, they are known to occasionally feed on pelagic species in deep water (Vibe, 1950; Kosygin, 1971). The depth to which bearded seals can dive for food is subject to some debate. Vibe (1950) suggests the maximum diving depth for this species is 80 m, while Braham *et al.*, (1977) report 200 m is the probable maximum depth. Stirling *et al.*, (1977) found that bearded seals preferred water depths in the 25 to 75 m range and Burns and Frost (1979) suggest that the maximum diving depth is about 100 metres.

In general, the distribution of bearded seals during winter is poorly known. Small numbers may overwinter in polynyas in the central Arctic (Finley, 1976) and a few are present along the ice edge off southeast Ellesmere Island (Finley and Renaud, 1980). Bearded seals may also winter in the Thule District of Greenland (Vibe, 1950).

Bearded seals are sparsely distributed throughout the offshore pack ice in Baffin Bay during spring and summer (Koski and Davis, 1979; Koski, 1980a). During winter, they probably inhabit all pack ice areas but presumably move to coastal regions as break-up proceeds. Bearded seals also occur throughout Parry Channel west to at least Viscount Melville Sound (Finley, 1976; Johnson *et al.*, 1976; MMI, 1979c; Stirling *et al.*, 1981), with highest densities occurring in coastal areas (Finley, 1976). This species is common along much of northwest Greenland, but scarce in Melville Bay (Vibe, 1950). Small numbers of bearded seals are also present on the offshore pack ice in Davis Strait during the spring (MMI, 1979b).

2.1.3 POLAR BEAR

The polar bear *(Ursus maritimus)* has a circumpolar distribution and in Canada ranges from the High Arctic Islands to James Bay and Labrador. It is found throughout the eastern shipping corridor (Plate 2.1-6). Male bears range from 450 to 550 kg in weight, while adult females weigh from 180 to 270 kg (Stirling *et al.*, 1975b).

Individual polar bears are usually restricted to large home ranges but they may move long distances. For example, marked bears have been resighted more than 400 km from their point of capture, although most had moved less than 150 km when they were resighted (Stirling *et al.*, 1978). Polar bears may cross international boundaries. Bears marked in the eastern Canadian Arctic have been resighted in Greenland (Schweinsburg *et al.*, 1977). Bears from the Canadian Beaufort Sea have been taken in Alaska (Stirling *et al.*, 1975b), and Alaskan bears have been taken in Siberia (Lentfer and Brooks, 1970). In November 1973, Canada, Denmark, Norway, the U.S.A. and the Soviet Union signed an international agreement for the conservation of polar bears.

Although polar bears are essentially marine mammals adapted to live on the sea ice, both sexes and all age classes may occupy temporary land based dens or shelters during adverse weather. Winter denning is particularly important for pregnant females. They occupy onshore dens in early November and cubs are born in December or January (Schweinsburg *et al.*, 1977). The female and cubs remain in their dens until late March or early April. In the Canadian High Arctic, maternity dens are excavated in snow drifts

PLATE 2.1-6 *Polar bears are widely distributed throughout Parry Channel and are common near the coast of eastern Baffin Island. They also occupy moving pack ice in Davis Strait and Baffin Bay. (Courtesy, M. Bradstreet, LGL Ltd.).*

on steep slopes or along stream banks near the sea. Uncommonly, dens have been found on sea ice in other areas (Harington, 1968; Lentfer, 1975; Stirling *et al.*, 1978).

Polar bears prey mostly on ringed seals, although bearded seals may be locally important (Stirling and Archibald, 1977; Stirling and Latour, 1978). Changes in the ringed seal population can affect the numbers and distribution of polar bears. For example, Stirling *et al.*, (1975b, 1977) and Stirling (1978) have shown that reduced ringed seal and bearded seal numbers following a severe ice year in the eastern Beaufort Sea in 1974 resulted in fewer polar bears in the area. Reduced reproductive rates and emigration were associated with the decline in the number of bears (Volume 3A Section 3.2.3).

Polar bears occur throughout Parry Channel, Baffin Bay and Davis Strait, but population estimates are only available for some areas. Stirling *et al.* (1978) estimated that 3,000 inhabited the area from Melville Island east to southwestern Devon Island and south to Boothia Peninsula. Koski (1980a) estimated that 1,700 bears occupied the offshore pack ice in western Baffin Bay in May, and Stirling *et al.*, (1980) estimated that 700 to 900 bears existed along southeastern Baffin Island. Estimates are not available for Greenland, but few bears occur in coastal areas south of Disko Bay (Vibe, 1967). Canadian Inuit in the region harvest about 130 polar bears annually and residents of western Greenland probably take an average of 70 bears annually (Section 2.5.1.6).

Polar bears prefer to occupy landfast ice (Stirling *et al.*, 1980) and are widely distributed throughout Parry Channel. They are also common near the coast of eastern Baffin Island. Nevertheless polar bears also occupy moving pack ice in Davis Strait and Baffin Bay (MMI, 1979b; Koski, 1980a; Stirling *et al.*, 1980). Bears in pack ice areas include adult males, independent subadults, and females with yearling or older cubs (Stirling, 1978; K.J. Finley, pers. comm.) These bears are known to move back and forth between the landfast and pack ice, while females with small cubs remain on the coastal landfast ice (Stirling *et al.*, 1980).

Polar bears frequently hunt at the ice edge, and during March they have been observed as far as 200 km from land along the pack ice edge in Davis Strait (MMI, 1979a). Finley (1976) reported numerous bears along the ice edge in eastern Barrow Strait in June, and Koski (1980a) sighted polar bears almost seven times more often along the Lancaster Sound ice edge than in other areas of western Baffin Bay during spring. Polar bears also concentrate along fractures in the ice where seals are more easily caught (Stirling and McEwan, 1975; Stirling *et al.*, 1978). These zones tend to occur in northern Lancaster Sound and run from headland to headland along eastern Baffin Island (Stirling *et al.*, 1978, 1980).

During the open water season, polar bears retreat to the few remaining areas of fast ice and then go ashore. In Parry Channel, the bays of southwestern Devon Island provide summer refuge for polar bears (Stirling *et al.*, 1978). When bays on southeastern Baffin Island are ice-free polar bears are most often seen on the tips of peninsulas (Stirling *et al.*, 1980).

Some maternal denning areas in the central Arctic and southeastern Baffin Island have been identified and are shown on Figures 2.1-8 and 2.1-9 (Stirling *et al.*, 1978, 1980). However, many areas have not been surveyed or have received inadequate coverage. The most important known denning areas along the eastern shipping corridor are located on northeastern Victoria Island, northern Prince of Wales Island, Russell Island and on the eastern coast of Cumberland Peninsula.

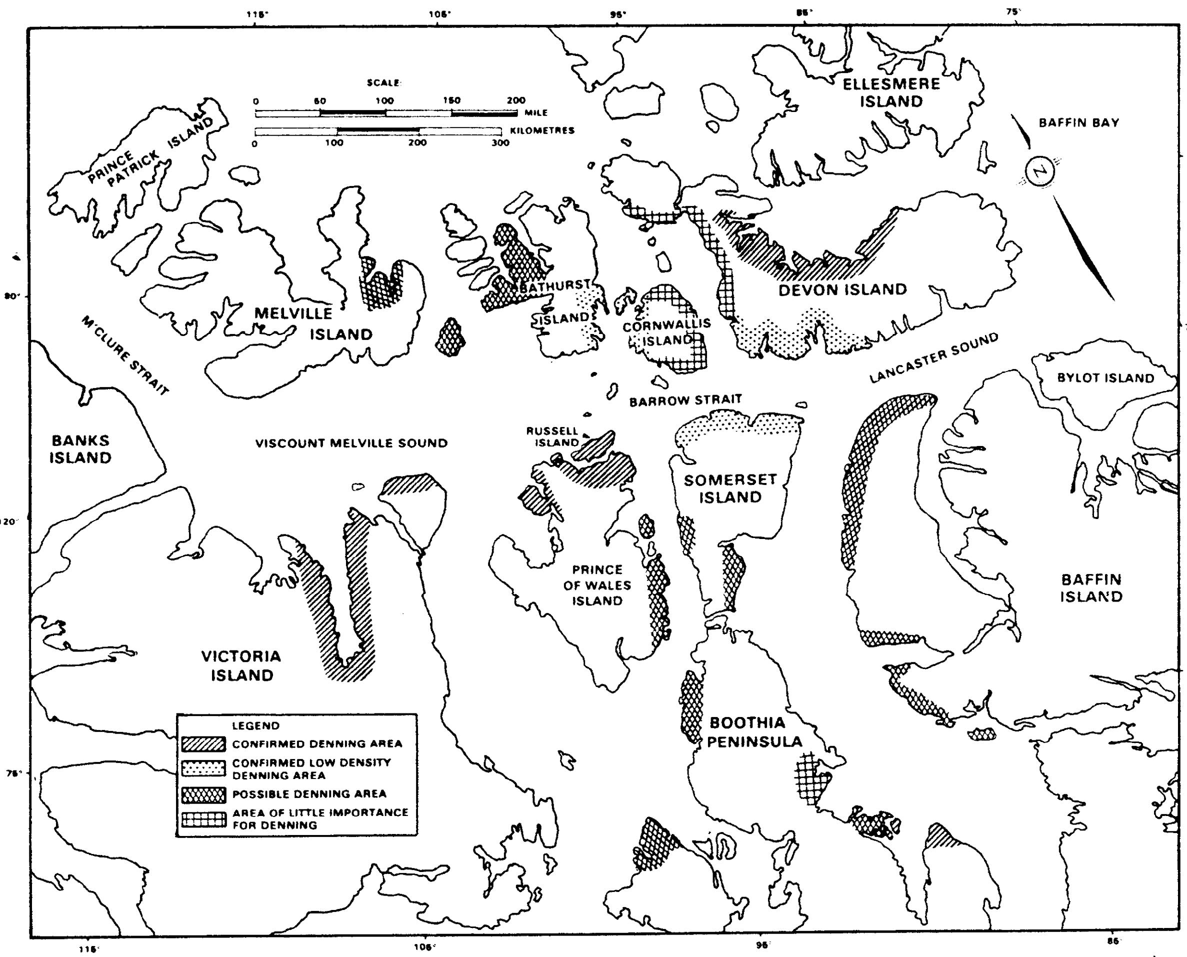


FIGURE 2.1-8 *Polar bear denning areas in the Northwest Passage Region. The most important known denning areas along the shipping corridor are located on northeastern Victoria Island, northern Prince of Wales Island, Russel Island, and on the eastern coast of Cumberland Peninsula.*

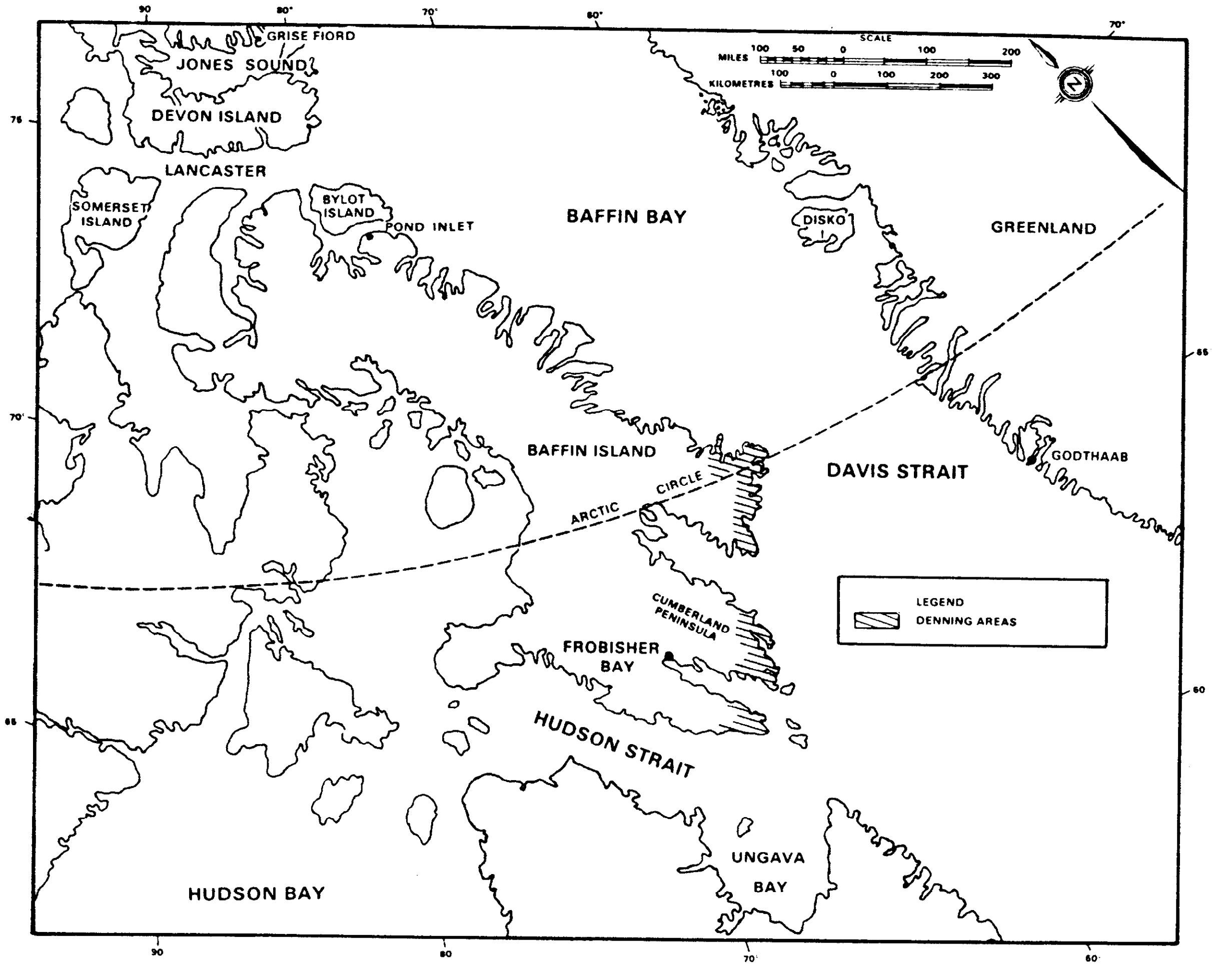


FIGURE 2.1-9 *Polar bear denning areas along southeastern Baffin Island.*

2.1.4 ARCTIC FOX

The Arctic fox *(Alopex lagopus)* is a small terrestrial mammal that ranges throughout the Arctic tundra of North America and Eurasia. Arctic fox dens have been found throughout most tundra areas of the Canadian Arctic (Macpherson, 1969). Although Arctic foxes are terrestrial during summer, foxes from coastal populations in the High Arctic may move onto the sea ice during winter to scavenge on the remains of polar bear kills (Macpherson, 1969; Stirling and Smith, 1977). In addition, Arctic foxes dig into subnivean birth lairs of ringed seals and prey upon newborn pups (Smith, 1976). During a three year study in Prince Albert Sound and eastern Amundsen Gulf, Smith (1976) estimated that Arctic foxes killed a minimum of 4.4% to 21.9% (in different years) of pups in the lairs. During the summer, Arctic foxes in the High Arctic prey primarily on lemmings. However, because they scavenge on the ice in winter, populations in the High Arctic are not as strongly influenced by lemming cycles as are mainland populations (Macpherson, 1969).

The abundance and distribution of Arctic foxes on sea ice areas along the eastern shipping route have not been documented. Since polar bears hunt subadult seals from the sea ice (McLaren, 1958a; Stirling and Smith, 1977), the abundance of offshore carrion during most of the winter appears to attract Arctic foxes, making them relatively widespread in distribution offshore. Tracks of Arctic foxes have been seen on the pack ice in Baffin Bay (Koski, 1980a), and on the multi-year ice of Viscount Melville Sound, (MMI 1979c).

2.1.5 TERRESTRIAL MAMMALS

The only species of terrestrial mammals that are of concern along the primary eastern shipping corridor are Peary caribou *(Rangifer tarandus pearyi)* and muskoxen *(Ovibos moschatus)*. Peary caribou are regular migrants between the islands of the Queen Elizabeth group and also between Prince of Wales Island and Somerset Island (Fischer and Duncan, 1976; Miller *et al.*, 1977; Miller and Gunn, 1978). Other inter-island movements that have been reported follow a route across Barrow Strait between Bathurst Island and Prince of Wales Island (Gunn *et al.*, 1981), but it is not known if this particular route is used regularly.

Although muskoxen are not known to make regular channel crossings, this is the only mechanism for colonization of uninhabited islands. Somerset Island is believed to have been repopulated from Prince of Wales Island in 1975 (Russell and Edmonds, 1978).

Both Victoria Island and Banks Island have large populations of caribou and muskoxen (Jakimchuk and Carruthers, 1980; Vincent and Gunn, 1981) but crossings of Prince of Wales Strait have not been reported.

2.2 BIRDS

This section summarizes the distribution and habits of birds associated with the marine environment of the Northwest Passage, including Parry Channel, Baffin Bay and Davis Strait. These birds include the true seabirds, which come to land only to nest, as well as the loons, waterfowl and gulls that use the marine areas seasonally. Use of offshore and coastal areas along the primary eastern shipping corridor by these birds is emphasized. About 32 species regularly occur in marine waters of Baffin Bay and Davis Strait, whereas about 22 occur in Parry Channel and Prince of Wales Strait (Tables 2.2-1 and 2.2-2). In addition, 16 species of shorebirds nest in terrestrial areas adjacent to the Northwest Passage and may use littoral zones while staging for fall migration.

Tables 2.2-1 and 2.2-2 give the approximate status of species addressed in the text plus a number of less common species. The amount of quantitative information varies markedly among areas. Single season data exist for small parts of Viscount Melville Sound (McLaren and Renaud, 1977; Barry *et al.*, 1981; McLaren and Alliston, 1981). Studies involving aerial survey programs have been conducted in recent years in Barrow Strait, Lancaster Sound and western Baffin Bay (Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; Nettleship and Gaston, 1978; McLaren and Renaud, 1979; McLaren, 1980), and in southwestern Davis Strait (MAL, 1977, 1978; MMI, 1979a, b). Aerial surveys conducted in Parry Channel and Baffin Bay include only the spring to autumn period, while those in Davis Strait also include the winter period. Ship-based studies of the distribution of seabirds have been conducted in offshore Davis Strait and Baffin Bay in late summer and fall (Brown *et al.*, 1975; Brown, 1978, 1979)

None of the true seabirds and comparatively few gulls or waterfowl nest in Viscount Melville Sound or Prince of Wales Strait, probably because ice persists there until well into July in most years. Most of the marine-associated birds that nest in Viscount Melville Sound and Prince of Wales Strait probably winter along the Pacific coast and migrate via the Beaufort Sea. No major concentration areas of any species of waterbird are known in Viscount Melville Sound.

In contrast, the eastern portion of the shipping corridor supports several million seabirds as well as tens of thousands of waterfowl and lesser numbers of 'coastal' gulls. The most abundant seabirds are the northern fulmar, black-legged kittiwake, thick-billed murre, black guillemot and dovekie. As many as 30 million dovekies may nest along the coast of northwestern Greenland (Freuchen and Salomonsen, 1958). An estimated 4.5 million of the other four species nest at colonies in both the eastern Canadian Arctic and western Greenland (Brown *et al.*, 1975). Most seabirds do not breed until at least four or five years of age and subadult birds occur along the eastern shipping corridor in summer. For example, Gaston (1980) estimated that over 800,000 immature thick-billed murres are present in Lancaster Sound, Baffin Bay and Davis Strait in summer.

Many of these seabirds, as well as large numbers of oldsquaws, king eiders and common eiders, winter along the ice free southwest coast of Greenland.

In April and May many migrants move north along the coasts of Greenland and Baffin Island and some species also travel on a broad offshore front. On arrival in Canadian waters, many seabirds concentrate near their colonies while large flocks of ducks occur along coasts or ice edges where the water is shallow enough for feeding. The latter areas vary from year to year depending on ice conditions.

Lancaster Sound is a major route to central Arctic nesting areas and is used by large numbers of both resident and migrant birds in spring. The fast ice edge across Parry Channel, which may be in any of several positions from the mouth of Lancaster Sound to the centre of Barrow Strait, is a major area of concentration when it is at an easterly position; birds gather along it waiting for open water to appear in the mid west.

In summer, most breeding waterfowl are at nesting areas. In July and August, male oldsquaws gather at coastal moulting areas and male eiders migrate from the Canadian Arctic to moulting areas along the coast of Greenland. Seabirds are concentrated primarily in the vicinity of their colonies in summer but fairly large numbers of some species may also occur in offshore waters.

TABLE 2.2-1
STATUS OF BIRD SPECIES THAT OCCUR REGULARLY ALONG COASTS AND/OR OFFSHORE IN BAFFIN BAY AND DAVIS STRAIT (adapted from APP, 1979)

Species	Baffin Bay (North of 70‡) West Month	Baffin Bay (North of 70‡) East Month	Davis Strait (South of 70‡) West Month	Davis Strait (South of 70‡) East Month
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Common Loon *Gavia immer*	- - - - - - - - - - - -	- - - - ? b b b ? ? - -	- - - - ? b b b ? ? - -	+ + + + X B B B X X + +
Arctic Loon *Gavia arctica*	- - - - ? + + + ? - - -	- - - - - - - - - - - -	- - - - ? b b b ? ? - -	- - - - - - - - - - - -
Red-throated Loon *Gavia stellata*	- - - - - B B B X ? - -	- - - - X B B B X - - -	- - - - ? B B B ? ? ? -	- - - - - B B B X X + -
Northern Fulmar *Fulmarus glacialis*	- - - + X B B B B X ? -	- - - X X B B B B X ? -	+ + + + X B B B B X + +	+ + + X X B B B B X + +
Greater Shearwater *Puffinus gravis*	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - + - - - -	- - - - - - + X X X + - -
Mallard *Anas platyrhynchos*	- - - - - - - - - - - -	- - - - + b b b + + - -	- - - - - - - - - - - -	+ + + + + b b b + + + +
Oldsquaw *Clangula hyemalis*	- - - - X B B B X X ? -	- - - + X B B B X + - -	? ? ? ? ? B B B X ? ? ?	X X X X X B B B X X X X
Common Elder *Somateria mollissima*	- - - + X B B B B X ? -	+ + + X X B B B X + + +	? ? ? ? ? B B B B X ? ?	X X X X X B B B B X X X
King Eider *Somateria spectabilis*	- - - - X B B B B X ? -	+ + + X X B B B X + + +	? ? ? ? ? B B B B X ? ?	X X X X + + X X X X X X
Harlequin Duck *Histrionicus histrionicus*	- - - - - - - - - - - -	- - - - ? b b b + - - -	- - - - ? b b b ? ? - -	X X X X X B B B X X X X
Red-breasted Merganser *Mergus serrator*	- - - - - b b b - - - -	- - - - - b b b X - - -	- - - - ? B B B ? ? - -	X X X X X B B B X X X X
Great Cormorant *Phalacrocorax carbo*	- - - - - - - - - - - -	- - - X X b b b X X + -	- - - - - - - - - - - -	+ + + X X B B B X X X +
Purple Sandpiper *Calidris maritima*	- - - - - b b b ? - - -	- - - + + b b b + + - -	- - - - ? B B B ? - - -	X X X X X B B B X X X X
Red Phalarope *Phalaropus fulicarius*	- - - - - B B B + - - -	- - - - - B B B + - - -	- - - - - B B B B ? - -	- - - - - b b b + + + -
Pomarine Jaegar *Stercorarius pomarinus*	- - - - - - - - - - - -	- - - - - b b b + - - -	- - - - - B B B ? - - -	- - - - - B B B + - - -
Parasitic Jaeger *Stercorarius parasiticus*	- - - - - B B B + - - -	- - - - + b b b + - - -	- - - - ? B B B X - - -	- - - - X B B B X - - -
Long-tailed Jaeger *Stercorarius longicaudus*	- - - - - B B B + - - -	- - - - - B B B - - - -	- - - - ? B B B ? - - -	- - - - + b b b + - - -
Skua *Catharacta skua*	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - + + + - -	- - - - + + + + + + - -
Glaucous Gull *Larus hyperboreus*	- - - ? X B B B X + - -	- - - + X B B B X X - -	? ? ? ? X B B B X X ? ?	+ + + X X b b b X X X +
Iceland Gull *Larus glaucoides*	- - - - - - - - - - - -	- - - + X B B B X X X -	? ? ? ? ? B B B X + ? ?	X X X X X B B B X X X X
Great Black-backed Gull *Larus Marimus*	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - + + + + + + + + -	X X X X X B B B X X X X
Thayer's Gull *Larus thayeri*	- - - - + B B B X ? - -	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - -
Ivory Gull *Pagophila eburnea*	? ? ? + + + + + + + ? ?	? ? ? + + + + + + + ? ?	+ + + + + + - - - + + +	+ + + + + - - - - + + +
Black-legged Kittiwake *Rissa Tridactyla*	- - - - X B B B X X ? -	- - - X X B B B X X ? -	- - - - X B B B X X + +	- - + X X B B B X X + +
Sabine's Gull *Xema sabini*	- - - - - b b b + - - -	- - - - - b b b X ? - -	- - - - - ? ? + + - - -	- - - - - - - + - - - -
Artic Tern *Sterna paradisaea*	- - - - - X B B X - - -	- - - - - X B B X - - -	- - - - ? B B B ? ? - -	- - - + X B B B X + - -
Razorbill *Alca torda*	- - - - - - - - - - - -	- - - + X b b b X - - -	- - - - - - - - - - - -	- - - + X B B B X - - -
Thick-billed Murre *Uria lomvia*	- - - - X B B B X + - -	- - - X X B B B X ? - -	? ? ? + X B B B X X ? ?	X X X X X B B B X X X X
Dovekie *Alle alle*	- - - - X + + + + + - -	- - - - X B B B X X - -	? ? ? + + + ? X X X + -	X X X X + b b b + X X X
Black Guillemot *Cepphus grylle*	+ + + + X B B B X X + +	+ + + + X B B B X X + +	+ + + ? ? B B B X X + +	X X X X X B B B X X X X
Atlantic Puffin *Fratercula arctica*	- - - - - - - - - - - -	- - - ? ? b b b X X - -	- - - - - - - + + - - -	+ + + + X B B B X X + +

Legend
- \- Rare or Absent.
- \+ Present in relatively small numbers.
- X Present in relatively large numbers.
- B Breeds in relatively large numbers.
- b Breeds in relatively small numbers.
- ? Status unknown.

TABLE 2.2-2

STATUS OF BIRD SPECIES THAT OCCUR REGULARLY ALONG COASTS AND/OR OFFSHORE IN PARRY CHANNEL (based on LGL Ltd., 1981 and sources cited there).

Species	Lancaster Sound Month J F M A M J J A S O N D	Barrow Strait Month J F M A M J J A S O N D	Viscount Melville Sound Month J F M A M J J A S O N D
Yellow-billed Loon *Gavia adamsii*	- - - - - - + ? + ? - - -	- - - - - - + ? ? ? - - -	- - - - - - ? + ? ? - - -
Arctic Loon *Gavia arctica*	- - - - - - + + + ? - - -	- - - - - - ? ? ? - - - -	- - - - - - × ? ? ? - - -
Red-throated Loon *Gavia stellata*	- - - - - B B B + - - -	- - - - - - B B B ? - - -	- - - - - - B B B ? - - -
Northern Fulmar *Fulmarus glacialis*	- - - + X B B B B + - -	- - - ? X B B B B ? - -	- - - - - - - - - - - -
Brant *Branta bernicla*	- - - - - b b b + - - -	- - - - - - b b b + - - -	- - - - - - B B B + - - -
Snow Goose *Chen caerulescens*	- - - - - b b b + - - -	- - - - - - b b b ? - - -	- - - - - - b b b ? - - -
Oldsquaw *Clangula hyemalis*	- - - - + B B B X + - -	- - - - ? B B B ? ? - -	- - - - - - b b b ? - - -
Common Eider *Somateria mollissima*	- - - + X B B B X + - -	- - - ? ? B B B ? ? - -	- - - - - - - - - - - -
King Eider *Somateria spectabilis*	- - - + X B B B X + - -	- - - ? ? B B B ? ? - -	- - - - ? b b b ? - - -
Red Phalarope *Phalaropus fulicarius*	- - - - - B B B X - - -	- - - - - - B B B ? - - -	- - - - - - B B B ? - - -
Pomarine Jaeger *Stercorarius pomarinus*	- - - - ? b b b ? - - -	- - - - ? b b b ? - - -	- - - - ? b b b ? - - -
Parasitic Jaeger *Stercorarius parasiticus*	- - - - ? b b b + - - -	- - - - ? b b b ? - - -	- - - - ? b b b ? - - -
Long-tailed Jaeger *Stercorarius longicaudus*	- - - - ? B B B + - - -	- - - - ? B B B ? - - -	- - - - ? B B B ? - - -
Glaucous Gull *Larus hyperboreus*	- - - ? X B B B X + - -	- - - ? ? B B B ? ? - -	- - - - ? b b b ? - - -
Thayer's Gull *Larus thayeri*	- - - - X B B B X + - -	- - - - ? B B B ? ? - -	- - - - ? ? ? + ? - - -
Ivory Gull *Pagophila eburnea*	- - - - + + + + X + - -	- - - - ? + + + X ? - -	- - - - ? ? ? + ? - - -
Black-legged Kittiwake *Rissa tridactyla*	- - - - X B B B X + - -	- - - - ? B B B ? ? - -	- - - - - - - - - - - -
Sabine's Gull *Xema sabini*	- - - - ? b b b + - - -	- - - - ? b b b ? - - -	- - - - ? ? ? + - - - -
Arctic Tern *Sterna paradisaea*	- - - - - X B B X - - -	- - - - - X B B ? - - -	- - - - X B B ? - - - -
Thick-billed Murre *Uria lomvia*	- - - - X B B B X - - -	- - - - X B B B X - - -	- - - - - - - - - - - -
Dovekie *Alle alle*	- - - - X + + + + - - -	- - - - ? + - - - - - -	- - - - - - - - - - - -
Black Guillemot *Cepphus grylle*	+ + + + X B B B + + + +	? ? ? ? X B B B X ? ? ?	- - - - - - - - - - - -

Legend
- \- Rare or Absent.
- \+ Present in relatively small numbers.
- X Present in relatively large numbers.
- B Breeds in relatively large numbers.
- b Breeds in relatively small numbers.
- ? Status unknown.

In late summer marine-associated birds disperse widely both along coasts and offshore. Concentrations may, however, occur, especially along glacier fronts. Most species have departed from Lancaster Sound and Baffin Bay by early October.

The nesting cycle of many Arctic birds requires 90 to 100 days from nest initiation to fledging of the young. This time encompasses virtually all of the short Arctic summer and if spring is late many individuals and species may not attempt to nest (Wynne-Edwards, 1939; Bird and Bird, 1940; Marshall, 1952; Barry, 1962, 1967; Kerbes, 1969; Ryder, 1970; Davis *et al.*, 1974). In years when birds do not attempt to nest, their distribution can be quite different from that in nesting years.

Climatic conditions can vary substantially among areas within one year, thus affecting the proportion of birds that nest and also the proportion of young that survive (Jehl and Hussell, 1966). The following accounts describe the distribution of the most abundant breeding species found along the eastern shipping corridor. When known, the effect of a late spring on distribution is reviewed. A more detailed review for all species is contained in LGL Ltd. (1981).

2.2.1 LOONS

Of the four species of loons that occur along the eastern shipping corridor, only the red-throated loon (Plate 2.2-1) is widespread and fairly common (Salomonsen, 1950; Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; MMI, 1979b). The yellow-billed loon occurs commonly only in Prince of Wales Strait (Barry *et al.*, 1981; McLaren and Alliston, 1981) and the common loon occurs only along southeast Baffin Island and southwest Greenland. The Arctic loon occurs regularly only along southeast Baffin Island and in Prince of Wales Strait.

All of the loon species are present along coasts but large concentrations are not known to occur (Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; MMI, 1979b; McLaren, 1980). Loons are most common along coasts during spring and fall migration. Red-throated loons and probably yellow-billed loons forage in marine areas during summer but the other two species occur primarily on inland lakes at that time.

2.2.2 FULMARS, SHEARWATERS AND STORM-PETRELS

Three species of birds in this group occur along the eastern shipping corridor - northern fulmar, greater shearwater and Leach's storm-petrel. Only the northern fulmar is common. Greater shearwaters nest in the Southern Hemisphere and occur in Davis Strait during the austral winter. They occur primarily on the fishing banks off Greenland north to about 67°N, although 'huge flocks' have been reported along the coast of Greenland (Salomonsen, 1970). Few shearwaters occur in southwest Davis Strait (MMI, 1979a, b). Leach's storm-petrel *(Oceanodroma furcata)* is an occasional visitor along the southwest coast of Greenland (Palmer, 1962).

2.2.2.1 Northern Fulmar

The northern fulmar is discontinuously circumpolar in its distribution. It breeds at colonies along coasts of the north Pacific, north Atlantic and Arctic oceans (Godfrey, 1966). In the eastern Atlantic, numbers have increased and new colonies have been established during the past 30 years (Fisher, 1952, 1966); there is also some indication that new colonies are being established in eastern North America (Nettleship and Lock, 1973; Nettleship and Montgomerie, 1974; Montevecchi *et al.*, 1978). However, the species reaches its peak of abundance in North America in the eastern Arctic.

Fulmars withdraw from the northern parts of their breeding range in winter. From November to March they are common in open water of Davis Strait (MAL, 1977; MMI, 1979a), although their centre of abundance is in the Labrador Sea and North Atlantic Ocean. There are no records of fulmars in Baffin Bay and Parry Channel in winter.

Fulmars tend to avoid continuous fast ice and tend to be widely distributed in offshore waters. Concentrations of fulmars often occur along fast ice edges, pack ice edges, glacier fronts, coasts and tide lines; around icebergs and plankton blooms; and in areas where offal is present (McLaren, 1980).

The northern fulmar is a surface-feeder and its primary foods consist of pelagic invertebrates. Brood-rearing fulmars, however, may feed largely on fish (Bradstreet, 1976). Fulmars are also opportunistic scavengers.

The northern fulmar has the longest nesting interval, approximately 100 days from egg-laying to fledging, of any Arctic-nesting species (Godfrey, 1966). Breeding fulmars tend to retain the same mates and nest sites from year to year (Ollason and Dunnet, 1978) and both adults share in incubation and brood-rearing. Adults attend and brood the chick for about two weeks after hatching; however, after this time the young are left unattended at the cliff for increasingly long periods while the adults forage (Palmer, 1962). Upon termination of nesting, adult fulmars moult. Flight feathers are replaced sequentially and there is

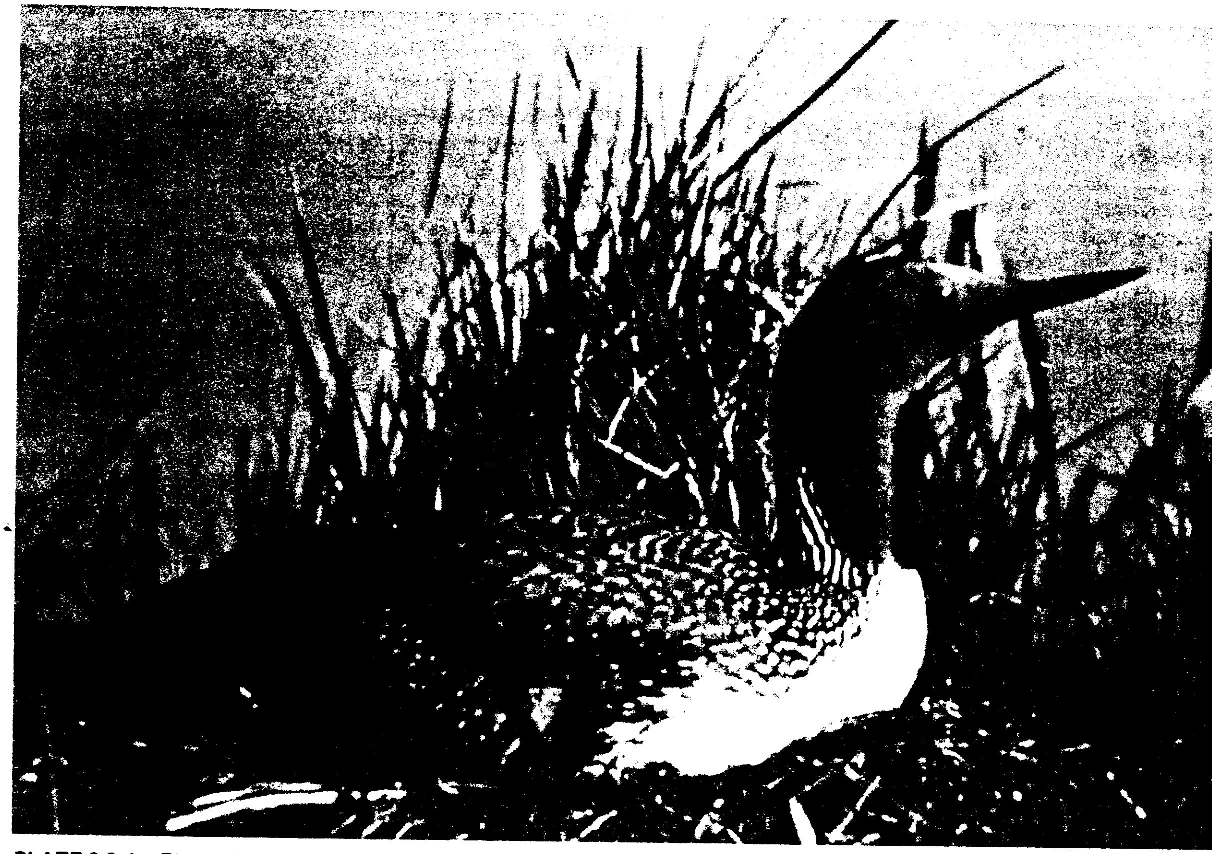


PLATE 2.2-1 *The red-throated loon is the only loon species that is common along the eastern shipping corridor. All of the loon species are present along the coasts but large concentrations are not known to occur.*

no flightless period (Palmer, 1962).

Northern fulmars are long-lived with a mean life expectancy after first breeding in a boreal colony of 33.9 years for males and 35.5 years for females (Dunnet and Ollason, 1978). They are slow to mature with an average age at first breeding for females at a boreal colony of 10.3 years (Dunnet *et al.*, 1979). They also have a low annual reproductive potential with a clutch size of one egg, and no replacement clutches are laid (Ollason and Dunnet, 1978).

In March and April, fulmars begin to move north toward their nesting areas, a movement that may coincide with the seasonal warming of the surface layers of the ocean (Brown, 1970; Brown *et al.*, 1975). Fulmars arrive at colonies along the Greenland coast and southern Baffin Island in early April (Salomonsen, 1950) and have reached Parry Channel by late April (McLaren and Renaud, 1979). They are, however, still common throughout Davis Strait and Baffin Bay in April and May. Numbers in Davis Strait may be slightly higher near the Greenland coast at this time (MAL, 1978).

At least 18 colonies, totalling an estimated 900,000 nesting birds, are located along the coasts of the central and eastern Canadian Arctic and Greenland (Brown *et al.*, 1975; Figures 2.2-1 and 2.2-2). These colonies include a large proportion of the entire North American and Greenland population. Most colonies are in Baffin Bay. No colonies and few fulmars occur west of Barrow Strait.

Fulmars initially visit the nesting colonies for a short time and then undertake a 'pre-laying exodus,' dispersing into offshore areas (Dunnet *et al.*, 1963; Macdonald, 1977; McLaren and Renaud, 1979). In eastern Lancaster Sound and Baffin Bay in 1978 and 1979, the numbers of fulmars decreased after mid May, reaching a minimum in late May and early June (McLaren and Renaud, 1979; McLaren, 1980). For example, the density along coasts and ice edges of northern Baffin Bay decreased from 2.2 birds/km^2 in mid May to 0.2 birds/km^2 on June 1 in 1979. Similarly, the numbers estimated to be in offshore Lancaster Sound and western Baffin Bay decreased from almost 50,000 birds to less than 9,000 (McLaren, 1980). A similar pattern of decreasing densities and numbers was observed in late May of 1978 (McLaren and Renaud, 1979). The very low numbers present in these areas at that time suggest that during the pre-

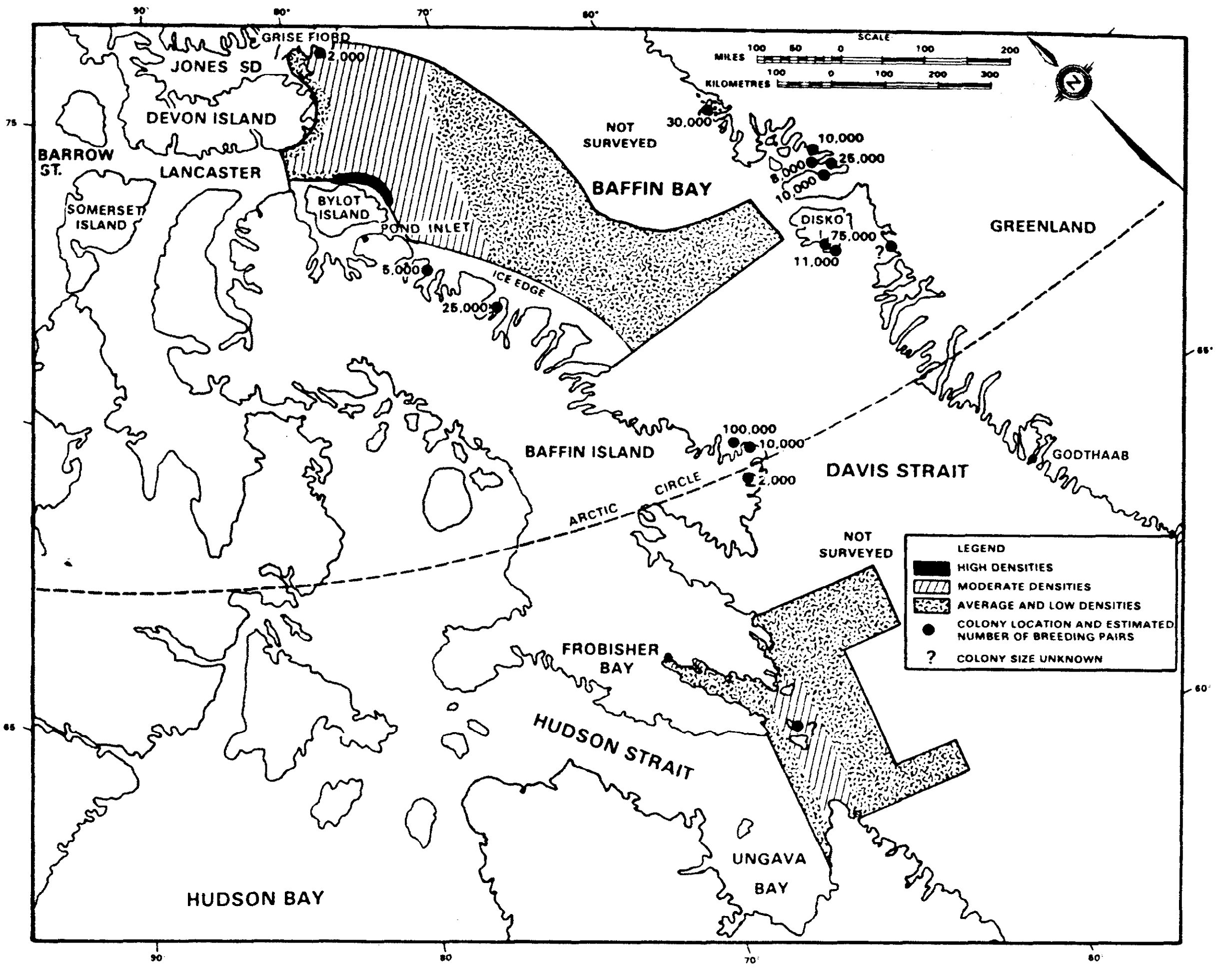


FIGURE 2.2-1 *Distribution of northern fulmars in Baffin Bay and Davis Strait in June and July (based on McLaren and Renaud, 1979; MMI, 1979b; McLaren, 1980). Fulmars tend to avoid continuous fast ice and are widely distributed in offshore waters.*

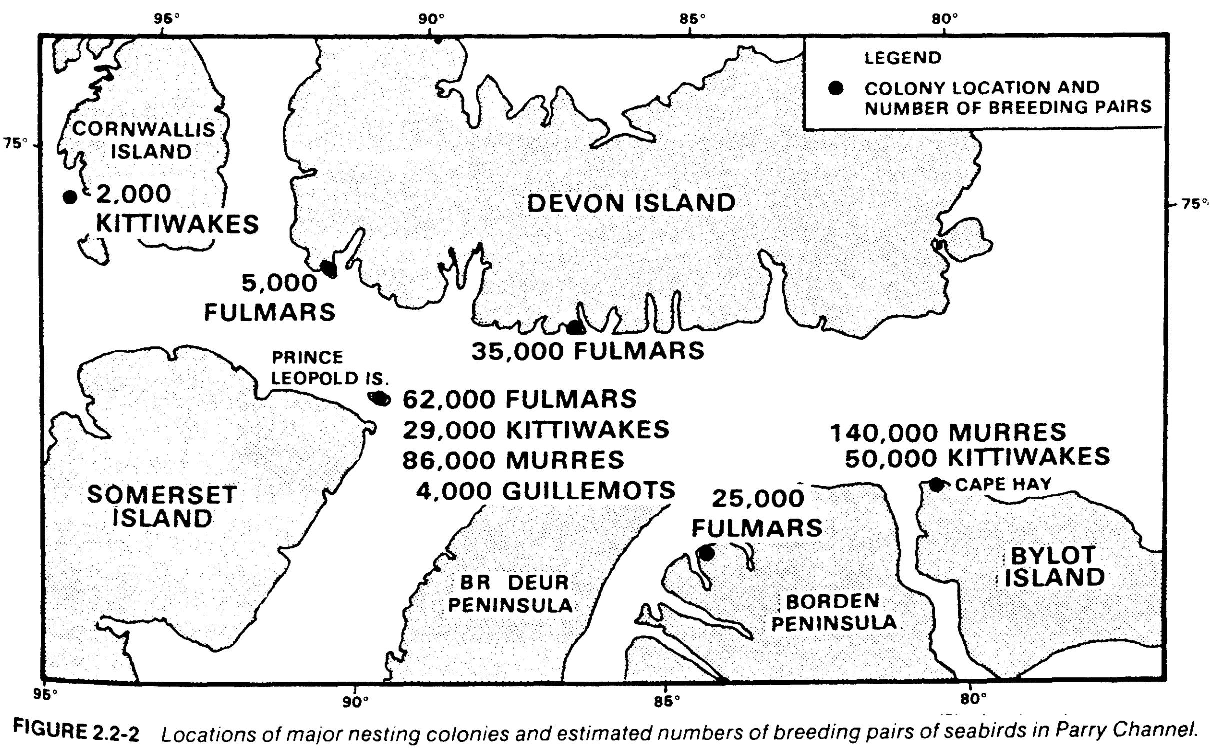


FIGURE 2.2-2 *Locations of major nesting colonies and estimated numbers of breeding pairs of seabirds in Parry Channel.*

laying exodus, most fulmars move completely out of Baffin Bay, possibly to areas off south Baffin Island, and/or perhaps, west Greenland.

Fulmars return to Baffin Bay and Lancaster Sound from their pre-laying exodus during the first week of June (McLaren and Renaud, 1979; McLaren, 1980), just prior to nest initiation. During the six to seven week incubation period (D.N. Nettleship, pers. comm.), fulmars are commonly and widely distributed along coasts and ice edges and in offshore areas of Lancaster Sound and Baffin Bay. Average densities along ice edges and coasts during this period (9.7 birds/km^2) are about twice those recorded in May prior to the pre-laying exodus. Densities along fast ice edges are about twice those along ice free coastlines (McLaren and Renaud, 1979; McLaren, 1980). Fulmars are likely to be present in all offshore areas between Barrow Strait and 60°N during this period (Brown *et al.*, 1975; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980), although densities in extreme southwest Davis Strait are low until late July (MMI, 1979b). Densities tend to be highest near nesting colonies and lowest in areas where pack ice is substantial (McLaren and Renaud, 1979; MMI, 1979b).

In addition to nesting birds, non-nesting birds, which probably include both subadults and non-nesting adults, are present at nesting colonies. Nettleship and Gaston (1978) estimated that 40% of the fulmars at the Prince Leopold Island colony in 1976 were non-breeders. During the nesting period, activities of fulmars are centred around the colonies, although foraging trips may extend up to 300 km from the colony (Hatch, 1979). Fulmar chicks hatch in late July and the nestling stage lasts for 7 to 8 weeks. The young fledge in mid September.

From August to September, large numbers of fulmars gather along southeast Ellesmere Island and along south and east Devon Island (Nettleship, 1974; Johnson *et al.*, 1976; McLaren and Renaud, 1979). Concentrations are much higher at glacier fronts than along the remainder of the coastline (Figure 2.2-3) (McLaren and Renaud, 1979). McLaren and

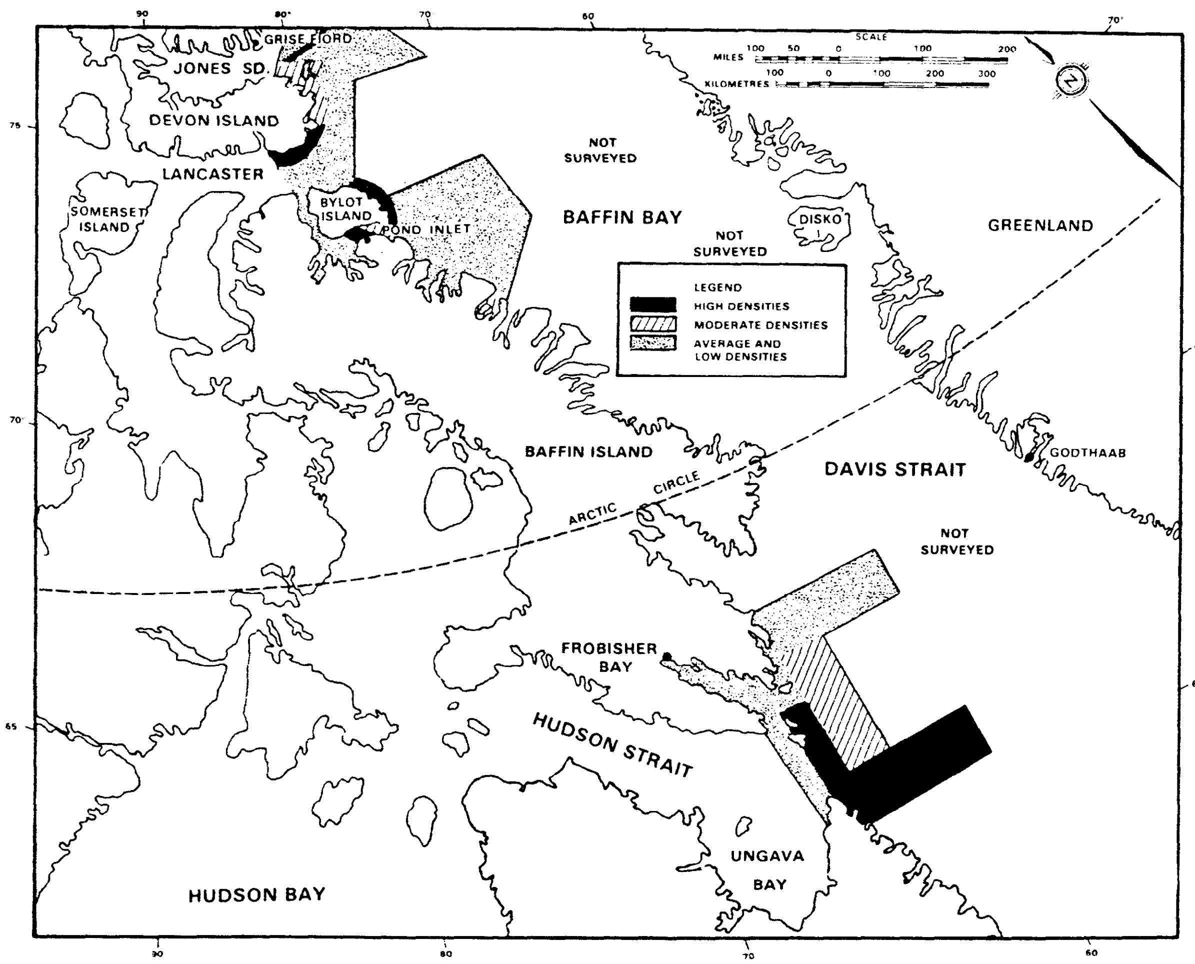


FIGURE 2.2-3 *Distribution of northern fulmars in Baffin Bay and Davis Strait in August and September (McLaren and Renaud, 1979; MMI, 1979b). At this time, large numbers tend to gather along south and east Devon Island.*

Renaud (1979) recorded over 12,000 fulmars along southeastern Devon Island near the Cunningham Glacier front on August 28, 1978. They recorded over 5,000 fulmars (94.5/km^2) along southern Ellesmere Island on September 21, 1978. Large concentrations of fulmars also occur along southeast Baffin Island in August and September. Densities along that coast averaged 23.9 birds/km^2 from late July through September, 1978 and peaked at 75.4 birds/km^2 on August 13 and 14 (MMI, 1979b).

Migration toward wintering grounds begins soon after the young fledge. An increase in fulmar numbers was observed in eastern Lancaster Sound in mid September, 1976 (Johnson *et al.*, 1976), shortly after an apparent decline in fulmar numbers in east Barrow Strait (Nettleship and Gaston, 1978). Between September 13 and 19, 1976, fulmar numbers in Lancaster Sound decreased by 80% (Johnson *et al.*, 1976). In 1978, when few fulmars nested successfully at Prince Leopold Island (D.N. Nettleship, pers. comm.), few fulmars remained in eastern Lancaster Sound and northwest Baffin Bay after late September. The latest record for fulmars in the Parry Channel area is October 19, 1955, at Arctic Bay (Ellis, 1956).

Fulmars also depart from their Greenland colonies in September (Salomonsen, 1950). Ship-based surveys show that fulmars are common throughout Baffin Bay (average of 3 to 10 birds/10 min watch) in September (Brown *et al.*, 1975; Brown, 1978). Numbers in Baffin Bay decrease in October but numbers in Davis Strait remain at about the same level through at least November (Brown, 1979).

2.2.3 GREAT CORMORANT

The great cormorant has a world-wide distribution but along the eastern shipping corridor nests only at several colonies of 50 to 100 pairs in the Disko Bay area of Greenland. Great cormorants winter along the southwest coast of Greenland (Salomonsen, 1967).

2.2.4 GEESE

Two species of geese that commonly occur along the eastern shipping corridor, snow goose and brant, are addressed in this section. The Canada goose *(Branta canadensis)* is an uncommon bird in the area.

2.2.4.1 Brant

Two subspecies of brant *(Branta bernicla)* nest along the route. Black brant *(B. b. nigricans)* nest on the western islands and Atlantic brant *(B. b. hrota)* nest on the eastern islands and in Greenland. Breeding ranges overlap on Prince Patrick and Melville islands and in the Parry River region of Queen Maud Gulf south of Victoria Island, where intermediate forms between the two subspecies occur (Godfrey, 1966) (Figure 2.2-4).

Black brant winter on the Pacific coast and probably migrate to Melville, Banks, and Victoria islands across the Beaufort Sea (Einarson, 1965; Barry, 1967). Barry (1960) estimated a summer population of 9,000 brant on Banks Island in 1960. Manning *et al.* (1956), using limited and largely non-quantitative ground surveys, had estimated 80,000 brant on Banks Island in 1953 but stated that most individuals were in the south and southwestern parts of the island. About 1,500 adult and subadult brant, both black and intermediate forms, are estimated to be present on eastern Melville Island each summer (Maltby, pers. comm.; McLaren and Renaud, 1977).

Atlantic brant are not common along the eastern shipping corridor. The centres of summer abundance are Foxe Basin and the Thule District of Greenland. Nevertheless, small numbers migrate northward along the east coast of Baffin Island and larger numbers of European-wintering brant, both Atlantic and intermediate forms, migrate up the northwest coast of Greenland after overflying the ice cap from the east (Salomonsen, 1950; Maltby-Prevett *et al.*, 1975).

Regardless of wintering area and migration route, brant arrive at nesting areas in early to mid June (Handley, 1950; Salomonsen, 1950; Barry, 1967; Davis *et al.*, 1974; Alliston *et al.*, 1976; Renaud *et al.*, 1981). Brant generally nest in coastal meadows, often just above the high tide line, and many nests may be lost when storm surges occur during the nesting season (Barry, 1967). The nests are often placed on the edges of freshwater or tidal pools or on small islets (Bellrose, 1976) and may be in loose colonies or widely dispersed (Barry, 1964).

Non-breeding birds begin to moult in early July but breeding birds do not begin to moult until about two weeks after their young hatch (generally in late July). Breeding adults regain flight capability by the time their young fledge (Barry, 1967). McLaren and Renaud (1977) found that many brant on southern Melville Island remained inland until mid August when flocks of up to about 60 birds began to appear along the coast. It seems likely that brant move to coastal areas earlier in non-breeding years.

Fall migration of immature brant, and adults in non-breeding years, may begin as early as the beginning of August (Handley, 1950; McLaren and Renaud, 1977; Maltby, pers. comm.). Adults with young leave in late August or early September, although a few may remain in Greenland until late September (Salo-

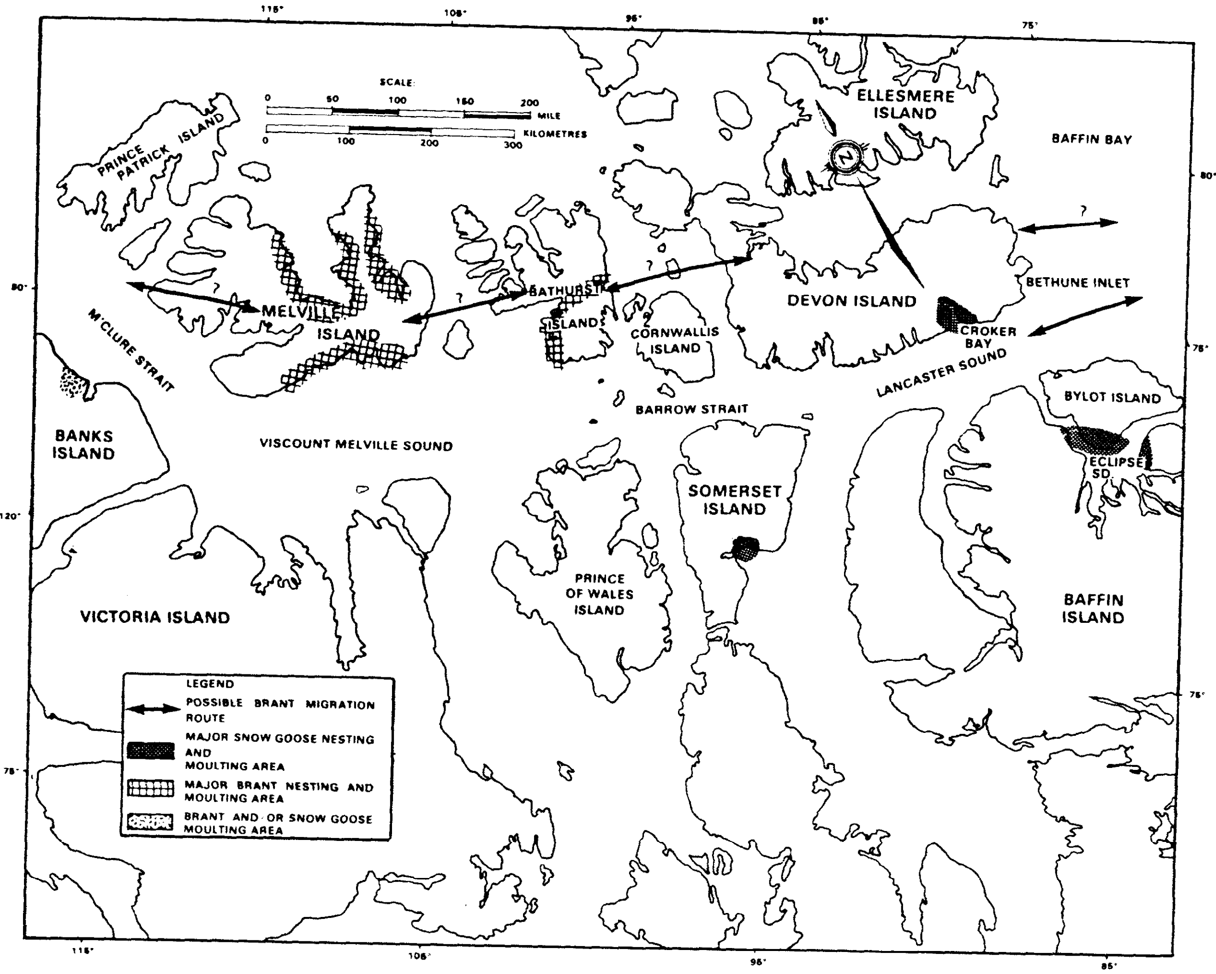


FIGURE 2.2-4 *Snow geese and brant are the two most common species of geese occurring along the shipping corridor. Their nesting and moulting areas and probable migration routes in Parry Channel, shown here, are based on sources cited in the text.*

monsen, 1950; Johnson *et al.*, 1976; McLaren and Renaud, 1979).

2.2.4.2 Snow Geese

Two subspecies of snow geese occur along the eastern shipping corridor. The majority of snow geese found along the route are greater snow geese *(Chen caerulescens atlantica)*. Lesser snow geese *(C. c. caerulescens)* occur only on northern Banks Island, where as many as 25,000 birds (probably immatures) moult in the Thomsen River valley (C.W.S., 1972); some may use adjacent coastal waters. These geese come from the major nesting colony on southwestern Banks Island. Lesser snow geese are described in detail in Section 4.2 of Volume 3A.

Greater snow geese arrive in the High Arctic in early June and move directly to terrestrial nesting areas. The timing of nesting and moulting is very similar to that for brant.

Small numbers of greater snow geese nest on most of the islands adjacent to the eastern shipping corridor (Miller and Russell, 1974; Alliston *et al.*, 1976; Renaud *et al.*, 1981) but by far the largest colony (20,000 birds; H. Boyd in C.W.S., 1972) occurs on southwest Bylot Island (Figure 2.2-4). Few snow geese are seen in marine areas until late summer, toward the end of the moulting period (Lemieux, 1959; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979). Johnson *et al.* (1976) observed as many as 680 geese in Croker Bay, Devon Island, although many of these birds were on tundra ponds rather than the ocean. McLaren and Renaud (1979) saw up to 700 snow geese in coastal waters in Eclipse Sound and 500 in Bethune Inlet, southeast Devon Island, in late August.

Snow geese leave the area in late August or early September (Davis *et al.*, 1974; Alliston *et al.*, 1976; McLaren and Renaud, 1979). However, few have been observed in marine areas during migration (McLaren and Renaud, 1979; MMI, 1979b).

2.2.5 DABBLING DUCKS

Four species of dabbling ducks (mallard, *Anas platyrhynchos;* pintail, *A. acuta;* green-winged teal, *A. crecca;/ and* European wigeon, *A. penelope*) occur in the study area (Salomonsen, 1950; Palmer, 1976a). All are restricted to southwest Greenland, and pintails, teal and wigeon are all uncommon to rare. Only the mallard and, rarely, the pintail nest in Greenland.

The subspecies of mallard, *A. p. conboschas,* that nests in Greenland forms a discrete population with ecological traits distinct from other North American mallards. Greenland mallards remain inland during the nesting season and moulting also occurs on inland lakes. They winter on the ocean along the southwest coast of Greenland from Disko Bay to Cape Farewell. They are most common in the extreme south of this area. During winter they feed mainly on molluscs and crustaceans in the littoral zone (Salomonsen, 1950, 1970).

2.2.6 DIVING DUCKS

Six species of diving ducks are known to nest along the eastern shipping corridor. Barrow's goldeneye *(Bucephala clangula)* probably nests in extreme northern Labrador and southwest Greenland (Godfrey, 1966; Salomonsen, 1950). The harlequin duck and red-breasted merganser nest sparsely to commonly along much of Baffin Bay and Davis Strait (see Table 2.2-1). The three most abundant duck species - oldsquaw, king eider and common eider - are discussed in detail below.

2.2.6.1 Oldsquaw

The oldsquaw occurs throughout tundra areas of North America and Greenland wherever suitable habitat exists (Godfrey, 1966; Bellrose, 1976; Palmer, 1976b). Breeding birds are widely distributed and nesting occurs both along the Arctic coasts and far inland (Godfrey, 1966; Alison, 1975; Bellrose, 1976).

Oldsquaws nesting in areas along the western parts of the corridor probably winter along the Pacific coast whereas those in eastern parts winter along southwest Greenland, the Atlantic coast of North America and on the Great Lakes. Although most oldsquaws migrate overland or along coasts (Bellrose, 1976; Palmer, 1976b) some may migrate offshore. Most of those wintering in southwest Greenland follow the coast north although Salomonsen (1950) also reported oldsquaws offshore. MMI (1979b) recorded very small numbers of northward-migrating oldsquaws offshore in Davis Strait.

In the west, oldsquaws have been reported off Banks Island by mid May (Manning *et al.,* 1956) but observers along the Alaskan and Yukon north coast have not recorded oldsquaws before late May (Johnson *et al.,* 1975; Johnson and Richardson, 1981; Richardson and Johnson, 1981). The early-arriving birds at Banks Island may have followed offshore routes across the Beaufort Sea. There is no information about timing of arrival in Viscount Melville Sound or Prince of Wales Strait, but oldsquaws generally arrive in Baffin Bay, Lancaster Sound and northwest Greenland by the second or third week of May (Salomonsen, 1950; Ellis, 1956; Johnson *et al.,* 1976; McLaren and Renaud, 1979; McLaren, 1980). Oldsquaws have been recorded as early as April 29 in Foxe Basin (Macpherson and McLaren, 1959) but MMI (1979b) did not record them along southwestern Baffin Island until about May 15. MMI (1979b) saw small numbers of oldsquaws migrating north along southeast Baffin Island, mostly in early June. Salomonsen (1950) reported large numbers (flocks of up to 200 birds) migrating north from southwest Greenland by mid May. Although oldsquaws first arrive in northern Baffin Bay in May, the major influx of birds does not occur until sometime in the first three weeks of June. The precise timing varies among years, possibly as a result of varying conditions along the migration route (Johnson *et al.,* 1976; McLaren and Renaud, 1979; McLaren and McLaren, in press).

The distribution of oldsquaws after arrival also varies among years, probably because of varying ice conditions. During spring, oldsquaws appear to concentrate in shallow areas where benthic food organisms are accessible. For example, in 1978 McLaren and Renaud (1979) found low densities of oldsquaws in Lancaster Sound (2.7 birds/km^2) but high densities (17.7 birds/km^2) near Coburg Island. In 1979, when the shores of eastern Lancaster Sound were free of ice, densities were much higher there (44.0 than near birds/km^2) Coburg Island (5.0 birds/km^2) (McLaren, 1980).

Oldsquaws usually arrive at nesting sites in the High Arctic by mid June (Van Tyne and Drury, 1959; Manning and Macpherson, 1961; Hussell and Holroyd, 1974; Renaud *et al.,* 1981). Additional birds are presumably still arriving in Baffin Bay from the south until the last week of June since coastal densities do not begin to decrease until this time (Johnson *et al.,* 1976; McLaren and Renaud, 1979; McLaren, 1980).

Although oldsquaws nest on all islands adjacent to the eastern shipping corridor, estimates of breeding densities vary considerably both among islands and for the same island. Estimates for Banks Island vary from 6,000 to 60,000 birds (Manning *et al.,* 1956; Barry, 1960) but to the north on Melville Island, oldsquaws are uncommon and nesting records are few (Alliston *et al.,* 1976; McLaren and Renaud, 1977; Maltby, 1978). Other areas where population estimates exist include a southeast-northwest axis of Victoria Island where Barry (1960) estimated 20,000 nesting oldsquaws, and Prince of Wales Island where Manning and Macpherson (1961) estimated 80,000 birds. Oldsquaws are very uncommon nesting birds on southern Cornwallis Island and near Arctic Bay on northern Baffin Island (Geale, 1971; Renaud *et al.*, 1979) but they are common near Pond Inlet (Renaud *et al.*, 1981). Oldsquaws are also uncommon on the Cumberland Peninsula of Baffin Island (Watson, 1957).

The average clutch size of oldsquaws is about seven eggs. Incubation, which does not begin until the clutch is complete, requires about 26 days (Alison, 1975). The peak of laying is probably late June and early July with hatch in late July or early August (Manning and Macpherson, 1961; Hussell and Holroyd, 1974). In some areas, females nesting near the coast lead their broods to salt water after they hatch (Parmelee *et al.*, 1967). However, very few oldsquaw broods have been observed in marine areas of the eastern shipping corridor (Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1977; McLaren and Renaud, 1979). Most broods remain in inland areas until they fledge or are large enough, when seen from the air, to be indistinguishable from adults (Alison, 1975).

Male oldsquaws leave the nesting areas soon after incubation begins and move to moulting areas on large lakes or along the coast (Figures 2.2-5 and 2.2-6) (Bellrose, 1976; Alliston *et al.*, 1976). The distance to moulting areas may vary greatly. Some birds fly long distances whereas others move to coasts adjacent to the nesting areas (Palmer, 1976b). Breeding drakes may join pre-breeders already present along coasts. The moulting flocks are, in turn, joined first by failed breeders and later by females with young. The different timing of moult in various segments of the population leads to a protracted period in which moulters may be observed. McLaren

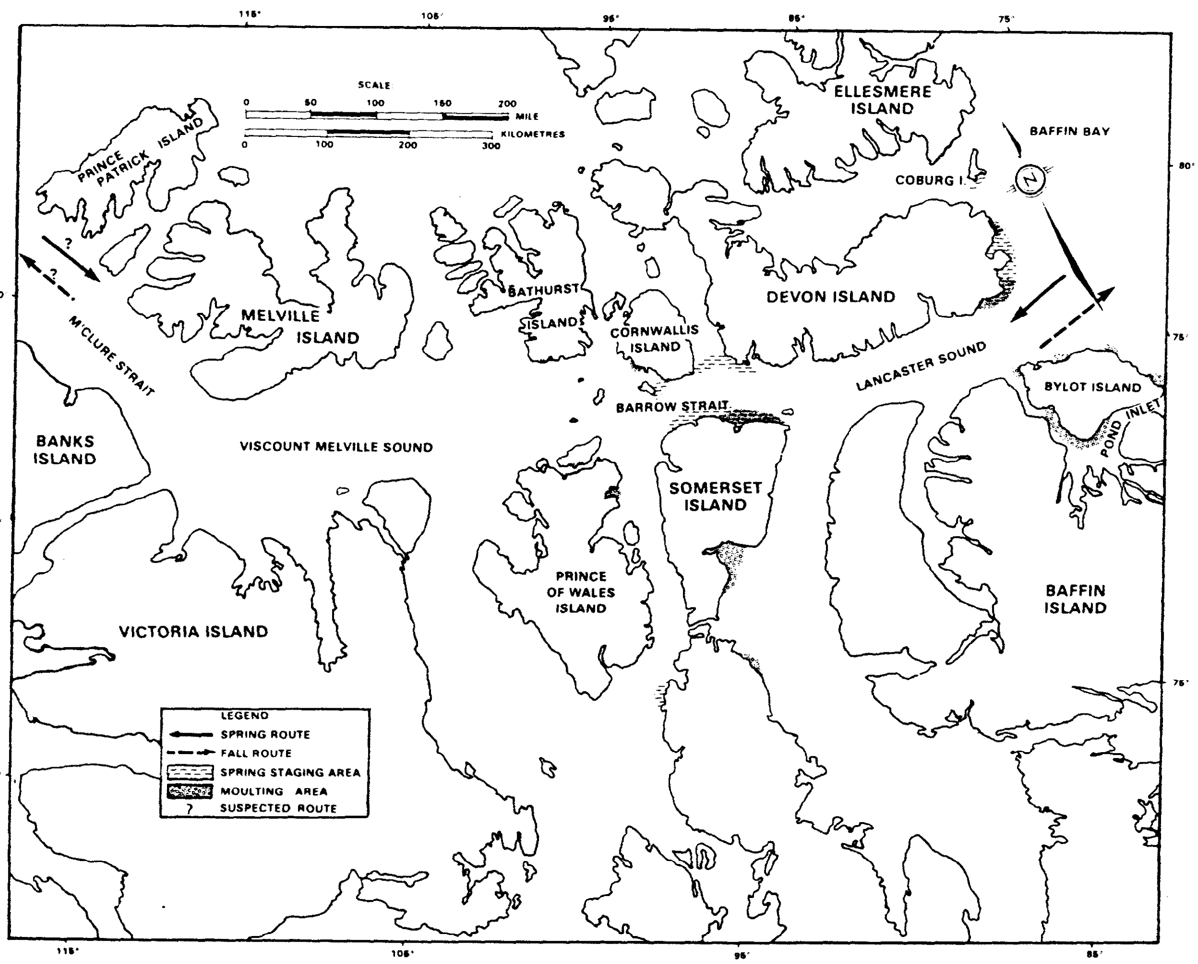


FIGURE 2.2-5 *Oldsquaw migration routes, spring staging areas and moulting areas in Parry Channel, based on sources cited in the text. Male oldsquaws leave the nesting areas soon after incubation begins and move to moulting areas on large lakes or along the coast.*

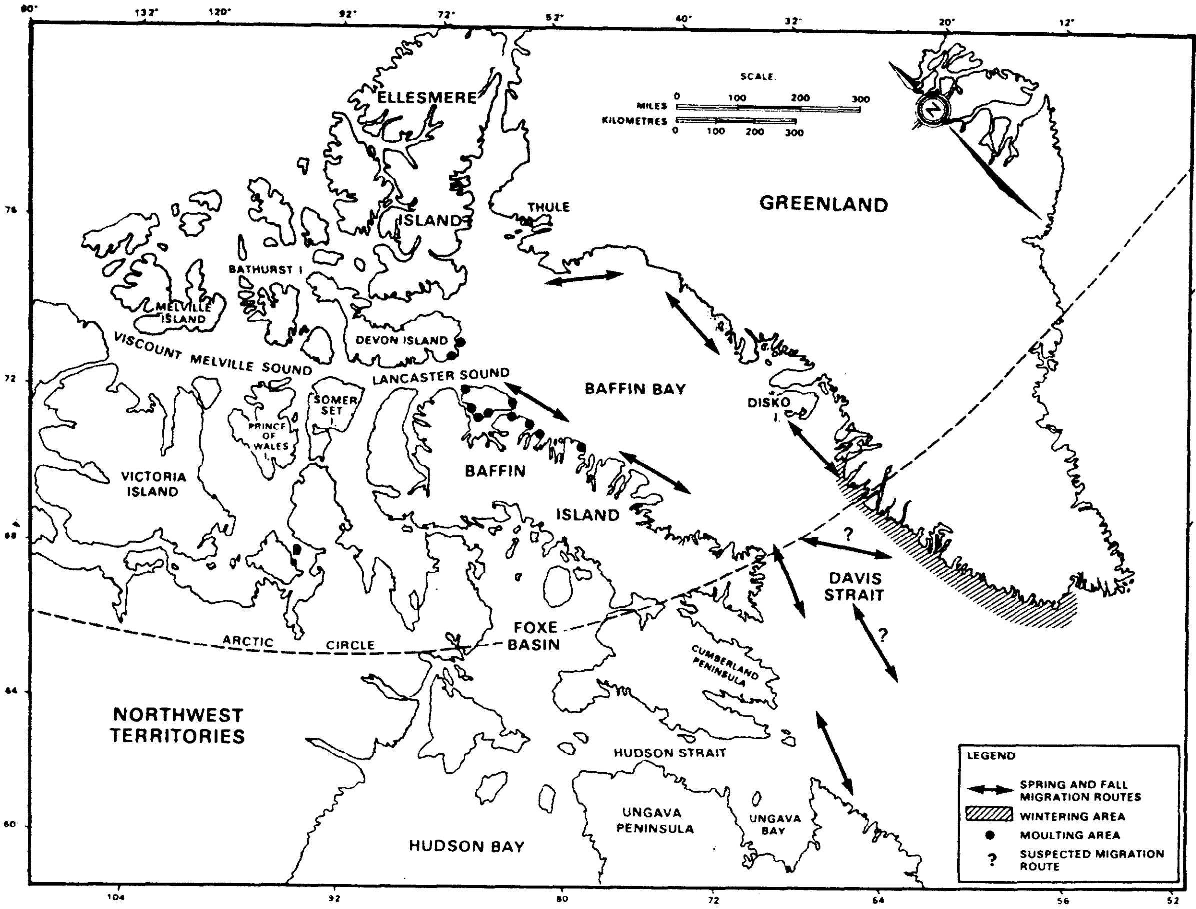


FIGURE 2.2-6 *Oldsquaw migration routes, moulting areas and wintering areas in Baffin Bay and Davis Strait (from sources cited in text).*

and Renaud (1979) last observed moulting oldsquaws on September 27, 1978, when some birds had probably already departed southward.

Moulting oldsquaws have been recorded as early as July 7 in the Canadian Arctic (Johnson *et al.*, 1976) but in Greenland the moult apparently begins in late July (Salomonsen, 1950). Sizable flocks of oldsquaws (more than 100 birds) have been recorded along coasts of most of the islands east of Melville Island but particular areas seem to be preferred (Figure 2.2-5). For example, Alliston *et al.* (1976) recorded over 1,500 oldsquaws along the north coast of Somerset Island in August, 1975, and McLaren and Renaud (1979) recorded 2,500 in a small area along eastern Bylot Island and 1,500 along southern Bylot Island in August, 1978. Salomonsen (1972) reported 'huge flocks' of moulting oldsquaws along the Greenland coast in the Thule District in 1968.

Oldsquaws probably begin to leave High Arctic areas in early September. McLaren and Renaud (1979) noted a large decrease in the number of oldsquaws in northwest Baffin Bay in the last 10 days of September, 1978, and almost all were gone by October 10. Johnson *et al.* (1976) noted an increase in numbers of oldsquaws in Lancaster Sound after mid September, presumably resulting from the arrival of migrants from areas further west. Oldsquaws leave the Thule District of Greenland in mid September. They may remain as far north as Disko Island until mid November but do not regularly overwinter north of about 66°N (Salomonsen, 1950).

2.2.6.2 Eiders

Two species of eiders, common eider and king eider, nest along the eastern shipping corridor. In the case of the common eider, two subspecies occur along the route. The northern race of the common eider *(Somateria mollissima borealis)* nests in numerous coastal locations as far west as Cornwallis Island, and the western race *(S. m. v-nigra)* nests along Prince of Wales Strait. The king eider *(Somateria spectabilis)* nests along all of the route (Palmer, 1976b). Both species include eastern and western wintering components. The two species are discussed together because their movements in the area are quite similar and the females are indistinguishable during aerial surveys.

Western Arctic populations of king and common eiders winter off southwestern Alaska, from the northern limits of open water in the Bering Sea south to the Alaska Peninsula and Aleutian Islands (Bellrose, 1976; Palmer, 1976b). Both groups of eiders migrate north primarily along the coast of Alaska to Point Barrow and then directly to the Canadian Arctic via offshore routes (see LGL and ESL, 1982 for more details). It is not certain how far east the western wintering king eiders migrate but Bellrose (1976) suggested that they go as far east as the Adelaide Peninsula, Keewatin District. Salomonsen (1968), on the other hand, reported that small numbers of birds banded in Greenland were recovered as far west as eastern Victoria Island. He hypothesized that king eiders from eastern areas nest as far west as Melville, Prince Patrick and northern Banks islands.

Eastern populations of king and common eiders winter off eastern Canada and southwest Greenland (Cooch, 1965; Palmer, 1976b). Northward migration along the Greenland coast begins in March and both species have generally reached northern Greenland by late April. King eiders reach the Coburg Island area in northwest Baffin Bay in early May and common eiders arrive slightly later in mid May (McLaren and Renaud, 1979; McLaren, 1980). Although MMI (1979b) recorded a large influx of common eiders along southwestern Baffin Island in late April, 1978, they recorded few king eiders. Common eiders were not seen migrating along northeastern Baffin Island and king eiders were not seen in this area until after the main influx to the Coburg Island area (McLaren and Renaud, 1979; McLaren, 1980). McLaren and McLaren (in press) reported few eiders in offshore areas of Baffin Bay in May and suggested that both species cross extreme northern Baffin Bay or Smith Sound from Greenland to reach Coburg Island (Figure 2.2-7).

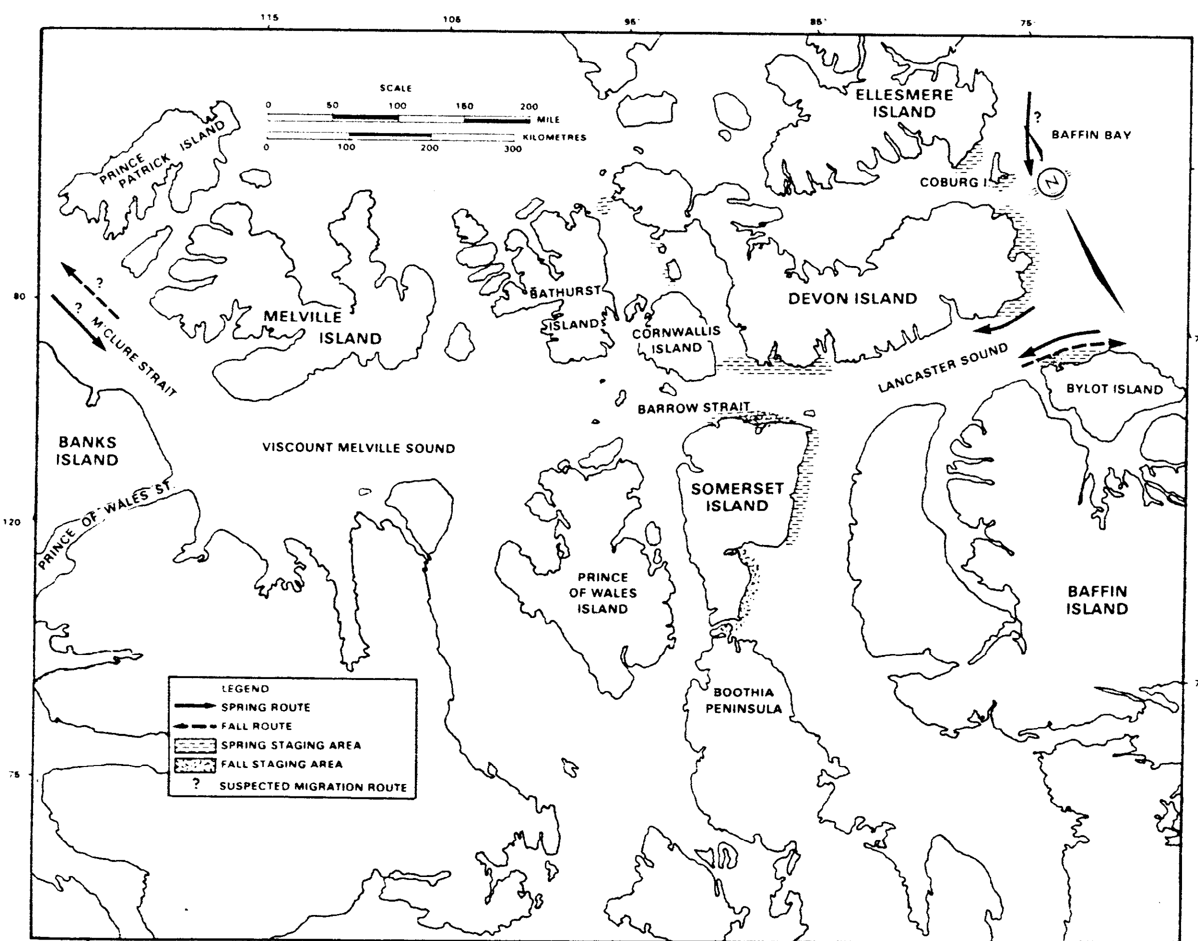


FIGURE 2.2-7 *Two species of elders, king and common, nest along the eastern shipping corridor. Their migration routes and staging areas in Parry Channel, shown here, are based on sources cited in text.*

Many eiders that nest in the central Northwest Passage region probably arrive in early June via Lancaster Sound (Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980; McLaren and McLaren, in press). In each of 1976, 1978, and 1979, numbers of eiders (both king and common but mostly king) increased rapidly in eastern Lancaster Sound in early June, reaching a peak by about June 10. Numbers of both species then declined rapidly, presumably as eiders moved west through Lancaster Sound or dispersed to local nesting areas. Peak numbers recorded exceeded 20,000 eiders in 1976 and 1979 and about 13,000 in 1978 (Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). King eiders are abundant in open water areas of Barrow Strait by early June. The length of time that individual eiders remain in Lancaster Sound is not known but the total number passing through the sound is probably much larger than the peak counts recorded during aerial surveys.

Eiders are abundant in most coastal areas until late June when they presumably move to nesting sites (Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). King eiders nest primarily at inland locations but common eiders generally nest close to salt water, usually on small islands. Common eiders may nest in dense colonies but many birds also nest in small groups or solitarily at widely scattered locations along coasts.

Numbers of common eiders either nesting or wintering along the route are large. Salomonsen (1970) estimated 50,000 breeding pairs plus an unknown number of immatures in Greenland. The largest colonies in Greenland, at least 10,000 pairs, are in the Thule District, north of the eastern shipping corridor; but these birds migrate through and probably winter in the area. Numbers of nesting pairs in more southerly parts of Greenland have been substantially reduced by hunting and egging (Salomonsen, 1950, 1970). There are no estimates of numbers of common eiders nesting along the Canadian side of Davis Strait and Baffin Bay and along Parry Channel, although a number of small and medium-sized colonies are known (Geale, 1971; MMI, 1979b; McLaren and Renaud, 1979).

Palmer (1976b) reported the centre of abundance of king eiders to be from the Boothia Peninsula west to Banks Island. Manning *et al.* (1956) estimated 150,000 nesting birds on Banks Island in 1952 and Barry (1960) estimated over 100,000 eiders on Banks Island in late summer, 1960. Barry (1960) also estimated 800,000 king eiders on Victoria Island in late summer, 1960. Manning and Macpherson (1961) estimated 65,000 king eiders on Prince of Wales Island early in the nesting season. Total numbers on Bathurst Island immediately to the north are probably much lower (Lamothe, 1973).

Shortly after incubation begins, males of both species desert the females and migrate to moulting areas. For western-nesting king and common eiders these areas are probably in the Bering Sea (Palmer, 1976b). For eastern nesting eiders the major moulting areas are along the west coast of Greenland. Relatively few have been observed moulting in Lancaster Sound and western Baffin Bay (Johnson *et al.*, 1976; McLaren and Renaud, 1979), although Tuck and Lemieux (1959) observed over 10,000 king eiders that may have been moulting near Cape Hay, northwest Bylot Island, in mid July, 1957.

The major moulting area for king eiders from most of the eastern and central Arctic is the west coast of Greenland in an area spanning about 5° of latitude centred on Disko Bay (Salomonsen, 1968). Two major migration routes to this area are across the centre of Baffin Island (Wynne-Edwards, 1952) and along the north shore of Baffin and Bylot islands (McLaren and McLaren, in press).

Common eider males also migrate from the central Arctic via Lancaster Sound. Most are believed to return to wintering areas off southwest Greenland where they join subadult drakes which frequently do not leave the wintering areas at all (Salomonsen, 1950). Common eider drakes also moult along southeastern Baffin Island (MMI, 1979b) but it is unclear whether these are locally breeding birds or emigrants from other areas.

Many female eiders without broods, presumably subadults and/or failed nesters, stage in coastal areas (Figure 2.2-8) and then leave Parry Channel before moulting. Johnson *et al.* (1976) reported over 10,000 female eiders (none identified to species but likely both common and king eiders) migrating east through Lancaster Sound during the second week of August 1976. McLaren and Renaud (1979) reported over 25,000 female eiders (again not identified to species) in the same area in 1978. Most (about 22,000) were migrating along the coast of Bylot Island. Total numbers migrating through Lancaster Sound are undoubtedly much larger. Salomonsen (1979) suggested that the Clyde River area of east Baffin Island was a moulting area for adult female eiders.

After hatch, female eiders often move their broods to coastal areas (Salomonsen, 1950; Cooch, 1965; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979). Some successful females apparently leave their flightless broods and migrate to moulting areas (Palmer, 1976b) whereas others may remain and moult with their broods (cf. McLaren and

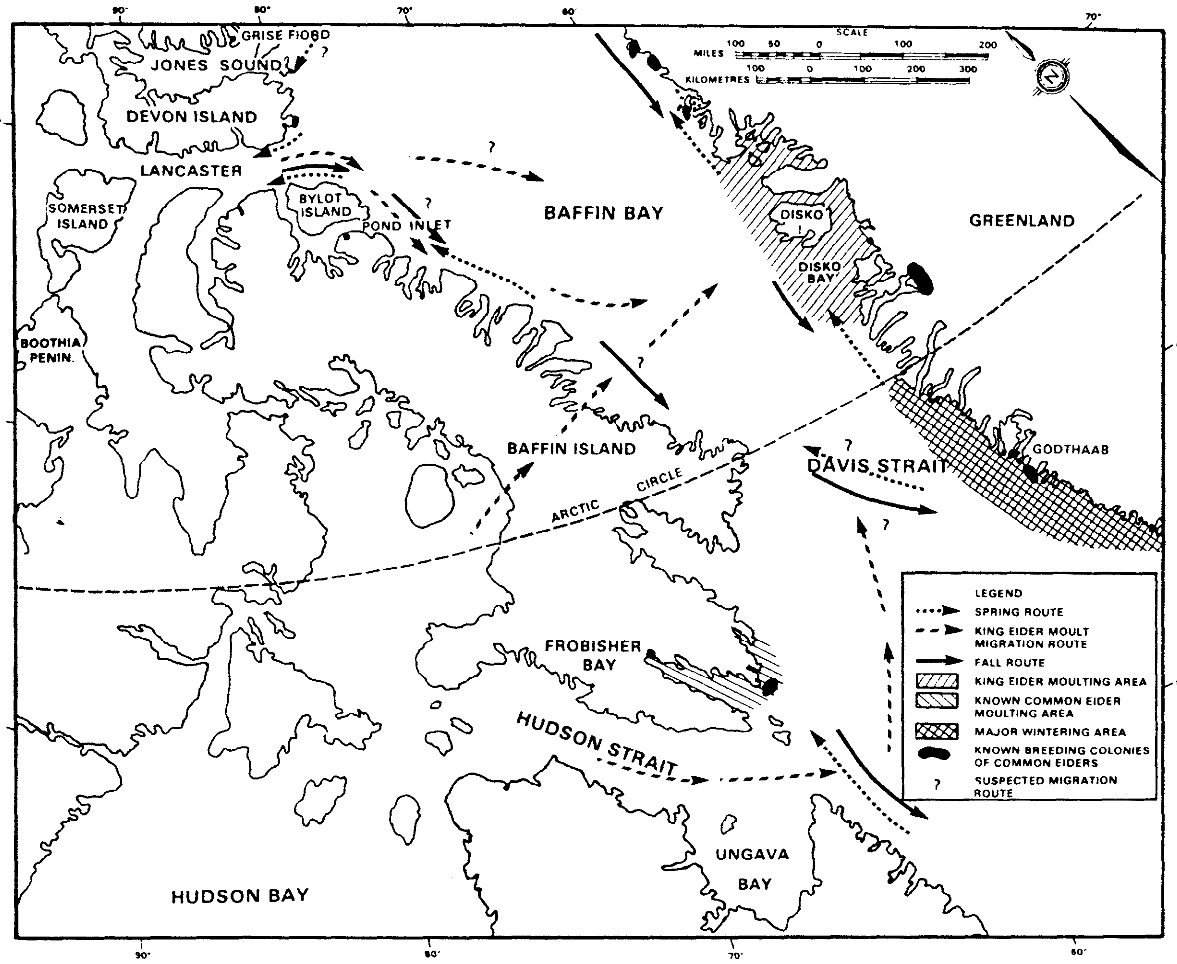


FIGURE 2.2-8 *Nesting areas of common eiders and migration routes; moulting areas and wintering areas of king and common eiders in Baffin Bay and Davis Strait, based on sources cited in text.*

Renaud, 1979). For the common eider in particular a number of broods may join to form a 'creche.' Creches, especially of older ducklings, may or may not be attended by adult females and the adults, if present, may or may not have hatched the ducklings present. There is considerable variation among subspecies and among areas in the extent of creche formation and the degree to which a female tends to stay with her own brood (see Palmer, 1976b for review).

Most eiders leave northern areas in September, although a few may remain into October (Salomonsen, 1950; McLaren and Renaud, 1979; Barry *et al.*, 1981). Relatively large numbers are still present along southeast Baffin Island in November (MMI, 1979b) and small numbers of common eiders may overwinter among the pack ice in this area (Soper, 1946; MMI, 1979a).

2.2.7 SHOREBIRDS

Sixteen species of shorebirds nest in terrestrial areas along the eastern shipping corridor (Table 2.2-3).

TABLE 2.2-3
SHOREBIRDS BREEDING IN TERRESTRIAL AREAS ADJACENT TO THE NORTHWEST PASSAGE (BASED ON GODFREY, 1966)

Common Name	Scientific Name
Ringed Plover	Charadrius hiaticula
*Semipalmated Plover	Charadrius semipalmatus
American Golden Plover	Pluvialis dominica
Black-bellied Plover	Pluvialis squatarola
Ruddy Turnstone	Arenaria interpres
Red Knot	Calidris canutus
Purple Sandpiper	Calidris maritima
*Pectoral Sandpiper	Calidris melanotos
White-rumped Sandpiper	Calidris fuscicollis
Baird's Sandpiper	Calidris bairdii
*Dunlin	Calidris alpina
*Semipalmated Sandpiper	Calidris pusilla
Sanderling	Calidris alba
Buff-breasted Sandpiper	Tryngites subruficollis
Red Phalarope	Phalaropus fulicarius
*Northern Phalarope	Lobipes lobatus

*Species that, in the Arctic Islands, nest primarily on those islands south of Parry Channel.

Several species are confined primarily to islands south of Parry Channel and one, the ringed plover, occurs only along the east sides of Ellesmere, Devon and Baffin islands and in Greenland (Godfrey, 1966). Except for the purple sandpiper, whose winter range includes southwest Greenland (Salomonsen, 1950), all shorebirds migrate to wintering areas south of this area (Palmer, 1967).

The two phalarope species are the only shorebird species that habitually swim. The others are more typically waders. Thus, the phalaropes are more vulnerable than the strictly wading shorebirds to marine oil spills and they are, accordingly, discussed in a separate section below. Most of the limited information on the use of littoral areas by shorebirds is qualitative in nature.

Throughout the Arctic, shorebirds arrive in the breeding areas from late May to mid June (Gabrielsŏn and Lincoln, 1959; Solomonsen, 1950; Johnson *et al.*, 1975; Kessel and Gibson, 1978). During this period marine beaches are usually covered by ice or snow; hence shorebirds are unlikely to be found in marine habitats. Spring migrant shorebirds rarely occur in large flocks and dispersal onto terrestrial breeding habitats proceeds rapidly. Clutch initiation often occurs within a week of arrival on the breeding grounds.

All species typically lay 4-egg clutches in habitats ranging from very marshy (e.g. red phalarope, pectoral sandpiper) to very dry (e.g. semipalmated plover, ruddy turnstone) (Palmer, 1967). Females of most shorebird species nesting along the eastern shipping corridor lay only one clutch per year. Female sanderlings and phalaropes may lay two clutches per year (see LGL Ltd., 1981 for more details).

Arctic shorebirds are subject to reduced breeding or, in extreme cases, complete non-breeding when spring is abnormally late (Alliston *et al.*, 1976; Maltby, 1978). Populations can also be adversely affected when inclement weather causes food shortages either at the time the adults arrive on the breeding grounds (Morrison, 1975) or later during the course of the breeding cycle (Jehl and Hussell, 1966). The sporadic nature of breeding for some species (e.g. pectoral sandpipers, buff-breasted sandpipers), which may be common in an area one year and rare or absent in other years, suggests that in these species there may be great year to year variability in nesting locations.

The southward migration of shorebirds is protracted, with the earliest individuals (probably largely non-breeders) departing as early as late June. Adults of all species usually stage and depart by mid August. Young-of-the-year of most species remain near the nesting areas after most adults have departed; most young probably depart by early September although individuals of some species may remain in the Arctic until early October (Johnson *et al.*, 1975; Kessel and Gibson, 1978; Conners *et al.*, 1979).

During late spring and early summer, most shorebirds depend on tundra habitats for food as well as nesting sites. However, during late summer and early fall, many staging and migrating shorebird species (especially the young-of-the-year) feed in littoral habitats. Beaches suitable for use by shorebirds occur primarily along the western part of the Northwest Passage; in many eastern areas cliffs fall directly to the water (LGL Ltd., 1981).

2.2.7.1 Phalaropes

Two species of phalaropes occur in the area, namely the red phalarope and the northern phalarope. The red phalarope nests along most of the eastern shipping corridor (Godfrey, 1966; Alliston *et al.*, 1976; Maltby, 1978) whereas the northern phalarope nests only on southern Baffin Island and southern Greenland (Salomonsen, 1950; Godfrey, 1966).

Both phalarope species usually lay four eggs which the male alone incubates. Females desert the males shortly after egg-laying and gather in flocks on the tundra prior to migration (Parmelee *et al.*, 1967; Bergman, 1974; Connors and Risebrough, 1977). Males migrate after the young have fledged and most have left tundra areas by August (Parmelee *et al.*, 1967; Bergman, 1974). Young depart from the region between about mid August to mid September. Males and young stage for migration in coastal areas (Connors and Risebrough, 1977; Johnson and Richardson, 1981).

Little is known about staging areas and migration routes of either species of phalarope along the eastern shipping corridor. It seems likely that those nesting in western areas winter in the southern Pacific and follow offshore migration routes over the Beaufort Sea (see LGL and ESL, 1982). In the east, MMI (1979b) reported fairly large numbers of phalaropes (not identified but believed to be mostly red phalaropes) migrating northwards over offshore areas of the northern Labrador Sea and Davis Strait in mid June, 1978. Farther north, McLaren and Renaud (1979) noted an influx of red phalaropes to northwest Baffin Bay starting about June 20, 1978. These birds were seen both offshore and along ice edges. In 1976, phalaropes arriving in Lancaster Sound were also seen both offshore and along coastal ice edges (Johnson *et al.*, 1976).

MMI (1979b) detected another movement of phalaropes through offshore waters in southern Davis Strait at the beginning of August. These were presumably females that had left their mates and possibly males that had lost their nests. Whether these birds had staged in coastal areas farther north is not known.

Phalaropes stage along coasts in late August. McLaren and Renaud (1977) reported flocks of up to 60 red phalaropes in Bridport Inlet, southern Melville Island, in late August, 1977, and McLaren and Renaud (1979) found flocks of up to 100 birds along southwest Bylot Island in 1978. Other areas used by staging phalaropes undoubtedly exist. These birds, presumably including both males and young-of-the-year, probably leave the study area in small numbers over a relatively protracted period. MMI (1979b) recorded small numbers of phalaropes over offshore Davis Strait and the Labrador Sea until early October but saw no large scale movements after the beginning of August.

2.2.8 JAEGERS AND SKUAS

Three species of jaegers, namely parasitic, pomarine and long-tailed, occur in substantial numbers along the eastern shipping corridor. All three species have essentially circumpolar Arctic or subarctic ranges and winter at sea in south temperate and tropical regions. Small numbers of skuas, mainly immatures, also occur in southern Davis Strait in summer (Salomonsen, 1967; Furness, 1978).

2.2.8.1 Jaegers

Jaegers use the marine portions of the area mainly during spring and fall migration. Numbers of jaegers present during the breeding season depends on nesting effort and success in a given year. In non-nesting years, many adult jaegers are believed to return to the marine environment after prospecting nesting areas (Maher, 1974; Watson and Divoky, 1974; Richardson and Johnson, 1981). Few immature jaegers are believed to return to the Arctic in summer (Salomonsen, 1950; Frame, 1973; Maher, 1974; Watson and Divoky, 1974).

Parasitic jaegers arrive in south Greenland in early May and occasionally in late April (Salomonsen, 1950). They presumably pass central Greenland in mid to late May since they do not reach the Thule District until mid June. Pomarine jaegers reach central west Greenland in mid to late May or early June (Salomonsen, 1950). In 1978, aerial surveys in Davis Strait and Baffin Bay indicated that peak spring migration of all three species occurs about mid June (MMI, 1979b; McLaren and Renaud, 1979). In Davis Strait most migration is offshore, although they are also regularly seen along coasts and ice edges (McLaren and Renaud, 1979; McLaren, 1980).

Johnson *et al.* (1976) noted that peak numbers of jaegers occurred in Lancaster Sound during the second week in June. Davis *et al.* (1974) and Alliston *et al.* (1976) recorded all three species in the Barrow Strait area in early to mid June. These birds probably arrived from the east since the western part of the passage offers no open water until late June or early July. Jaegers nesting on the western islands most likely arrive from the west.

Jaegers arrive at terrestrial nesting areas in mid June (Van Tyne and Drury, 1959; Manning and Macpherson, 1961; Hussell and Holroyd, 1974). However, a portion of the population does not nest or fails early in the nesting season (Taylor, 1974). It is possible that the small numbers of birds observed in marine areas in mid summer are non-nesting birds (Johnson *et al.*, 1976; MMI, 1979b; McLaren and Renaud, 1979).

Southward migration occurs in late August and early September, although individuals have been seen in Baffin Bay as late as October 9 (McLaren and Renaud, 1979). Sightings from ships in Davis Strait indicate that numbers of all species decrease between August and September and that the decrease is greatest for long-tailed jaegers (Brown *et al.*, 1975). Brown *et al.* (1975) also found that all three species migrated in autumn through both coastal and offshore areas.

2.2.9 GULLS AND TERNS

Seven gull species and the Arctic tern occur regularly along the eastern shipping corridor. The great black-backed gull occurs mainly in southeastern Davis Strait. Sabine's gull occurs throughout the area but in small numbers (Tables 2.2-1 and 2.2-2). The other species are more common and are discussed below.

2.2.9.1 Glaucous Gull

The glaucous gull (Plate 2.2-2) has a circumpolar breeding range and is probably the most widely distributed, but not the most abundant, gull species nesting in Arctic and subarctic regions of North America (Gabrielson and Lincoln, 1959; Godfrey, 1966). In Canada, this species nests north to northern Ellesmere Island and south to northern Labrador and the Belcher Islands in Hudson Bay (Godfrey, 1966). Wintering areas are primarily along the west and east coasts of North America (Gabrielson and Lincoln, 1959; Godfrey, 1966). Glaucous gulls also winter in southwest Greenland, occasionally as far north as Disko Bay, but the majority of the northern-wintering birds are immatures (Salomonsen, 1950).

Glaucous gulls usually reach nesting areas in central west Greenland in mid April (Salomonsen, 1950) and are present in southwest Davis Strait by late April

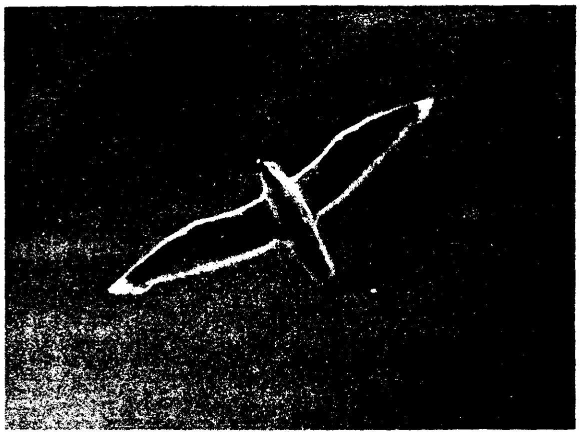


PLATE 2.2-2 *The glaucous gull is a widely distributed nester in Arctic and subarctic regions of North America. (Courtesy, D. Karasiuk).*

(MMI. 1979b). They reach northwest Baffin Bay by early May when they are common both along coasts and in offshore areas (McLaren and Renaud, 1979). In the central Arctic, glaucous gulls arrive in late May (Manning and Macpherson, 1961) and there, too, they occur both coastally and offshore (Alliston *et al.*, 1976).

Glaucous gulls nest colonially on cliffs or islands and also singly, often on islands (Godfrey, 1966). A number of colonies are known in the Arctic Islands, particularly the central islands (Davis *et al.*, 1974; Nettleship, 1974; Alliston *et al.*, 1976) but none is very large. The largest, on Prince Leopold Island, contained about 200 pairs in 1972 (Nettleship, 1974).

The greatest concentration of colonies in the central Arctic is on southern Devon Island where at least 16 are located between Wellington Channel and Maxwell Bay. None is larger than about 50 pairs and the overall total was about 300 pairs in 1975 (Alliston *et al.*, 1976). Smaller numbers, probably totalling less than 200 pairs, nest along the coasts of other islands adjacent to central Parry Channel (Davis *et al.*, 1974; Alliston *et al.*, 1976; McLaren and Renaud, 1977). Farther east in eastern Lancaster Sound and northwestern Baffin Bay, about 10 colonies are known, although others probably exist. These colonies support about 275 pairs of glaucous gulls (Nettleship, 1974; Johnson *et al.*, 1976; McLaren and Renaud, 1979). MMI (1979b) reported 74 colonies containing in excess of 2,500 pairs of glaucous and/or Iceland gulls (gulls at most colonies were not identified to species) along the northern tip of Labrador and southeastern Baffin Island, south from Cumberland Sound. Glaucous gull colonies of up to 100 birds are also common along the entire west coast of Greenland (Salomonsen, 1950).

At Prince Leopold Island, and presumably elsewhere, nesting begins in late May (Nettleship, 1977). Glaucous gulls lay two, or more commonly, three eggs and incubation requires about 38 days (Godfrey, 1966; Swartz, 1966; Campbell, 1973). The young do not attain flight until about 50 days old (Swartz, 1966). Fledging in the central Arctic occurs in late August or early September (Nettleship, 1977).

Glaucous gulls remain abundant in marine areas throughout the summer (Davis *et al.*, 1974; Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979). McLaren and Renaud (1979) found glaucous gulls to be abundant in a few locations, primarily along glacier fronts of southeast Devon and Ellesmere islands, in late August and September.

Most glaucous gulls have left northern Baffin Bay by early October. However, in October they are still relatively common in offshore areas of southern Baffin Bay and Davis Strait (Brown *et al.*, 1975; MMI, 1979b).

2.2.9.2 Iceland Gull

Two subspecies of Iceland gulls *(Larus glaucoides)* nest in the region. *L. g. kumlieni* nests on Baffin Island south of 69°N (Godfrey, 1966) and *L. g. glaucoides* nests in western Greenland north to Upernavik District (Salomonsen, 1950).

Banding returns have shown that Greenland-nesting Iceland gulls winter off southwest Greenland (Salomonsen, 1950). Baffin Island birds winter in waters south from Davis Strait (Brown *et al.*, 1975). MMI (1979b) recorded them most frequently along the pack ice edge and over other open water in Davis Strait, rather than in the heavy pack ice.

Iceland gulls nest primarily on cliffs facing tidal inlets of fiords rather than along exposed coastlines. However, birds too young to breed remain in flocks along exposed as well as protected coastlines throughout the summer (Salomonsen, 1950).

Greenland birds arrive at nesting colonies in late April or early May (Salomonsen, 1950) and Canadian birds probably arrive about the same time (MMI, 1979b). Macpherson (1961) estimated a nesting population of about 1,000 Iceland gulls between Resolution Island and Cumberland Sound, south Baffin Island. There are no population estimates for Greenland but the species is very common (Salomonsen, 1950).

Nesting chronology is slightly later in Canada than in Greenland. In Canada, egg-laying extends throughout the first half of June; about half the nests have hatched by July 10 (Macpherson, 1961). Fledged young appear in late August; MMI (1979b) noted a threefold increase in the numbers of pale-mantled gulls (glaucous and/or Iceland) at this time in 1978. They attributed the increase both to the presence of fledged young and to reduced nest tenacity in older birds. In Greenland, Iceland gull eggs hatch in the second half of June and the young fledge in late July and early August (Salomonsen, 1950).

After fledging, young Iceland gulls may wander far north of the breeding areas before withdrawing to their wintering areas during October to November (Salomonsen, 1950; Brown *et al.*, 1975).

2.2.9.3 Thayer's Gull

Thayer's gulls nest colonially on cliffs along the west coast of Baffin Bay and along Parry Channel and winter on the Pacific coast from British Columbia to California (Godfrey, 1966). Migration routes to and from breeding areas are unknown. Thayer's gulls probably first arrive in nesting areas in mid May but the major spring influx occurs in June (Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). During spring migration, they are widespread, although densities are low - an average of 0.2 birds/km^2 along coasts and ice edges, and 0.01 birds/km^2 offshore (McLaren and Renaud, 1979). Thayer's gulls become almost entirely coastal in summer (Johnson *et al.*, 1976; McLaren and Renaud, 1979).

Davis *et al.* (1974) and Alliston *et al.* (1976) reported numerous Thayer's gull colonies in the central Canadian Arctic Islands. However, most were inland or considerably south of Parry Channel. Only two colonies, five pairs on Griffith Island and 100 pairs on Browne Island, were in or along Parry Channel. Nettleship (1974) reported another two colonies totalling about 60 pairs on Cornwallis and Devon islands.

Thayer's gulls probably begin nesting in late June and hatching occurs in late July (Alliston *et al.*, 1976). The time of fledging is not known but fledged young have not been seen in Lancaster Sound before early September (Johnson *et al.*, 1976), and they remain uncommon until about mid September (McLaren and Renaud, 1979). Thayer's gulls are present in northern Baffin Bay until at least the second week of October but numbers begin to decrease in mid September (McLaren and Renaud, 1979). They presumably leave nesting areas in the central Arctic at that time.

2.2.9.4 Ivory Gull

The ivory gull (Plate 2.2-3) has a circumpolar distribution and remains in Arctic and subarctic areas throughout the year. Ivory gulls nest colonially and

PLATE 2.2-3 *The ivory gull, classed as a rare species by COSEWIC, does not nest along the eastern shipping corridor. Small numbers of this species shown here are present along the coasts and in offshore waters of eastern Lancaster Sound and Baffin Bay throughout the summer. (Courtesy, M. Bradstreet, LGL Ltd.).*

the main nesting areas are in the Eastern Hemisphere (Salomonsen, 1950). There are only about 10 known breeding locations in North America and western Greenland and none of them is along the eastern shipping corridor (Salomonsen, 1950; MacDonald and Macpherson, 1962; MacDonald, 1976; Frisch and Morgan, 1979; Witts and Morrison, 1980). In Canada the ivory gull is classed as a rare species by the Committee On The Status of Endangered Wildlife In Canada (COSEWIC). A definition of the various categories used by this committee is given in Table 4.2-1 of Volume 3A.

Ivory gulls winter in the drift ice from Davis Strait south to the northern Gulf of St. Lawrence (Godfrey, 1966). Densities of 0.3 birds/km^2 have been recorded during aerial surveys along the edge of the pack ice in Davis Strait in March (MMI, 1979a).

Ivory gulls arrive in northern Baffin Bay and Lancaster Sound in mid May (Johnson *et al.*, 1976; McLaren and Renaud, 1979) and they have entirely deserted southern Davis Strait by late June (MMI, 1979b). Ivory gulls are present in small numbers along the coasts and in offshore waters of eastern Lancaster Sound and Baffin Bay throughout the summer (Johnson *et al.*, 1976; McLaren and Renaud, 1979). Very small numbers are present in Barrow Strait in summer (Alliston *et al.*, 1976).

Juvenile ivory gulls begin to appear in Parry Channel in early September and the colony at Seymour Island (north of Bathurst Island), is abandoned at this time (MacDonald, 1976). Flocks of 100 or more ivory gulls have been recorded at numerous locations in the central and eastern Arctic in September and October (Duvall and Handley, 1946, 1948; Alliston *et al.*, 1976; Finley and Johnston, 1977; McLaren and Renaud, 1979). Several of these concentrations have been observed along glacier fronts on southern Devon Island, an area where increasingly large numbers of ivory gulls are present from mid August until late September (McLaren and Renaud, 1979). In late September and early October numbers increase offshore as fall migration apparently begins. Ivory gulls are not present in southern Davis Strait in early October but they have generally arrived by early November (MMI, 1979b).

2.2.9.5 Black-legged Kittiwake

The black-legged kittiwake has a circumpolar nesting distribution. Along the eastern shipping corridor, black-legged kittiwakes nest colonially on cliffs of Parry Channel, Baffin Bay and Davis Strait (Figures 2.2-2 and 2.2-9). The westernmost colony is on Browne Island, south of western Cornwallis Island. At least 300,000 kittiwakes are estimated to nest along the eastern shipping corridor in North America and Greenland (Brown *et al.*, 1975; Alliston *et al.*, 1976; Nettleship and Gaston, 1978). Kittiwakes from eastern Canada and Greenland winter primarily off Newfoundland and Labrador. Small numbers winter along the pack ice edge in southern Davis Strait (MAL, 1977; Brown, 1979) and off southwest Greenland (Salomonsen, 1950).

Black-legged kittiwakes do not begin to breed until 3 to 4 years of age for females and 4 to 5 years of age for males (Coulson, 1966). Mean life expectancy after first breeding in temperate areas is 5 to 7 years (Coulson and Wooller, 1976).

Spring migration begins in March. Kittiwakes arrive at colonies in south Greenland in late March and in north Greenland in mid May (Salomonsen, 1950). On the west side of Baffin Bay and in eastern Lancaster Sound kittiwakes also arrive in mid to late May (McLaren and Renaud, 1979). Migration is along coasts and ice edges and also on a broad offshore front. In both 1978 and 1979, large flocks were first

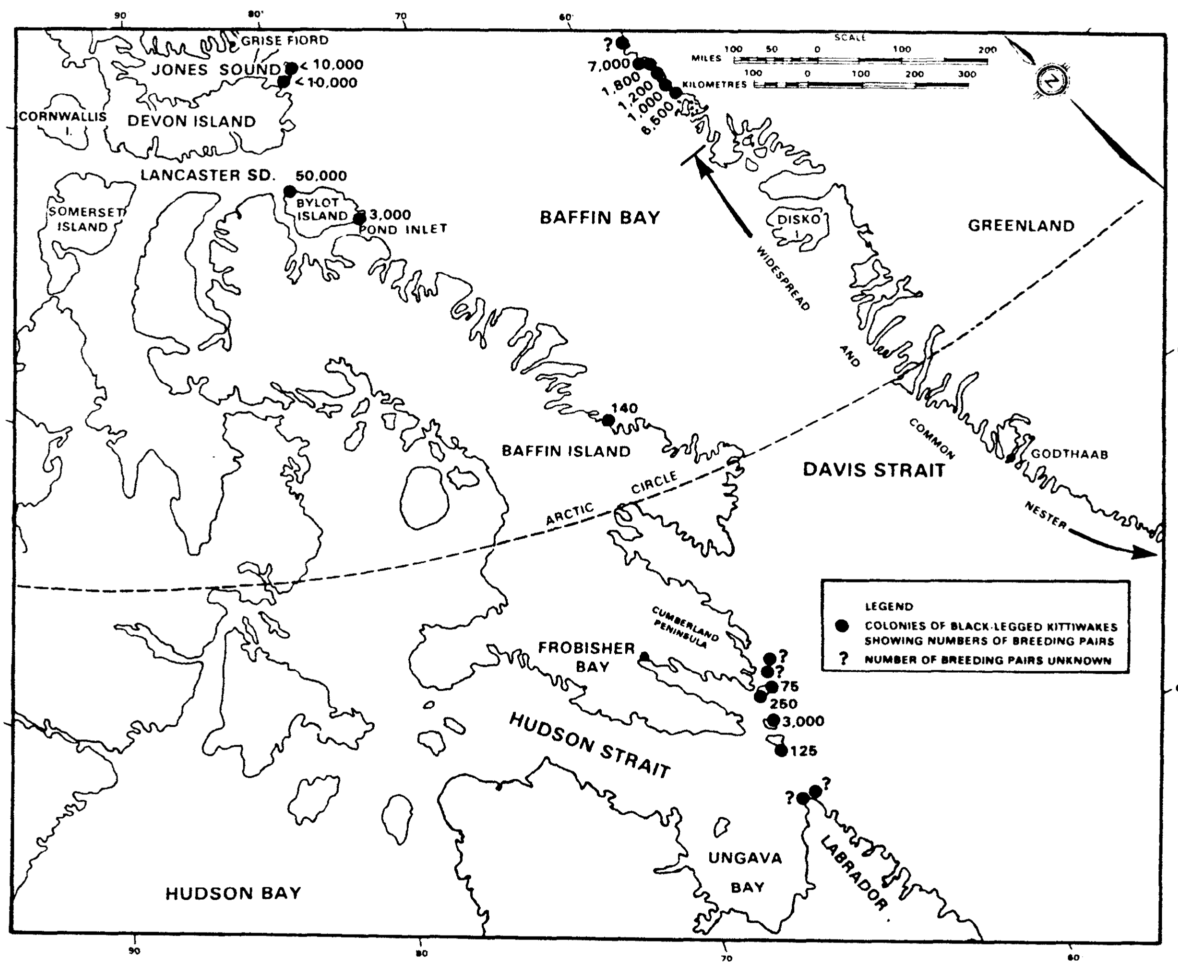


FIGURE 2.2-9 *Black-legged kittiwake nesting colonies and estimated numbers of breeding pairs in Baffin Bay and Davis Strait. Based on Brown et al. (1975). At least 300,000 kittiwakes are estimated to nest along the shipping corridor in North America and Greenland. (Figure 2.2-2 shows colonies in Parry Channel).*

seen near Bylot Island colonies between May 29 and June 2 (McLaren and Renaud, 1979; McLaren, 1980). In 1976, large flocks began arriving at the Prince Leopold Island colony on May 27 (D.N. Nettleship, pers. comm.). However, this timing may be influenced substantially by ice conditions, at least in the eastern Arctic (McLaren and Renaud, 1979).

Migration to breeding areas in the eastern High Arctic continues through June. By mid June, kittiwakes are common along many of the coasts and fast ice edges and in offshore areas of Baffin Bay and Parry Channel and are abundant near nesting colonies (Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). Densities of kittiwakes along coasts of Barrow Strait in June, 1974, when the fast ice edge was west of Somerset Island, averaged 7.3 birds/km^2 (Davis *et al.*, 1974). Recorded densities along coasts of western Baffin Bay averaged about 8 birds/km^2 from mid May to mid August, 1978, but increased steadily from 0.8 birds/km^2 in mid May to 17.8 birds/km^2 in mid July in 1979 (McLaren and Renaud, 1979; McLaren, 1980). In offshore areas, densities are generally low. They peaked at about 1 bird/km^2 in late June, 1978, when over 40,000 kittiwakes were estimated to be offshore in northwest Baffin Bay and eastern Lancaster Sound (McLaren and Renaud, 1979). In 1979, offshore densities in eastern Lancaster Sound increased from May to mid July, peaking at 2.4 birds/km^2 between July 9 to 15 (McLaren, 1980). No surveys were flown after July 15 in 1979.

Black-legged kittiwakes begin egg laying in late June and early July (Plate 2.2-4). During the 27 day incubation period (D.N. Nettleship, pers. comm.), kittiwakes tend to remain near the nesting colonies. Densities in offshore waters during July and August are much lower than in June (Johnson *et al.*, 1976). Hatching begins in mid to late July. The nesting period is about 38 days and fledging begins in the last half of August (D.N. Nettleship, pers. comm.). Most young have left the nest by early September.

During the first half of August, kittiwake distribution is similar to that during July when most kittiwakes are at or near their nesting colonies. In late August, numbers away from colonies increase, particularly along coasts (Nettleship and Gaston, 1978; MMI, 1979b; McLaren and Renaud, 1979). Numbers in coastal areas continue to increase through September. Important areas include northwest Bylot and north Baffin islands (10,000 birds on September 13, 1976; Johnson *et al.*, 1976), southeast Devon Island (25,000 to 40,000 birds on September 15, 1978; McLaren and Renaud, 1979) and southeast Baffin Island (MMI, 1979b). Overall coastal densities in Baffin Bay peaked at about 70 birds/km^2 in late September, 1978 (McLaren and Renaud, 1979). In Davis Strait, peak coastal densities of 19.2 birds/km^2 were observed in late August, 1978 (MMI, 1979a).

Kittiwakes are also fairly common in offshore Baffin Bay and Davis Strait in summer (McLaren and Renaud, 1979; MMI, 1979b). Ship-based observations in September show from 1 to over 100 kittiwakes per 10 minute watch, but most observations range from 1 to 30 birds per watch (Brown *et al.*, 1975). The increase in numbers of kittiwakes observed in late summer may reflect the addition of fledged young or the arrival of immatures from other areas (Coulson, 1966).

In Baffin Bay, numbers of kittiwakes decrease rapidly after late September and most are gone by mid October (McLaren and Renaud, 1979). Kittiwakes leave Greenland in October and November (Salomonsen, 1950) but numbers in southern Davis Strait remain relatively high in October and November (Brown *et al.*, 1975; MMI, 1979a; MMI, 1980).

2.2.9.6 Arctic Tern

Arctic terns nest either colonially or singly, throughout the Arctic (Godfrey, 1966; McLaren and Renaud, 1977; Maltby, 1978). Arctic terns winter in the southern Atlantic and Pacific oceans and do not return to nesting areas until June.

Arctic terns have been recorded as early as June 3 in Davis Strait (MMI, 1979b) and June 6 in Barrow Strait (Alliston *et al.*, 1976) but most do not arrive until the second half of June. Most of the migration is offshore (Alliston *et al.*, 1976; Johnson *et al.*, 1976; McLaren and Renaud, 1979; MMI, 1979b; McLaren, 1980), but by late June or early July terns have moved to coastal waters.

Most Arctic terns nest along coasts or near large inland lakes (Manning and Macpherson, 1961; McLaren and Renaud, 1977). Egg laying begins in late June or early July and the young fledge in mid to late August (Drury, 1960; Hussell and Holroyd, 1974; McLaren and Renaud, 1977).

In August, flocks of Arctic terns are common along the coast of Parry Channel (Alliston *et al.*, 1976; McLaren and Renaud, 1977) but they are rather uncommon along east Baffin Island (McLaren and Renaud, 1979; MMI, 1979b). Although very small numbers of terns may still be present in Davis Strait in October, most have vacated the area by mid September (McLaren and Renaud, 1979; MMI, 1979b).

2.2.10 ALCIDS

Six species of alcids occur along the eastern shipping corridor. Thick-billed murres and black guillemots

PLATE 2.2-4 *Nesting back-legged kittiwakes. At least 300,000 kittiwakes are estimated to nest along the eastern shipping corridor in North America and Greenland. (Courtesy, M. Bradstreet, LGL Ltd.).*

occur throughout Davis Strait, Baffin Bay and eastern Parry Channel. Dovekies nest only in Greenland but very large numbers occur in Lancaster Sound and northwestern Baffin Bay during spring migration. The other three species, common murre, Atlantic puffin and razor-bill are found only in relatively small numbers in western Greenland.

2.2.10.1 Murres

The thick-billed murre (Plate 2.2-5) is essentially circumpolar in its distribution. It breeds at large colonies in the Arctic and boreal zones of the north Atlantic and Pacific, and in the Arctic Ocean. It is abundant in Baffin Bay, Davis Strait and parts of Parry Channel (Table 2.2-1 and 2.2-2). The closely related common murre *(Uria aalge)* has a primarily boreal distribution. Very small numbers are believed to nest at one colony in southwest Greenland (Salomonsen, 1950; Tuck, 1961).

At least 33 thick-billed murre colonies containing an estimated 1.6 million nesting pairs (Figures 2.2-2 and 2.2-10) are located along the eastern shipping corridor (Gaston, 1980). Gaston also estimated that over 4 million murres, including adults and subadults but excluding young-of-the-year, are present in the area during the breeding season (Plate 2.2-6).

Although murres are abundant they are subject to several impacts from man: egg collecting (Brody, 1976; Finley and Miller, 1980), hunting of adults and young (Salomonsen, 1970; Brody, 1976; Evans and Waterston, 1976; Kapel and Petersen, 1979), drowning due to entanglement in fishing gear (Tull *et al.*, 1972; Christensen and Lear, 1977; Evans and Waterston, 1976; King *et al.*, 1979), and, particularly in the southern portions of their range, exposure to marine oil spills. Murre populations in general are believed to be declining due primarily to impacts from human activities (Tull *et al.*, 1972; Evans and Waterston, 1976). This situation is worsened by the low reproductive potential of murres, which limits their ability to recover from losses.

The age of first breeding of thick-billed murres is not known but is 4 to 5 years in the closely related common murre. Productivity at an Arctic thick-billed murre colony has been calculated at 0.7 chicks/pair/year, and survival of chicks from hatch to the end of the first winter is estimated at 30%. The survival rate of thick-billed murres to breeding age at Bylot Island has been calculated at 34.5% and the mean life expectancy after first breeding is 11 years. Clutch size is one egg, however, replacement clutches are often laid if the first clutch is destroyed (Tuck, 1961; Birkhead, 1974; Mead, 1974; Birkhead and

PLATE 2.2-5 *The thick-billed murre, such as the one shown in this photo, is abundant in Baffin Bay, Davis Strait and eastern Parry Channel. (Courtesy, M. Bradstreet, LGL Ltd.).*

Hudson, 1977; Gaston and Nettleship, in press).

Large numbers of murres (more than 1 million birds) winter in offshore waters along the southwest coast of Greenland, and small numbers winter among the pack ice in southern Davis Strait (Salomonsen, 1950; Tuck, 1961; MAL, 1977; MMI, 1979b). Wintering birds arrive in these areas between November and December and usually leave again in March. Along the southwest Greenland coast, large migrating flocks are present in March and murres are at colonies in central west Greenland (71°N) by mid April (Salomonsen, 1950). The first migrants usually reach Lancaster Sound and Baffin Bay in early May (McLaren and Renaud, 1979), and have been recorded at the colony on Prince Leopold Island in Parry Channel on May 5 (D.N. Nettleship, pers. comm.). However, the major migration into northwest Baffin Bay and eastern Lancaster Sound does not occur until about May 22 to 24 (Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). During most of May, murres are widely distributed offshore. For example, an estimated 550,000 were in western Baffin Bay in late May, 1979 (McLaren, 1980). By late May, however, large numbers also appear along coasts, fast ice edges and in waters at the base of nesting colonies.

From late May until early July, murres are common and widely distributed throughout eastern Barrow Strait, Lancaster Sound and Baffin Bay. During this period, varying numbers are present at and near nesting colonies as prospective nesters arrive and then depart prior to nesting. However, murres are present regularly at other locations in the area, especially along fast ice edges, which are a preferred habitat (Davis *et al.*, 1974; Bradstreet and Finley, 1977; Bradstreet, 1979b, 1980; McLaren, 1980). Such locations include the ice edges across Parry Channel (Alliston *et al.*, 1976; McLaren and Renaud, 1979) and across the entrances of Jones Sound and Pond Inlet (McLaren and Renaud, 1979; McLaren, 1980). For example, McLaren and Renaud (1979) reported 132.5 murres/km^2 along the Lancaster Sound ice edge on May 29, 1978, and McLaren (1980) reported 155.1/km^2 in the same area on June 30, 1979.

Thick-billed murres normally begin nesting in late June and early July and young hatch in early August (D.N. Nettleship, pers. comm.). In 1978, however, murres began laying at colonies on northwest Bylot Island and Prince Leopold Island about three weeks later than normal. The median dates of laying in 1978 were July 18 and July 24, at Bylot and Prince Leopold islands, respectively (D.N. Nettleship, pers. comm.; LGL Ltd., unpubl. data).

During incubation, nesting murres tend to remain near their colony, either at the base of the nesting cliff or along nearby ice edges. However, some incubating murres fly up to 175 km from the colony to forage (M.S.W. Bradstreet, pers. comm.) and densities are relatively high in offshore areas. Average densities of 2 to 6 murres/km^2 have been recorded in offshore waters of Baffin Bay from mid May to mid August (McLaren and Renaud, 1979; McLaren, 1980). In southern Davis Strait offshore densities average about 0.2 to 1.0 birds/km^2 during this period (MMI, 1979b).

Nesting murres tend to remain close to their colonies during the chick-rearing period. Densities decrease with distance from the colonies. Murres are seen regularly in offshore areas of Lancaster Sound, Baffin Bay and Davis Strait and there is some evidence that murres distant from colonies are failed breeders or subadults (LGL Ltd., unpubl. data). Few murres are present in coastal areas away from colony sites.

The pre-fledging period of thick-billed murre chicks lasts 5 to 6 weeks. However, chicks leave the nesting cliffs at 18 to 25 days old (Tuck, 1961) and begin a swimming migration, usually accompanied by an adult male (M.S.W. Bradstreet, pers. comm.). Adults

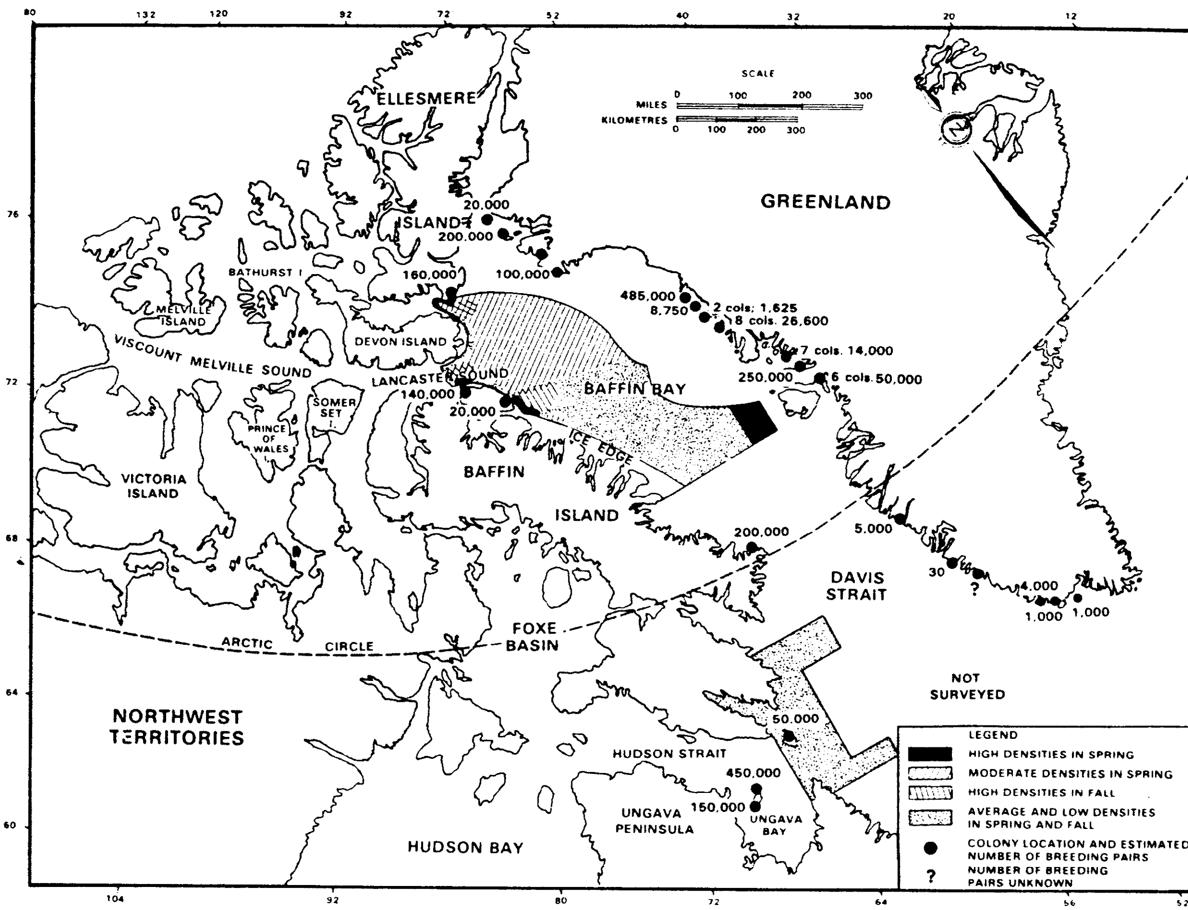


FIGURE 2.2-10 *Thick-billed murre distribution in Baffin Bay and Davis Strait from sources cited in text. (See Figure 2.2-2 for colony locations in Parry Channel). At least 33 thick-billed murre colonies, containing an estimated 1.6 million nesting pairs, are located along the shipping corridor.*

undergo a wing moult at about this time and are also flightless for two to three weeks (Tuck, 1961).

Young murres begin to leave the nesting cliff in late August and most have left the colonies by the beginning of September. In 1978, however, eggs of murres that nested at colonies in and west of Lancaster Sound hatched about August 20 and the young did not leave the cliff until early September (LGL Ltd., unpubl. data; D.N. Nettleship, pers. comm.).

Nettleship (1977) noted the first chicks leaving the Prince Leopold Island colony in Parry Channel on August 12 in 1975 and young were present at sea east of that colony on August 17 to 19, 1976 (Nettleship and Gaston, 1978). Tuck (1961) observed chicks leaving Cape Hay, northwest Bylot Island, on August 15 in 1957. Salomonsen (1950) noted that chicks at Greenland colonies fledged most frequently in the latter half of August. In 1978, chicks were not seen at sea in Baffin Bay until late August and early September, reflecting the retarded date of nest initiation in that year (McLaren and Renaud, 1979). Adult/-chick pairs seen in Baffin Bay northeast of Coburg Island in 1978 were presumably swimming south from colonies in northwest Greenland. Their presence indicates that many birds from those colonies migrate down the west side of Baffin Bay where currents are more favourable. Some adult/chick pairs from colonies on northwest Bylot Island and Prince Leopold Island move east and south along the north and east sides of Bylot Island while others move south through Navy Board Inlet.

Southward migration appears to be on a broad front across and down Baffin Bay and Davis Strait, with most adult/chick pairs travelling alone. Migration routes are not well understood. Murres banded at the Cape Hay colony on northern Bylot Island have been recovered during migration, but no murres have been banded at other High Arctic colonies. Some murres from the northern Canadian colonies may cross Baffin Bay and join birds from northwest Greenland colonies to migrate south along the west Greenland coast. Other Canadian Arctic birds migrate down the east coast of Baffin Island and then either cross Davis Strait to southwest Greenland or continue directly

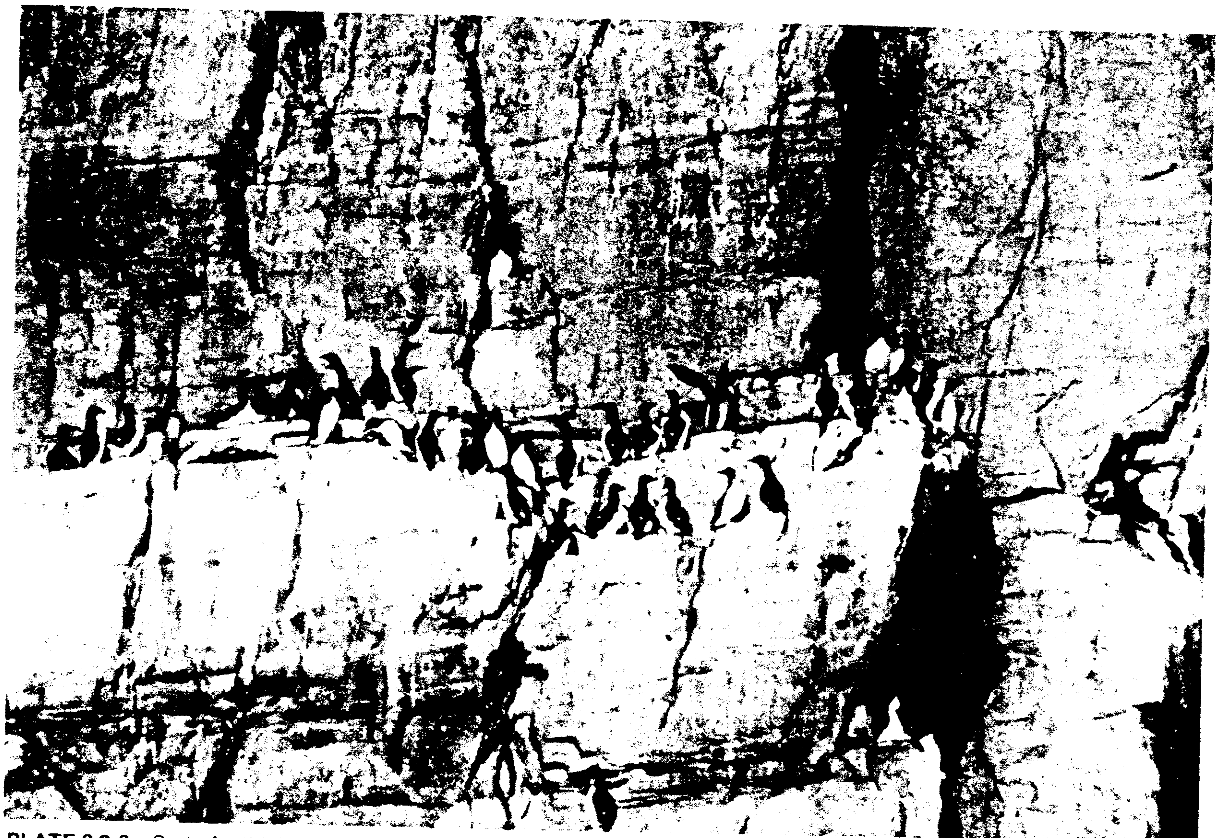


PLATE 2.2-6 *Part of a thick-billed murre colony on the cliff face of a small island located in Hudson Strait. (Courtesy, G. Greene, ESL Ltd.).*

south to the Labrador coast. Many of the murres arriving off southwest Greenland apparently move farther south to waters off Newfoundland from November through January. Murres from colonies in Hudson Strait may also migrate to southwest Greenland (cf. Brown *et al.,* 1975) but most are believed to move directly down the Labrador coast to Newfoundland waters (Gaston, 1980).

Few murres remain in northern Baffin Bay by the end of September (Brown *et al.,* 1975; McLaren and Renaud, 1979) but they are fairly common in Davis Strait throughout October. MMI (1979a) recorded 0.6 murres/km^2 during an aerial survey in offshore waters in early October, and Brown *et al.* (1975) reported an average of about 1 to 3 birds per 10 minute sea watch in October. By November most have arrived at wintering areas off southwest Greenland and Newfoundland or are migrating across south Davis Strait and the Labrador Sea.

2.2.10.2 Dovekie

The dovekie is one of the smallest and may be the most numerous alcid species (Norderhaug, 1970). Dovekies generally nest in large colonies numbering into the hundreds of thousands near coasts in High Arctic regions. Dovekies do not nest in Canada but there are enormous nesting colonies along the northwest coast of Greenland, north of 76°N (Figure 2.2-11). Freuchen and Salomonsen (1958) suggested the population may total 30 million individuals. Much smaller numbers nest at several colonies south from 74°N to the southern tip of Greenland. Population parameters (e.g. age at first breeding, mortality rates) and rate of nesting success for dovekies are unknown. Laying of the single egg (Bateson, 1961) occurs about mid June (Salomonsen, 1967).

Dovekies winter in areas of loose pack ice south from southern Greenland to Atlantic Canada. Salomonsen

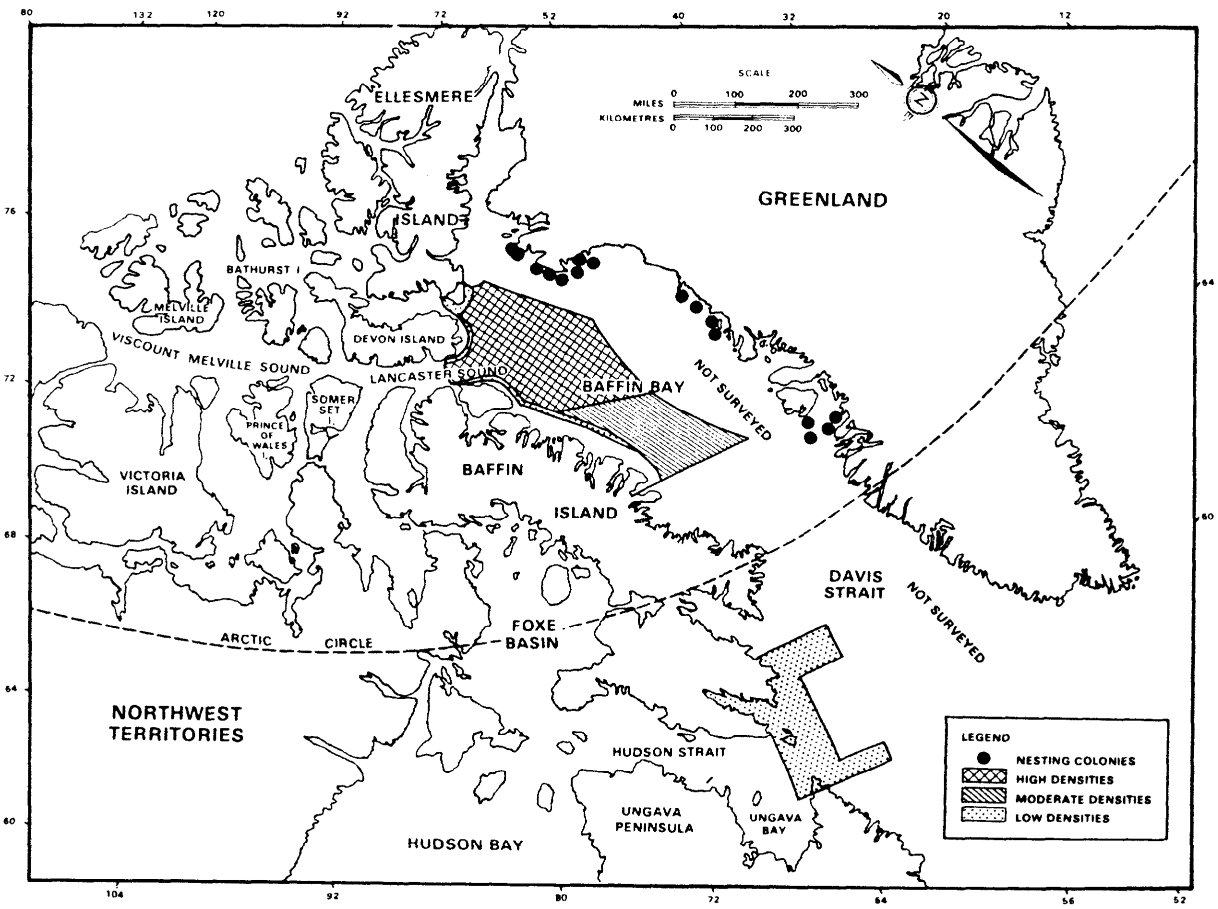


FIGURE 2.2-11 *Doveky colony locations and their distribution in May in Baffin Bay and Davis Strait from sources cited in text. Dovekies do not nest in Canada but there are enormous colonies along the northwest coast of Greenland.*

(1950) reported large numbers off southern Greenland in winter, and dovekies were commonly seen along the pack ice edge in Davis Strait in February 1977, sometimes in concentrations of up to 25,000 birds (cf. MAL, 1977).

Migration from wintering areas to nesting colonies apparently begins in April. Early migrants arrive at southern Greenland colonies in late April and at the northern colonies in early May (Bruemmer, 1978) but most arrive somewhat later (Salomonsen, 1950).

Migration routes of dovekies into and through Davis Strait are poorly known. They were rarely seen in western Davis Strait during surveys in April and May, 1978 (MMI, 1979b). In central and southern Baffin Bay, densities are also low, although in 1979 flocks of several hundred birds were seen migrating due north over the middle of Baffin Bay toward their nesting colonies (McLaren, 1980). Surveys conducted in 1976, 1978, and 1979 showed that a major spring migration route of dovekies passes into and through the eastern Lancaster Sound-western Baffin Bay area (Figure 2.2-11) (Johnson *et al.*, 1976; McLaren and Renaud, 1979; McLaren, 1980). Migrants were first recorded during the second week of May in each of those years. The peak of the influx occurs in mid May and involves many millions of birds. On May 14, 1978, about 14 million were estimated to be in Baffin Bay north of 71°30'N and west of 64°W. On May 23 to 24, 1976, and on May 17, 1978, an estimated 1.3 million dovekies were in eastern Lancaster Sound. In 1979, estimates of numbers present on various dates were much lower; about 4.3 million birds in western Baffin Bay on May 17 to 21 and 1.9 million in northwest Baffin Bay on May 24 to 26. In 1979, unlike 1976 and 1978, only small numbers entered Lancaster Sound with a peak estimate of 33,000 dovekies on May 24 to 26. During the spring influx, dovekies occur in flocks of up to 25,000 birds.

Year to year variation in the distribution of dovekies in eastern Lancaster Sound and Baffin Bay during May is likely a result of ice conditions. During their passage north in May, dovekies remain predominantly offshore. Peak densities are found in moderate to heavy pack ice. The species tends to avoid ice free areas (McLaren, 1980), a preference likely responsible for the virtual absence of dovekies in eastern Lancaster Sound in May, 1979 when little ice was present.

Most dovekies leave eastern Lancaster Sound and western Baffin Bay in late May. Numbers in eastern Lancaster Sound in 1976 decreased from 1.3 million birds on May 23 to 24, to almost nil on May 30 to 31. Estimated numbers in northwest Baffin Bay in 1978 decreased from more than 2 million birds on May 18, to about 250,000 birds on May 30 (Johnson *et al.*, 1976; McLaren and Renaud, 1979).

Salomonsen (1950) noted that, dovekies move out to the open sea after arriving at their colonies, returning to nest in June. It is likely that large numbers are present in waters near colonies in late May.

Densities recorded in the northernmost surveyed parts of Baffin Bay, closest to the main colonies, in June 1978 and 1979, were much higher than in other areas (McLaren and Renaud, 1979; McLaren, 1980). However, Brown (1976) reported dovekies foraging in Baffin Bay 100 km from the nearest colonies. Relatively small numbers of dovekies occur in eastern Lancaster Sound at this time, probably because of the distance from the colonies in Greenland and the generally ice free conditions in late June. There was, however, an unusual occurrence of 12,000 dovekies along the fast ice edge across Lancaster Sound on June 19, 1979 (McLaren, 1980). Dovekies are also common in southern Baffin Bay in June (MMI, 1979b), although numbers and densities do not approach those in northern areas. Individuals in the southern areas are likely to be subadults spending the summer foraging in the pack ice. This area is well out of the foraging range of dovekies from colonies in northwest Greenland.

The peak of hatching at the Greenland colonies is about July 15 to 20 and chick-rearing extends to mid August (Roby *et al.*, 1978; Evans, 1981). During this period, dovekies tend to remain close to their Greenland colonies. Consequently, few are seen in Lancaster Sound or western Baffin Bay. Those in Baffin Bay in early August may be failed adults or pre-breeders that have started migrating.

Virtually all dovekies have abandoned their colony sites in northwest Greenland by the beginning of September. Migration of young and adults is primarily down the west and central parts of Baffin Bay (Brown *et al.*, 1975; Salomonsen, 1979). Data from ship-based studies in Baffin Bay in the last half of August indicate that many more dovekies are in the western half of the bay, where pack ice persists through much of the summer, than in the eastern half. Small numbers of migrants also enter Lancaster Sound. However, few migrants have reached Davis Strait by the end of August. In September, dovekies are widely distributed throughout much of Baffin Bay and Lancaster Sound although numbers in the northern portions decrease as the month progresses (Brown *et al.*, 1975; Johnson *et al.*, 1976; McLaren and Renaud, 1979). By late September, dovekies are migrating through western Davis Strait (MMI, 1979b). Small numbers have reached the Labrador Sea by the end of September.

During October, dovekies are widely distributed throughout most of the study area. Numbers in northern Baffin Bay are low (Brown *et al.*, 1975; McLaren and Renaud, 1979). The main passage through Davis Strait is reported to be in early October (MMI, 1979b). Most are at wintering areas by December.

2.2.10.3 Black Guillemot

The breeding distribution of the black guillemot (Plate 2.2-7) is almost circumpolar. The species

PLATE 2.2-7 *The black guillemot, such as the one shown here, nests in scattered pairs and colonies along rocky coastlines throughout much of the eastern Arctic and Greenland. (Courtesy, M. Bradstreet, LGL Ltd.).*

breeds in large numbers in the Arctic and boreal regions of both the New and Old Worlds. It is absent only from the western Arctic Islands.

Guillemots winter as far north as water permits. Renaud and Bradstreet (1980) estimated that 5,000 to 10,000 guillemots winter in cracks and polynyas in the Canadian High Arctic, offshore Baffin Bay and northwest Greenland. Salomonsen (1950) believed that guillemots remaining in the far north in winter were young-of-the-year. Very small numbers winter along southern Baffin Island (MAL, 1977) and large numbers winter along the southwest coast of Greenland (Salomonsen, 1950).

Black guillemots feed largely on benthic and pelagic organisms, mostly fish obtained by diving (Bradstreet, 1979a, 1980). Foraging by this species during the open water season is generally confined to the littoral zone (Preston, 1968) although migrating guillemots and those nesting in the High Arctic are known to forage both along fast ice edges and offshore among the pack ice (Bradstreet, 1977, 1979a).

The minimum annual survival rate of adult guillemots in a boreal population was 80% (Preston, 1968) and, in an Arctic population, breeding first occurred in the second or, more commonly, third year (G. Divoky, pers. comm.). No estimates for survival rates of immature birds are available. Clutch size is generally two eggs, with one egg clutches being common and three egg clutches rare (Preston, 1968; Cairns, 1980). In boreal populations, replacement clutches are often laid if the first clutch is destroyed (Winn, 1950).

Although guillemots are essentially coastal birds during the breeding season (MAL, 1978; MMI, 1979a, b; McLaren, 1980). McLaren and Renaud (1979) and McLaren (1980) found them to be relatively abundant (0.6 birds/km^2) during spring migration in offshore parts of northwest Baffin Bay where pack ice was present. Salomonsen (1950) suggested that guillemots occur offshore only among ice, although they have been observed in central Baffin Bay in late summer (Brown *et al.*, 1975) when there is usually no ice.

Guillemots begin to move north from wintering areas in southwest Greenland as soon as open water is available, usually in late April, arriving at northern Greenland nesting areas by mid May (Salomonsen, 1950). The major influx into northwest Baffin Bay and Lancaster Sound is in mid May and many travel offshore (McLaren and Renaud, 1979; McLaren, 1980). From then through June, guillemots are commonly seen both along coasts and ice edges and offshore from Barrow Strait east. McLaren and Renaud (1979) recorded over 5 birds/km^2 along coasts and ice edges of Baffin Bay in mid May, 1978, and McLaren (1980) reported similar densities for the same period in 1979. Densities along the coasts of Lancaster Sound in June averaged 3.4 birds/km^2 in 1976 (S.R. Johnson in Bradstreet, 1979b). June densities along coasts and ice edges in Barrow Strait ranged from 3.2 to 13.8 birds/km^2 in 1974 to 1975, and 0.7 birds/km^2 were recorded offshore in 1974 (Bradstreet, 1979b).

The black guillemot nests in scattered pairs and in colonies along rocky coastlines throughout much of the eastern Arctic and Greenland (Figure 2.2-2). Although abundant, the species is difficult to census and few estimates of numbers nesting are available. Renaud and Bradstreet (1980) estimated that perhaps 50,000 to 100,000 guillemots summer in the eastern Canadian High Arctic and northwest Greenland.

Black guillemots nest in late June and early July. The incubation period is 27 to 33 days (Godfrey, 1966) and young hatch in late July. In some years, however, nesting may be delayed by up to three weeks (D.N. Nettleship, pers. comm.). During the incubation period, nesting guillemots tend to remain within a few kilometres of their nesting areas, often along nearby fast ice edges, and numbers offshore are low (Johnson *et al.*, 1976; Bradstreet, 1979b; McLaren and Renaud, 1979). This distribution persists through the chick-rearing period. Nevertheless, concentrations of several hundred individuals do occur. Alliston *et al.* (1976) observed a concentration of over 450 guillemots along southwest Devon Island on August 21, 1975. Coastal densities averaged 2.8 birds/km^2 in Barrow Strait in August 1975 (Alliston *et al.*, 1976) and densities averaged about 1.3 birds/km^2 along eastern Devon Island in late July and August, 1978. Densities along most other coasts of northwest Baffin Bay and Lancaster Sound, however, were lower (usually less than 1 bird/km^2) in August 1978 (McLaren and Renaud, 1979).

Chick-rearing lasts about three to four weeks in Arctic areas and most young fledge by the end of August (Nettleship, 1977). The young are not capable of sustained flight at nest-leaving and are not accompanied by an adult (Cairns, 1978).

During late August and September, guillemots are widely distributed in low densities throughout most coastal and offshore waters. MAL (1978) and MMI (1979b) noted an increase along southern Baffin Island in August, likely due to the fledging of local young. Migration from northern areas does not take place until September or later (Salomonsen, 1950; McLaren and Renaud, 1979). In 1979, an increase in numbers of guillemots in eastern Lancaster Sound was detected in late September (Johnson *et al.*, 1976), perhaps reflecting a passage through the Sound from nesting areas in the central Arctic.

Guillemots probably remain in east Parry Channel and Baffin Bay through October, and move south only when forced to by freeze-up. They were still common along the east coast of Baffin Island in mid October, 1979 (LGL Ltd., unpubl. data). There is a gradual southward migration of guillemots along the west coast of Greenland from October to December (Salomonsen, 1950).

2.2.10.4 Razorbill

Razorbills nest along the west coast of Greenland from 75°N south to about 61°N, and are most common between 64°N and 68°N. They are colonial nesters but most colonies consist of, at most, 600 to 700 pairs (Salomonsen, 1950). There are no estimates of the size of the breeding population.

Razorbills arrive at Greenland colonies from wintering areas in the north Atlantic Ocean in mid April (Salomonsen, 1950) but migration routes are unknown. Small numbers may winter off southwest Greenland. Egg-laying is in mid June, and young fledge in August. During the nesting season, birds remain close to the coast and are rarely seen on the fishing banks offshore in Davis Strait. After fledging the young swim with the flightless (moulting) adults to offshore feeding areas where they remain until the end of September. Migration south is presumed to follow the Labrador current and may occur in association with migrating thick-billed murres (Salomonsen, 1950). Young, non-breeding razorbills also move toward breeding areas in spring and are present near nesting colonies throughout the summer.

2.2.10.5 Atlantic Puffin

The Atlantic puffin nests at 31 or more colonies along the west Greenland coast north to the Thule District. No estimates of the breeding population are available, but few colonies contain more than 100 pairs (Brown *et al.*, 1975) and the population is small in comparison to numbers nesting in Atlantic Canada (Brown *et al.*, 1975; Lock, 1979; Chapdelaine, 1980).

Small numbers of puffins winter in Davis Strait off southwest Greenland but most winter farther south. Breeding puffins arrive at their nesting colonies in mid May; the immature birds arrive about 3 to 5 weeks later (Salomonsen, 1950; Nettleship, 1972). Migration routes are unknown, but Salomonsen (1950) states that, while common offshore in the Atlantic Ocean, puffins are rarely seen in the pack ice in Davis Strait. Presumably birds follow the Greenland coast northward over open water.

Egg-laying occurs in early to mid June; a clutch consists of one egg only. Hatching occurs about mid July and young leave the nest in late August or early September. After fledging, young move out to sea and slowly start to move south to wintering areas. Puffins have been recorded in offshore Davis Strait in August and September (Brown *et al.*, 1975). By October most puffins have left Davis Strait.

2.3 FISH

Although the Northwest Passage and Davis Strait encompass a large geographic area, it harbours relatively few fish species, compared to regions of similar size in more southern latitudes. While 300 species of marine fish occur along the southeastern and southwestern coasts of Canada (Leim and Scott, 1966; Hart, 1973), only about 100 marine species are known from the Northwest Passage, and Davis Strait (Table 2.3-1).

In Davis Strait, and to a lesser extent Baffin Bay, a number of temperate North Atlantic marine fish are found (e.g. Atlantic cod, Atlantic salmon, redfish). In

TABLE 2.3-1

FISH SPECIES KNOWN TO OCCUR IN THE NORTHWEST PASSAGE AND NORTHWEST BAFFIN BAY

Anadromous species are indicated by an asterisk.

Group and Species	Common Names	Northwest Passage	Davis Strait
Hagfishes:			
Myxine glutinosa	Atlantic hagfish		X
Lampreys:*			
Petromyzon marinus	sea lamprey		X
Sharks:			
Centroscyllium fabricii	black dogfish		X
Somniosus microcephalus	Greenland shark	X	X
Squalus acanthias	spiny dogfish		X
Rays:			
Raja fyllae	round skate		X
Raja hyperborea	darkbelly skate	X	
Raja lintea	white skate		X
Raja radiata	thorny skate		X
Raja spinicauda	spinytail skate		X
Herring:			
Clupea harengus harengus	Atlantic herring		X
Salmonids:*			
Salmo salar	Atlantic salmon		X
Salvelinus alpinus	Arctic char	X	X
Stendodus leucichthys	inconnu		X
Smelts:			
Mallotus villosus	capelin		X
Osmerus eperlanus*	boreal smelt (rainbow smelt)	X	
Argentines:			
Nansenia groenlandica	large-eyed argentine		X
Blacksmelts:			
Bathylagus euryops	goitre blacksmelt		X
Silver hatchetfishes:			
Argyropelecus aculeatus	Atlantic silver hatchetfish		X
Eels:			
Anguilla rostrata	American eel		X
Histiobranchus infernalis	—		X
Notacanthus nasus	spiny eel		X
Synaphobranchus kaupi	Gray's cutthroat eel		X
Gulpers:			
Saccopharynx ampullaceus	—		X
Barracudina:			
Paralepis coregoniodes borealis	—		X
Paralepis risso kroyeri	white barracudina		X
Lanternfishes:			
Lampanyctus crocodilus	jewel lanternfish		X
Myctophum arcticum	—		X
Myctophum glacialis	northern lanternfish		X

(continued)

Group and Species	Common Names	Northwest Passage	Davis Strait
Lancetfishes:			
Alepisaurus ferox	longnose lancetfish		X
Grenadiers:			
Coryphaenoides rupestris	rock grenadier	X	X
Macrourus berglax	roughhead grenadier		X
Macrourus goodei	—		X
Sticklebacks:			
Gasterosteus aculeatus	threespine stickleback		X
Pungitius pungitius	ninespine stickleback	X	
Cods:			
Arctogadus glacialis	polar cod	X	
Boreogadus saida	Arctic cod	X	X
Brosme brosme	cusk		X
Gadus morhua	Atlantic cod		X
Gadus ogac	Greenland cod	X	X
Gaidropsarus argentatus	silver rockling		X
Gaidropsarus ensis	threebeard rockling		X
Gaidropsarus septentrionalis	fivebeard rockling		X
Melanogrammus aeglefinus	haddock		X
Microgadus tomcod	Atlantic tomcod		X
Molva molva	European ling		X
Pollachius virens	pollock		X
Ribbonfishes:			
Trachypterus arcticus	dealfish	X	X
Rockfishes:			
Sebastes marinus	Atlantic redfish	X	X
Sculpins:			
Artediellus scaber	rough hookear sculpin	X	
Artediellus uncinatus	hookear sculpin		X
Cottunculus microps	polar sculpin		X
Cottunculus thompsoni	polar sculpin		X
Gymnocanthus tricuspis	Arctic staghorn sculpin	X	X
Icelus bicornis	twohorn sculpin	X	X
Icelus spatula	spatulate sculpin	X	X
Myoxocephalus quadricornis	fourhorn sculpin	X	X
Myoxocephalus scorpioides	Arctic sculpin	X	X
Myoxocephalus scorpius	shorthorn sculpin	X	X
Triglops pingeli	ribbed sculpin	X	X
Poachers and alligatorfishes:			
Aspidophoroides monopterygius	alligatorfish		X
Aspidophoroides olriki	Arctic alligatorfish		X
Leptagonus decagonus	Atlantic sea poacher	X	X
Lumpfishes and seasnails:			
Careproctus reinhardi	sea tadpole		X
Cyclopteropsis jordani	smooth lumpfish	X	
Cyclopterus lumpus	lumpfish		X
Eumicrotremus derjugini	leatherfin lumpsucker	X	X
Eumicrotremus spinosus	Atlantic spiny lumpsucker	X	X
Liparis gibbus[2]	dusky seasnail		X
Liparis hershelinus	bartail seasnail	X	
Liparis fabricii[2]	gelatinous seasnail	X	X
Liparis laptevi	Laptev seasnail	X	

(Table 2.3-1 continued)

Group and Species	Common Names	Northwest Passage	Davis Strait
Liparis liparis	striped seasnail		X
Liparis major	—		X
Liparis tunicatus	Greenland seasnail	X	X
Sand lances:			
Ammodytes dubius	northern sand lance		X
Gunnels:			
Pholis fasciata	banded gunnel		X
Pholis gunnellus	rock gunnel		X
Pricklebacks:			
Eumesogrammus praeciscus	fourline snakeblenny		X
Lumpenus fabricii	slender eelblenny		X
Lumpenus lumpretaeformis	snake-blenny		X
Lumpenus maculatus	shanny		X
Lumpenus medius	stout eelblenny		X
Stichaeus punctatus	Arctic shanny		X
Wolffishes:			
Anarhicas denticulatus	northern wolffish		X
Anarhicas lupus	Atlantic wolffish		X
Anarhicas minor	spotted wolffish		X
Eelpouts:			
Gymnelis retrodorsalis	tonkopeni gimnelis		X
Gymnelis viridis	fish doctor	X	X
Lycenchelys ingolfianus	wolf eel		X
Lycodes esmarki	Esmark's eelpout		X
Lycodes mucosus	saddled eelpout	X	X
Lycodes polaris	polar eelpout	X	
Lycodes raridens	—		X
Lycodes reticulatus	Arctic eelpout		X
Anglerfishes:			
Ceratias holbolli	deepsea angler		X
Himantolophus groenlandicus	Atlantic football fish		X
Oneirodes escherichti	bulbous dreamer		X
Bythites fuscus	—		X
Flatfishes:			
Glyptocephalus cynoglossus	witch flounder		X
Hippoglossoides platessoides	American plaice		X
Hippoglossus hippoglossus	Atlantic halibut		X
Reinhardtius hippoglossoides	Greenland halibut	X	X

[1] Scientific and common names are from Legendre et al. (1975) and Leim and Scott (1966).

[2] Reported as L. *cyclostigma* and *L. koefoedi* by Sekerak et al. (1979). Differences are due to recent changes in scientific nomenclature.

Sources:

Green and Steele (1975); Turnbull (1974); Sekerak et al. (1976b); Alverson and Wilimovsky (1966); Thomson et al. (1978); Buchanan et al. (1977); Quast (1972, 1974); Hildebrand (1948) and Frost et al. (1978).

(Table 2.3-1 continued)

general, these species occur in greater abundance and in more northern locations along the west coast of Greenland than along the east coast of Baffin Island. This is due primarily to the relatively warm West Greenland current that sweeps northward along the Greenland coast and extends the northern range of temperate or boreal species of fish in that region (Jensen, 1939; Dunbar, 1946; Dunbar and Thomson, 1979). The current is variable in strength and northward penetration, which varies the abundance of temperate fish in the area. On the other hand, the cold Baffin current flowing southward along Baffin Island, has a lower abundance of fish and fewer North Atlantic species.

In contrast to the western Arctic, few anadromous fish species are found in High Arctic or eastern Arctic locations. Whitefish, ciscoes, and smelt which are abundant in some nearshore regions of the Beaufort and Chukchi seas, are absent in the more easterly areas. The Arctic char is the only relatively abundant anadromous fish in the study area and even this species is scarce in the Northwest Passage. The only other anadromous species present is the Atlantic salmon, which occurs only in Davis Strait, primarily along the Greenland coast.

The Arctic cod *(Boreogadus saida)* appears to be the most important of the marine fish inhabiting the study area; it occurs over the entire region. Although it has a rather limited direct value to man (near some settlements it is fished for recreation and sometimes for food) it is of major importance in Arctic food chains. Recent studies indicate that it is a major food item for white whales, narwhals, ringed seals, harp seals and a number of species of seabirds (Bradstreet, 1976, 1977, 1980 a,b; Bradstreet and Cross, 1980; Divoky, 1976, 1978; Finley and Johnston, 1977; Finley and Gibb, in press; Frost *et al.*, 1978; Lowry *et al.*, 1978; Davis *et al.*, 1980). For a more detailed description of Arctic marine food webs, the reader is referred to Volume 3A, Section 3.1 of the Environmental Impact Statement.

The Arctic char and Arctic cod are discussed in some detail since they are the most widely distributed and important species. This is followed by a more general account of the use, by fish, of marine habitats in the Northwest Passage, Baffin Bay and Davis Strait.

2.3.1 ARCTIC CHAR

Because of its importance as a food and sport fish, the Arctic char *(Salvelinus alpinus)* is relatively well known in the area. Two forms of Arctic char exist. Resident char remain in fresh water throughout their lives and do not grow to a large size. Since they do not enter the marine environment, they are not discussed in this report. Anadromous char, which migrate to marine waters in early summer, feed in coastal waters and return to their natal rivers and lakes in early fall are the subject of this section.

The diet of char in marine waters consists primarily of nearshore epibenthic invertebrates and, to a lesser degree, small fish and large zooplankton. Studies in the High Arctic (Sekerak and Graves, 1975; Sekerak *et al.*, 1976a) and in the large bays off southeast Baffin Island (Grainger, 1953; Moore and Moore, 1974) all support this conclusion.

While the food species vary somewhat in different regions, mysids and amphipods are nearly always of major importance. Due to the abundant and accessible food supply in nearshore marine waters, anadromous char grow to a large size and weights of 5 to 7 kg are common, especially in the eastern Arctic. However, growth is slow and large char are generally 15 to 25 years old. Anadromous char do not generally mature until they are about ten years old, and mature fish probably spawn only once every two or three years (Grainger, 1953; Sekerak and Graves, 1975; Craig and McCart, 1976; Johnson 1980). These characteristics make populations of Arctic char highly vulnerable to over-fishing; once populations are reduced, they recover slowly.

While at sea, char in the eastern Arctic are not normally found more than about 40 km away from their rivers (Moore, 1975). However, some migrations of over 100 km have been reported (Johnson, 1980). Their distribution is further restricted to the warmer and frequently less saline shallow waters close to shorelines (Griffiths *et al.*, 1975; Moore, 1975; Sekerak *et al.*, 1976a; Craig and Haldorson, 1981). Thus, the marine distribution of char can be visualized as a relatively narrow band that extends in both directions along the shoreline from the estuary of each natal river.

Anadromous Arctic char are virtually unknown in the Northwest Passage. They do occur in the Pond Inlet-Eclipse Sound area (Figure 2.3-1) and become progressively more common south along the eastern coast of Baffin Island. Distributions of Arctic char along Baffin Island are illustrated in Figure 2.3-2. Residents of communities in this region participate in active fisheries for Arctic char and sometimes travel considerable distances to traditional fishing areas.

Harvest statistics for Arctic char are only fragmentary and are unavailable from most locations. In Pond Inlet the estimated catch was 4,700 char in 1979 and in the same year about 840 char were taken in Grise Fiord (Finley and Miller, 1980). Most of the char are used for domestic consumption.

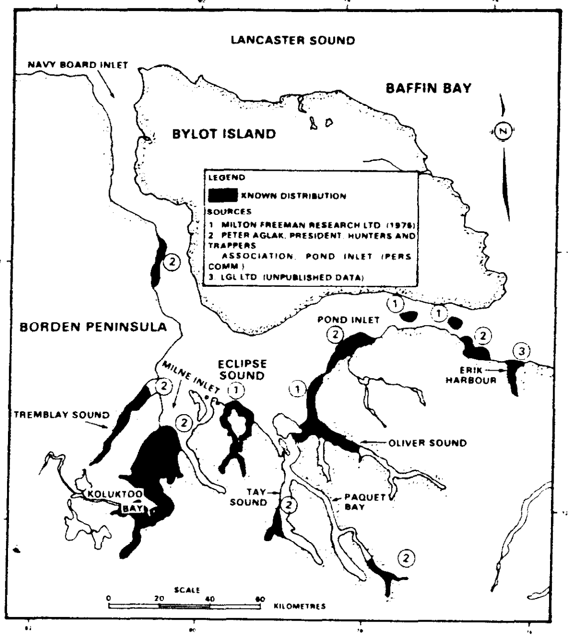
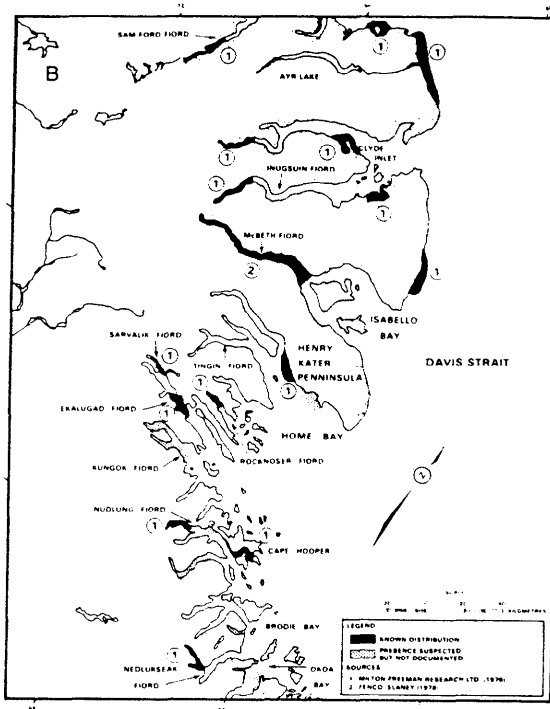
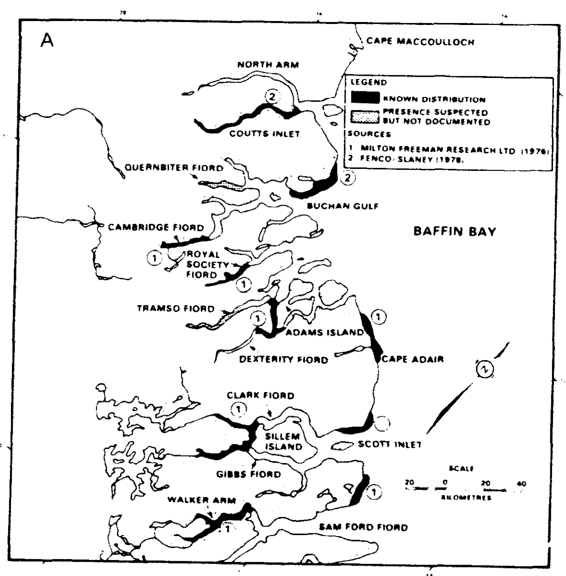


FIGURE 2.3-1 *Generalized distribution of anadromous Arctic char in the Pond Inlet-Eclipse Sound area. Anadromous Arctic char are virtually unknown in the Northwest Passage, but become progressively more common from Pond Inlet south.*





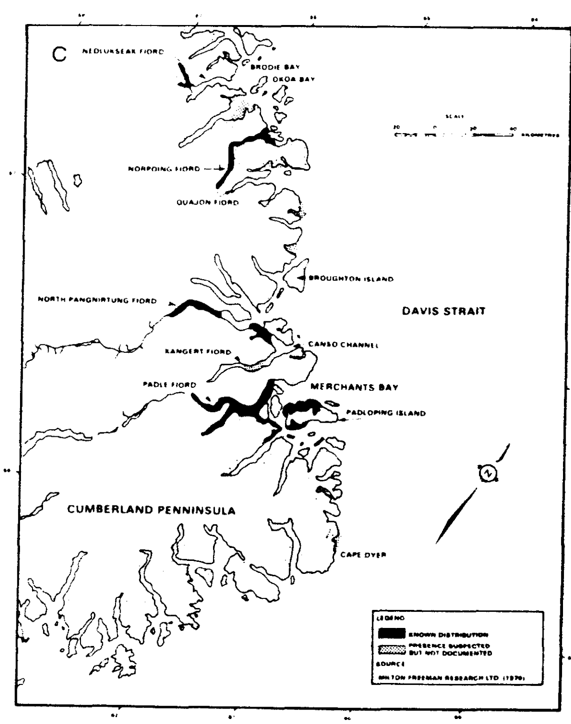


FIGURE 2.3-2 *Generalized distribution of anadromous Arctic char along eastern Baffin Island. Distribution shown from north (A) to south (C).*

2.3.2 ARCTIC COD

Arctic cod are especially important to many birds and marine mammals since few or no alternate food sources of comparable value exist in the Arctic. It has recently become evident that the behaviour and distribution of Arctic cod can affect or perhaps even determine the distribution and movement of some marine mammals and seabirds. Very little is known yet about the behavior and movements of Arctic cod; making this an important gap in the knowledge base. The Arctic cod is circumpolar in distribution. The southern limits of its range near the North American continent appear to be the Gulf of St. Lawrence and the northern Bering Sea. The Arctic cod is probably the most abundant and also one of the most widespread marine fish in the North American Arctic.

The behaviour and movements of Arctic cod are poorly understood. Small schools of Arctic cod were found in July in narrow ice cracks close to shore in Allen Bay and Resolute Bay, Cornwallis Island, and near southeastern Bylot Island in late June (Bain and Sekerak, 1978; Bradstreet, 1980b). According to residents of Resolute, this behaviour is reasonably predictable and they believe that cod seek such narrow cracks to escape predation. In June and early July, 1976, Bradstreet (1977) found that seabirds were feeding heavily on Arctic cod along the fast ice edge across Wellington Channel, Northwest Territories. He estimated, using very conservative assumptions, that at least 1.5 million cod were consumed in a 35 day period. The exact distribution of these fish remains unknown but the behaviour and distribution of feeding seabirds indicated that they occurred under fast ice and not in open water. Under-ice observations in May and June along the Pond Inlet ice edge revealed that Arctic cod (mostly one-year-olds) were more abundant beneath pressure ridges and rafted ice where shelter was available, than under smooth ice (Bradstreet, 1980a).

During late summer, very large schools of Arctic cod are sometimes found in nearshore areas. In August of 1976, large schools of Arctic cod were found in nearshore areas of Allen Bay (Cornwallis Island) and Creswell Bay (Somerset Island). Large numbers of cod were tide-stranded on the beaches in both areas and residents have indicated that tide-stranded cod are not uncommon (Bain and Sekerak, 1978). Another large school, believed to number in the millions, moved into nearshore areas of Simpson Lagoon, Alaska, in mid August, 1978 (Craig and Haldorson, 1981). Such movements of large numbers of Arctic cod into nearshore waters have also been noted in the Soviet Arctic (Ponomarenko, 1968; Rass, 1968).

Arctic cod are noted for their close association with sea ice and the epontic community (e.g. Andriashev, 1954; McAllister, 1975) although little information is actually available on such relationships in the North American Arctic (Bain and Sekerak, 1978). Divers in the central and eastern High Arctic during spring and summer have only reported low concentrations of Arctic cod near the undersurface of sea ice. In most instances where both the ocean bottom and the undersurface of ice were observed, more cod were found on the bottom (Bain and Sekerak, 1978; LGL Ltd., unpubl. data). However, even the low densities of cod that have been observed near ice (Green and Steele, 1975; Bradstreet, 1980a) represent extremely large numbers when the area involved is considered. The previously noted feeding behaviour of seabirds indicates that large schools of Arctic cod sometimes do occur beneath the ice (Bain and Sekerak, 1978) although their distribution in space or time is unknown.

Soviet ichthyologists report that Arctic cod spawn from the end of December to March, and undertake spawning migrations to specific regions. Spawning areas have been identified in the northwestern Bering Sea, Barents Sea and Laptev Sea (Andriashev, 1954). To date, almost nothing is known about Arctic cod spawning in the North American Arctic. Bain and Sekerak (1978) did not capture any mature Arctic cod near southern Cornwallis Island in three attempts during the winter of 1976-77. Arctic cod were found in nearshore waters in the Simpson Lagoon area of the Alaskan Beaufort Sea in the winter of 1978-79. They were in near spawning condition in November and were spawned out in February (Craig and Haldorson, 1981). This is the only report of spawning Arctic cod in the North American Arctic.

Arctic cod eggs are buoyant and young-of-the-year are planktonic, at least until near the end of their first summer. Hence, young cod become widely dispersed by currents and have been found in most Arctic regions that have been studied. This includes the Chukchi Sea (Quast, 1974), northern Viscount Melville Sound (Buchanan *et al.*, 1977), Barrow Strait and Wellington Channel (Bain *et al.*, 1977), Lancaster Sound and Baffin Bay (Sekerak *et al.*, 1976b, 1979), and Davis Strait (Imperial Oil Ltd. *et al.*, 1978) (Figure 2.3-3). During the spring and summer, young cod are most abundant in the upper 50 m of water, although they are normally rare at the surface. Sekerak *et al.*, (1976b) noted that in Lancaster Sound and northwest Baffin Bay young-of-the-year cod (age about 6 months) became less abundant after mid August, and they hypothesized that their apparent decrease might have resulted from a change in behaviour of the young fish. Arctic cod from one to five years old, observed in the spring and summer, are normally associated with the seabottom or the undersurface of ice but it is not known precisely when

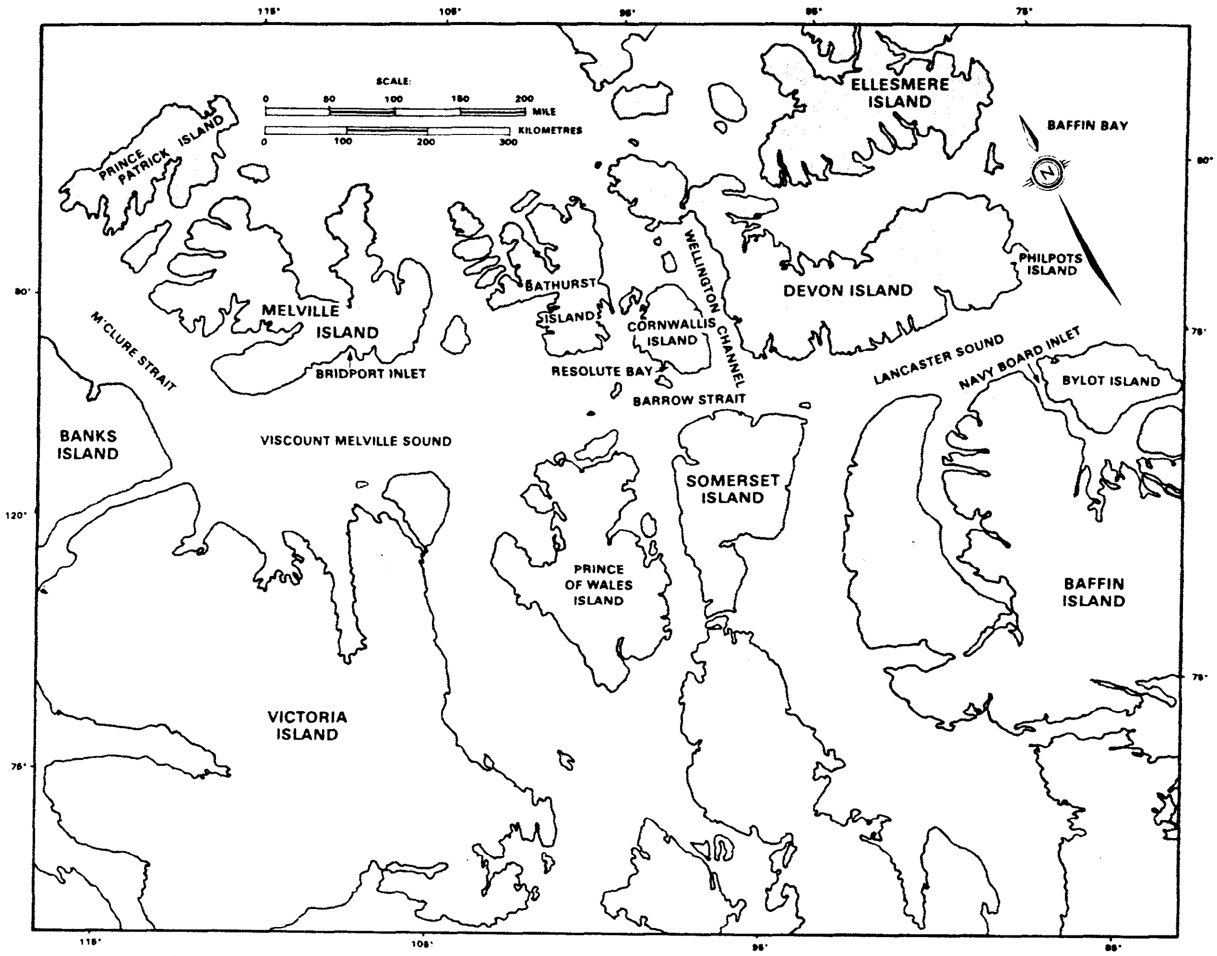


FIGURE 2.3-3 *Place names cited in relation to fisheries studies of the Northwest Passage.*

young cod cease to be planktonic. Some age and growth data on Arctic cod are available in the literature. In collections from near southern Cornwallis Island, specimens one and five years of age averaged 62 and 210 mm in fork length, respectively. Growth of these specimens appeared to be slower that than reported in the Soviet Arctic (Bain and Sekerak, 1978). Fork lengths of two and three year old Arctic cod captured in Simpson Lagoon, Beaufort Sea, Alaska (Craig and Haldorson, 1981), were similar to those of specimens from near Cornwallis Island. Arctic cod have a short life span and specimens five or more years old are rare. Male Arctic cod appear to mature before females. Craig and Haldorson (1981) reported that 45% of mature male cod collected were two years old, as compared to only 18% for mature females.

Food of Arctic cod includes amphipods, copepods, mysids, isopods, fish and pteropods. The diet seems to vary with area, habitat and size of cod. Bain and Sekerak (1978) found that epibenthic amphipods and, to a lesser degree, pelagic amphipods were by far the most important food for cod, and that the pelagic amphipod *Parathemisto libellula* formed a larger portion of the diet of cod in ice-free nearshore waters. In contrast, epibenthic amphipods *(Gammarus setosus, Onisimus littoralis)* were most important when cod were inhabiting nearshore ice cracks. However, Lowry and Frost (1981) found that copepods, amphipods, mysids and shrimp were the most important food items offshore in the Beaufort Sea - Chukchi Sea area, and Craig and Haldorson (1981) found that mysids were most important in nearshore Alaskan waters. Bradstreet and Cross (1980) found that amphipods were more important in the diet of nearshore cod than offshore cod.

There is some evidence of size selectivity in the diet of Arctic cod. Bohn and McElroy (1976) and Bain and Sekerak (1978) both noted that fish less than 100 mm long consumed more copepods than the larger fish. Bradstreet and Cross (1980) found that larger cod tended to select larger individuals of the major food species than did smaller cod. However, Frost *et al.*, (1978) found no size related differences in diet.

2.3.3 FISH IN THE NORTHWEST PASSAGE AND WESTERN BAFFIN BAY

The fish fauna of the Northwest Passage and west Baffin Bay is the least diverse in the entire area under consideration and only about 30 species have been reported from the region (Table 2.3-1). Present evidence indicates that only one anadromous species, the Arctic char, occurs in the Northwest Passage. No northern or boreal species from the North Pacific or Bering Sea are present, and only a few boreal or temperate fish from the North Atlantic (e.g. Greenland halibut, Greenland shark, darkbelly skate) occur, and these only in the easternmost part of the area. Information on fish in the area is fragmentary, particularly for the deep waters in the region. In addition, the northern limits of most of the fish in Davis Strait are unknown and additional sampling in Baffin Bay would likely lengthen the species list for the area. It is almost certain that the fish fauna of M'Clure Strait is even less diverse than that of eastern Lancaster Sound, but the western limits of fish found in the latter region are unknown.

Recent fisheries investigations in the Northwest Passage and western Baffin Bay have generally formed a small part of more general nearshore marine studies sponsored by industry (see Figure 2.3-3 for placenames). To our knowledge nothing is known about the fish of M'Clure Strait and only one study (Buchanan *et al.*, 1977) has been performed in a small bay (Bridport Inlet) in northern Viscount Melville Sound. More information is available for western nearshore portions of central and Parry Channel and adjacent regions. For example, data on fish are available from studies in Resolute Bay (Green and Steele, 1975; Bain *et al.*, 1977); southern Wellington Channel (Bain *et al.*, 1977); Brentford Bay, Boothia Peninsula (Thomson *et al.*, 1978); areas near Phoenix Head Glacier and Philpots Island, southeastern Devon Island (Thomson *et al.*, 1979) and northwestern Navy Board Inlet (Thomson *et al.*, 1979). Waters along the northeast coast of Baffin Island have been little studied although Thomson *et al.*, (1979) provided a small amount of information from Scott Inlet and Clark Fiord. General species lists and reports of specific fish have been provided by Walters (1955), Mary-Rousseliere (1959), Ellis (1962), Beck and Mansfield (1969) and Legendre *et al.*, (1975). A few data on the ichthyoplankton of the region are scattered throughout the general literature on zooplankton. The ichthyoplankton in southern Wellington Channel (Bain *et al.*, 1977) and in Lancaster Sound and northwest Baffin Bay (Sekerak *et al.*, 1976b, 1979) is reasonably well described and consists almost entirely of young Arctic cod. Although adult Greenland halibut occur in northwest Baffin Bay and Pond Inlet, their planktonic young-of-the-year have not been collected in the region. This suggests that spawning may not occur in the northernmost portions of their range.

2.3.3.1 Nearshore Zone

In contrast to the situation in the Beaufort Sea, the nearshore zone of the Northwest Passage appears to be used little by most fish. In the High Arctic this area is commonly referred to as the 'barren zone.' Depending on location and exposure, the barren zone ranges down to depths of from 2 to 15 m. It is nearly devoid of plants, infaunal invertebrates and fish, and only mobile epibenthic invertebrates are abundant in the area. Most of the area in this zone freezes to the bottom in winter.

In summer fourhorn sculpins are sometimes found scattered throughout this zone. As in the Beaufort Sea, nearshore shallow water areas are important summer feeding areas for Arctic char where such populations occur (Figures 2.3-1 and 2.3-2). The only other fish which occur in large numbers in nearshore areas is the Arctic cod. As previously explained, large numbers of these fish sometimes occur in shallow waters, particularly in late summer. It is not clear why such concentrations occur nor can the precise locations or timing of such movements be predicted at present. Small groups of Arctic cod are also found in nearshore ice cracks in late spring and summer in some areas.

Below depths from about 2 to 20 m, several species of sculpins, eelpouts, seasnails and lumpfish commonly occur. Only small numbers of such fish have been observed by divers (Green and Steele, 1975; Buchanan *et al.*, 1977; Thomson *et al.*, 1978, 1979) or collected by surface-operated gear, and present information suggests that these fish are most common in kelp beds and protected bays.

Although information is far from complete, the polar cod, *Arctogadus glacialis*, may be more abundant in western portions of the Northwest Passage than in the eastern Archipelago. For example, in contrast to eastern regions, polar cod was more abundant than Arctic cod in Bridport Inlet, Melville Island (Buchanan *et al.*, 1977).

2.3.3.2 Offshore Zone

Although Arctic cod have occasionally been observed in the water column there appear to be few pelagic fish in the region. However, the report by Sekerak *et al.*, (1979) of the bathypelagic veiled anglemouth was a new record for northwest Baffin Bay. That observation further demonstrates the incomplete knowledge of fish species in this portion of the study area.

With few exceptions, the biology and ecological significance of marine fish in the Parry Channel and western Baffin Bay region remain obscure. Some general observations can be made; for example, most sculpins spawn in winter, but on the whole, the available data consist almost entirely of distributional records. However, it is known that some benthic fish such as sculpins, Greenland cod and Greenland halibut are consumed by bearded seals, white whales and narwhal, although their importance to such consumers is generally unknown.

2.3.4 WESTERN DAVIS STRAIT

The Davis Strait region harbours the most diverse assemblage of fish in the entire area under consideration (about 90 species: Table 2.3-1). This is attributable to the relatively warm northward flowing West Greenland current. Few fisheries studies have been conducted in the area although populations of Arctic char have been studied in Frobisher Bay (Grainger, 1953) and Cumberland Sound (Moore and Moore, 1974; Moore, 1975). In addition, information on ichthyoplankton of the western portion of Davis Strait was provided by Imperial Oil Ltd. *et al.*, (1978).

With the exception of Arctic char, fish of the inshore regions of western Davis Strait are little studied. It is likely that many of the sculpins, eelpouts and lumpsuckers listed in Table 2.3-1 occur in nearshore areas and that the fish fauna along the Greenland coast of Davis Strait is more diverse than along Baffin Island. Imperial Oil Ltd. *et al.*, (1978) listed 11 fish species in inshore regions of southern Baffin Island, and Den Beste and McCart (1978) found 22 species of inshore fish near the mouth of Frobisher Bay and adjacent areas to the north. To our knowledge, four of these 22 species: spatulate sculpin, leatherfin lumpsucker, saddled eelpout and *Tonkoperi gimnelis*, were new records for the Davis Strait region. These are primarily Arctic species and could be expected to occur in the colder waters of the region. As was the case during diver observations in the Northwest Passage and northwest Baffin Bay, Den Beste and McCart (1978) reported no large concentrations of fish although both juvenile and adult fish were most abundant in kelp beds and protected bays.

Planktonic young-of-the-year fish had variable distributions. Relatively high densities of juvenile shorthorn sculpins were found in sheltered waters. Seasnails were the most abundant species of ichthyoplankton in unsheltered locations. This is in contrast to regions farther north where young-of-the-year Arctic cod formed 80% of the ichthyoplankton (Sekerak *et al.*, 1976b, 1979).

Imperial Oil Ltd. *et al.* (1978) conducted studies on ichthyoplankton in central and western Davis Strait in June, August and September. They found that young-of-the-year sandlance were widely distributed in June but were more common in extreme western Davis Strait in fall. They attributed this change in distribution to maturation and shoreward movement of the young (adults are coastal residents). Lumpfish young-of-the-year were also more common in western rather than central Davis Strait. Young Greenland halibut were common throughout the study area in June, August and September, and were captured in various degrees of development in late summer. This suggests different spawning times or rates of development in various areas. Young redfish were not abundant and were only collected at two locations, one in northwestern Davis Strait and the other northeast of the mouth of Hudson Strait. Captures of young-of-the-year Arctic cod were centred around the mouth of Hudson Strait in August and September.

2.3.5 EASTERN BAFFIN BAY AND DAVIS STRAIT

The fish fauna of inshore and offshore waters of eastern Baffin Bay has been the subject of considerable study (e.g. Jensen, 1942, 1944, 1948) because of experimental fishing projects conducted early in the century and the importance of fishing to the Greenland economy (see Mattox, 1971). The waters of West Greenland are subarctic, being composed of temperate Atlantic and Arctic water masses. The relative composition of these water masses and other hydrographic characteristics vary over both long and short time periods (Dunbar and Thomson, 1979) and are discussed in Section 1.3 of this volume. These fluctuations affect the stocks of marine fish of the region.

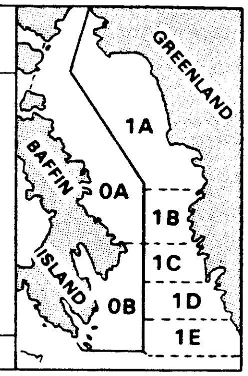
As shown in Table 2.3-2, eastern Baffin Bay and eastern Davis Strait support a substantial commercial fishery. Over 20 species (including the invertebrates-northern prawn and squid) are fished, but as shown in Table 2.3-2, three species, Atlantic cod, Greenland halibut and prawns, contributed about 70% of the total catch in 1978. The fishery is extremely important to Greenland and in addition several foreign countries also fish the waters.

Historically, the Atlantic cod has been the mainstay of the fishery in the region. However, landings have decreased dramatically in the last decade. Overfishing and changes in climate have been suggested as possible reasons for the decrease in landings of Atlantic cod. In the mid 1960's, catches of cod reached 400,000 metric tonnes (Mattox, 1971) but have decreased to approximately 30,000 to 40,000 metric tonnes in recent years. This decline in cod stocks has been accompanied by a general increase in the catch of Atlantic salmon. Catches of Atlantic salmon were negligible prior to 1960, peaked at 2,500 metric tonnes in the early 1970's and are presently being maintained at approximately 1,000 metric tonnes (Thomson, 1975; NAFO, 1980). For further information on fish harvesting statistics in the Northwest Passage region, the reader is referred to Volume 5 of the Environmental Impact Statement.

TABLE 2.3-2

CATCH OF MAJOR SPECIES (METRIC TONNES) IN THE BAFFIN BAY, DAVIS STRAIT AREA IN 1978 (FROM NAFO, 1980).

Species	Subarea 0	1A	1B	1C	1D	1E	Total
Atlantic cod	—	348	1,589	15,101	5,253	8,442	30,733
Greenland halibut	696	3,795	1,182	517	1,796	2,379	10,365
N. Atlantic redfish	1	—	5	417	1,143	3,313	4,879
Wolfishes	—	460	753	914	1,246	1,792	5,165
Roundnose grenadier	—	32	—	232	1,723	2,939	4,926
American plaice	—	—	—	167	2,205	2,251	4,623
Greenland cod	—	621	1,992	391	162	571	3,737
Atlantic salmon	—	81	349	245	186	113	974
Capelin	—	48	7	234	—	—	289
Char	?	1	31	43	41	5	121
Prawns	122	7,704	23,049	1,234	2,089	95	34,293
Total[1]	819	13,099	28,983	21,022	18,685	27,179	109,805



[1]Incl0des species not listed above.

The fishery for northern deepwater prawn has increased dramatically over the last decade (10 metric tonnes in 1972; 34,000 in 1978; NAFO, 1980) and is now the most valuable fishery in West Greenland. Prawns began to be exploited as Atlantic cod catches decreased and fishermen were forced to abandon traditional fishing stocks. Exploratory fishing is still being conducted and additional stocks of prawns may be discovered.

From the standpoint of this review, it is most important to note that the eggs and (or) the young-of-the-year of many important fish (sand lance, Arctic cod, Atlantic cod, Greenland cod, Greenland halibut, redfish and lumpfish) in Davis Strait are planktonic. In addition, seasnails, alligatorfish and some sculpins, whose ecological importance is obscure, also have planktonic young. As a whole, the ichthyoplankton of Davis Strait is quite important. In general, these species spawn in late winter to early spring and their young are present in the upper layers of the water column from spring to late summer when food is most abundant.

2.4 LOWER TROPHIC LEVELS

2.4.1 PHYTOPLANKTON

The extreme seasonality of the Arctic has a strong effect on the physiology, distribution and abundance of marine plants and zooplankton. The progression from the total darkness and extreme cold of winter to the 24 hour daylight and moderate temperatures of summer results in marked annual cycles in biological processes such as light-dependent photosynthetic production. The annual cycle of the Arctic marine environment can be separated into five phases.

1. Winter, from about October through March or early April, is characterized by an increasing thickness of sea ice, little or no solar radiation, increasing salinity of near surface water, and limited vertical circulation of water under the ice.

2. Spring, from approximately April to May, is distinguished by the continued presence of sea ice, reduced ice growth, increasing solar radiation, relatively high salinity water and weak under-ice currents.

3. Late spring, from about late May to July, is characterized by the melting of sea ice, a large influx of river water to the marine environment from the snowmelt, intense solar radiation often interrupted by ground fog, and very highly stratified areas of open water (fresh water above sea water).

4. Summer extends from approximately July to September, and is when the sea ice breaks up and eventually disappears in some areas. There is less intense solar radiation, water salinities approach oceanic levels, and there is periodic wind driven mixing of the water column. The summer season becomes shorter with increasing latitude in the northwestern Archipelago and in some areas, broken ice may remain throughout the year.

5. Fall, from about September to October, is characterized by the slow formation of slush ice along the shore, decreasing solar radiation, increasing salinity of oceanic waters with more ice formation, and sporadic wind driven water recirculation which becomes less common as sea ice becomes more extensive.

In all oceans, the majority of primary production is performed by microscopic unicellular algae. The principal requirements of these photosynthetic organisms include light and inorganic nutrients such as carbon, silicon, nitrogen, and phosphorus. Since the Arctic seasons include periods of little and no light, and periods with little or no vertical circulation (which supplies required nutrients), the growth of algae in the Arctic is highly seasonal. Three different types of algal propulations occur in the Arctic: planktonic, epontic and benthic. The first group to grow in spring are the epontic or attached under-ice algae. They are followed by the planktonic or free floating algae, which are abundant in the water column from late spring through summer. The benthic or attached bottom algae are generally present throughout the year and in some species, growth does not appear to be hindered by thick ice cover in late spring or early summer. In this section the planktonic algae are discussed. Epontic and benthic algae are considered in later sections.

2.4.1.1 Primary Productivity

In general, the Arctic Ocean is considered to be one of the least productive of the world's oceans (Dunbar, 1970; Platt and Subba-Rao, 1975). This low productivity results from a short growing season coupled with strong vertical stratification of the water column which often limits nutrient return to the photic (sunlit) zone. The annual phytoplankton productivity in the Arctic Ocean was estimated to be less than 1g C/m^2/yr by English (1961). The productivity of the nearshore Beaufort Sea is higher, but less than 20 g C/m^2/yr (Alexander *et al.*, 1974). By comparison, primary productivity in the Bering Sea is estimated at 121 g C/m^2/yr (McRoy and Goering, 1976). Rates of primary productivity in August in Brevoort Harbour, southeast Baffin Island were 92 to 204 mg C/m^2/h (Hsiao and Trucco, 1980) which was comparable to values from Frobisher Bay, (Grainger, 1971a) and much higher than the average of 14.8 mg C/m^2/h reported in late July and August in the Canadian Beaufort Sea (Hsiao *et al.*, 1977).

MacLaren Marex (1979b) found a mean productivity of 983 mg C/m^2/day based on nine samples, with a standard deviation (SD) of 565 mg C/m^2/day, during the spring bloom in Davis Strait. Later, in August, the productivity was 12.9 + SD 9.4 mg C/m^2/day. The former values are similar to those recorded during June and July, 1969, in Frobisher Bay, whereas the latter are much lower than August values from Frobisher Bay (Grainger, 1971a). There is some indication that primary productivity in the Lancaster Sound region may be relatively high (Thomson and Cross, 1980; LGL., unpubl. data) compared to that in the remainder of the area considered in this report.

All of the reported productivity values for the Beaufort Sea area and the Canadian High Arctic (Table 2.4-1) are very low. Values from Frobisher Bay in the eastern Canadian subarctic are intermediate between those from the High Arctic and those from the Atlantic, and are roughly equivalent to those from West Greenland (Petersen, 1964).

TABLE 2.4-1

ANNUAL PRIMARY PRODUCTIVITY ESTIMATES FROM EIGHT LOCATIONS IN THE NORTH AMERICAN ARCTIC

Location	Year	Primary Productivity (gC/m.^{2}/yr^1)	Reference
Bering Sea	several	75-150	Ikeda and Motoda (1978)
Northeast Chukchi Sea	1976	18	Carey (1978)
	1977	28	Carey (1978)
Western Beaufort Sea	1976	9	Carey (1978)
	1977	18	Carey (1978)
Dumbell Bay, Ellesmere Is.		9-12	Apollonio (1976a)
Resolute Bay, Cornwallis Is.	1971-72	32	Welch and Kalff (1975)
Jones Sound, N.W.T.	1961-72	35	Apollonio (1976b)
	1963	20	Apollonio (1976b)
Frobisher Bay, N.W.T.	1968	40	Grainger (1975)
	1969	70	Grainger (1975)

By comparison, primary productivity of Atlantic shelf waters and Atlantic offshore waters are estimated at 150 and 100 g C/m^2/year, respectively (Platt and Subba-Rao, 1975). Productivity estimates for the shelf waters of the Indian and Pacific oceans are even higher, and the highest overall values of 325 g C/m^2/year are from the Antarctic (Platt and Subba-Rao, 1975).

Therefore, with some important exceptions, such as Davis Strait and Lancaster Sound, the above data and those presented in Table 2.4-1 suggest a general decrease in primary productivity from the Atlantic through the Canadian Arctic to the Beaufort Sea. A similar trend is also indicated from data on the standing crop of zooplankton and benthos from the same areas.

2.4.1.2 Phytoplankton Succession and Standing Crop

Each phytoplankton species has physical and chemical requirements which differ from those of other species. Typically a complex of species with generally similar requirements will co-exist. As they change their environment through uptake of nutrients and the generation of dissolved organic compounds, conditions become more favorable for another complex of species and a shift in species composition occurs. Successional changes may also result from advective processes or grazing by marine animals (Braarud, 1962; Guillard and Kilham, 1977). In response to a myriad of seasonal changes in environmental conditions, phytoplankton community succession is usually fairly rapid (Lillick, 1940; Lund, 1966).

A few generalizations about factors affecting the community structure of phytoplankton have emerged. Diatoms generally are most abundant when nutrient levels are high, illumination low, and water temperatures relatively warm (Sverdrup *et al.*, 1942; Ryther, 1956; Raymont, 1980; Hulbert, 1970). Flagellates are most prevalent under conditions of higher light intensities and lower nutrient concentrations (Raymont, 1980; Fogg, 1965).

A diagrammatic representation of phytoplanktonic and epontic succession (discussed later) in Arctic waters, taken from Bain *et al.*, (1977), is presented in Figure 2.4-1. This diagram was compiled from reports of studies at a variety of sites in the Alaskan and Canadian Arctic. A more detailed tabulation of data, including some published since 1977, appears in Table 2.4-2. Locations where data were obtained are shown in Figure 2.4-2.

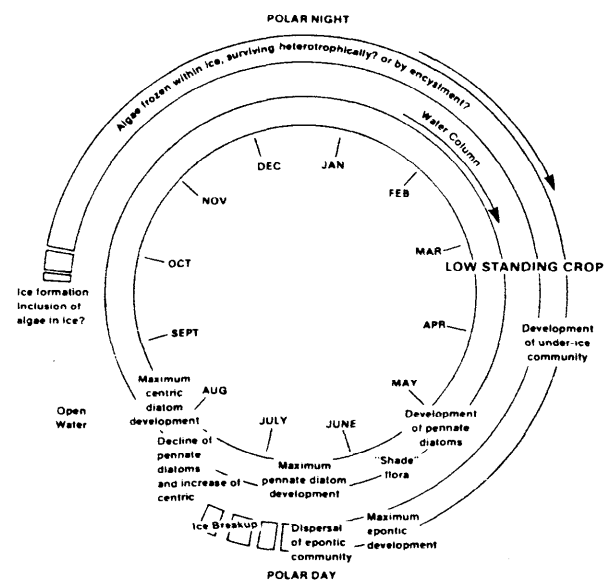


FIGURE 2.4-1 *Annual cycle of phytoplankton and epontic algal development in Arctic water. Timing of events is only approximate and some relationships are not clearly understood. from Bain et al. (1977); based on the work of Bursa (1961b, 1971), Apollonio (1965), Horner (1977), Thomson et al. (1975), Sekerak et al. (1976a, b) and Bain et al. (1977).*

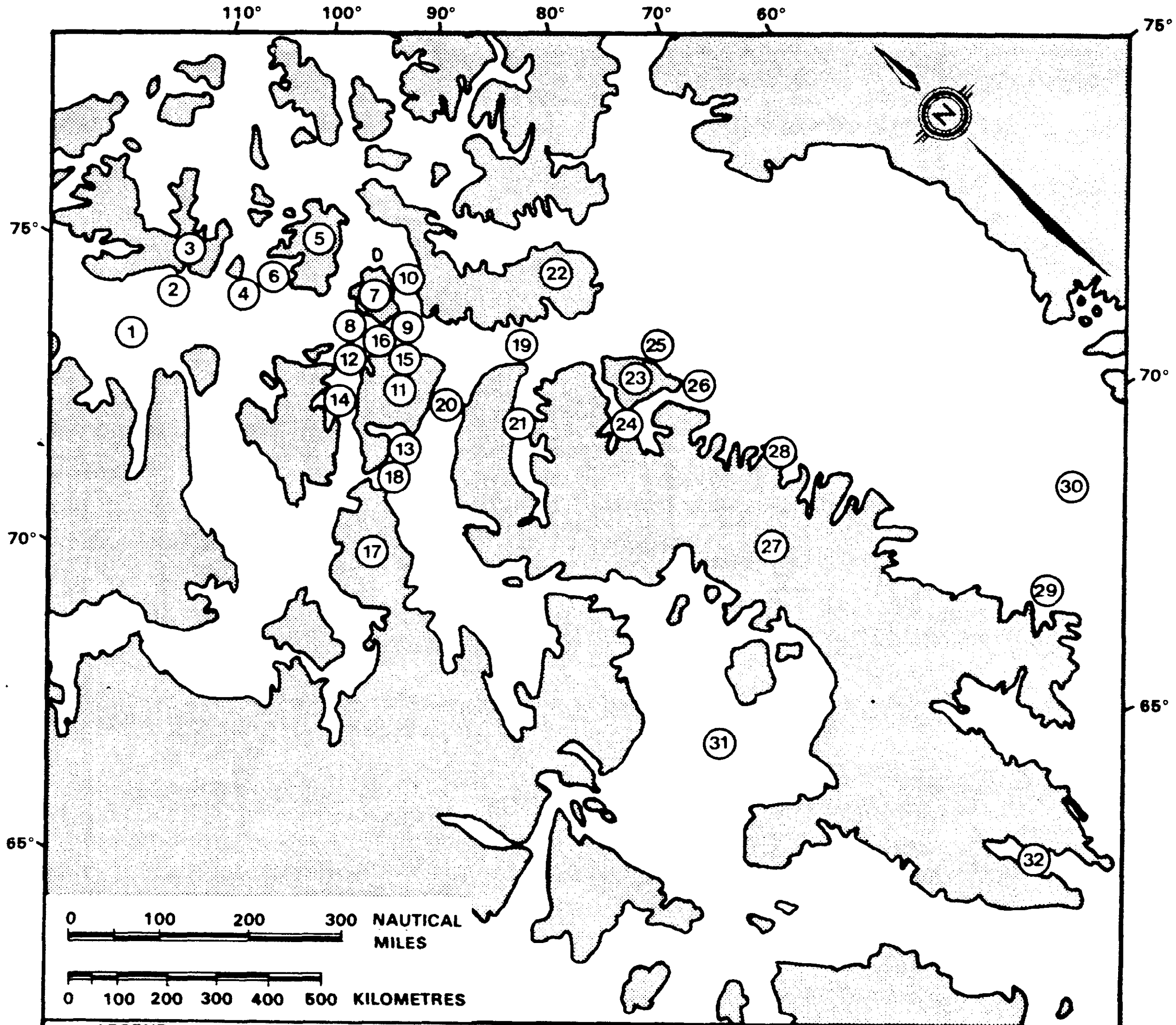
Increasing sunlight and transparency of the ice in spring due to snowmelt and disintegration of the epontic community lead to increased activity of the phtyoplankton in the water column. At this time, standing crop is low (Figure 2.4-3) and pennate diatoms of the genus *Nitzschia* or microflagellates are dominant (Plate 2.4-1, Section 2.4.4.1). Maximum development of the pennate diatoms occurs under the ice and is marked by a very large standing crop (e.g. Wellington Channel: Figure 2.4-3). Break-up and the associated decline of the pennate diatoms is followed by an increase in the number of centric diatoms, especially *Chaetoceros socialis* (Table 2.4-2; Bursa, 1961). Standing crop may be quite high throughout the summer, but there appears to be a great deal of regional variability (Figure 2.4-3). At the end of summer diatoms may be displaced by flagellates, and during winter phytoplankton populations are very small (Bursa, 1961).

Some major regional differences are apparent in the timing of the seasonal cycle. Chlorophyll *a* (an index of cell abundance) and total cell counts from Brentford Bay, Boothia Peninsula, in May, and Bridport Inlet, Southern Melville Sound, in early June, were extremely low and indicated that the bloom had not yet commenced. In Wellington Channel, the spring bloom began in early June and peaked in the latter part of the month (Bain *et al.*, 1977). In offshore waters of Davis Strait the spring bloom occurred in April and May (MacLaren Marex, 1979b). In Frobisher Bay, southeast Baffin Island, the spring bloom does not get underway until late June or early July. Initiation of the spring bloom in nearshore regions is likely retarded because of the more persistent ice cover. In High Arctic areas pennate diatoms of the genera *Nitzschia* and *Navicula* are dominant in spring (Figure 2.4-3; Table 2.4-2). However, MacLaren Marex (1979b) noted that centric diatoms were dominant in May. These differences are also probably related to the presence or absence of an ice cover and the light requirements of the various species. In summer, *Chaetoceros* spp. are dominant in most High Arctic regions and in the Davis Strait area (Table 2.4-2), including Brevoort Harbour (Hsiao and Trucco, 1980) as well as Foxe Basin (Bursa, 1961).

2.4.2 NUTRIENT REGIMES AND PHYTOPLANKTON REQUIREMENTS

Plant growth is dependent on temperature, light intensity and an adequate supply of inorganic nutrients, particularly nitrate and phosphate. Nutrient concentrations in the water column vary throughout the year as a result of dynamic processes such as utilization by plants, *in situ* regeneration by microorganisms, zooplankton and fish, upwelling of deeper waters, sediment resuspension, and input from terrestrial sources. The mechanisms affecting nutrient concentrations are described in more detail in a supporting document to this EIS (LGL and ESL, 1982) and are briefly summarized here.

Nitrogen or phosphorus are usually believed to limit phytoplankton growth. However, there are data which indicate that other nutrients, such as molybdenum, other trace metals and vitamins are also required. Other nutrients may be group or species specific. For example, diatoms require silicon for the formation of their frustules (shells). A general review



LEGEND

1. VISCOUNT MELVILLE SOUND
2. BRIDPORT INLET
3. MELVILLE ISLAND
4. AUSTIN CHANNEL
5. BATHURST ISLAND
6. GRAHAM MOORE BAY
7. CORNWALLIS ISLAND
8. RESOLUTE BAY
9. ASSISTANCE BAY
10. WELLINGTON CHANNEL
11. SOMERSET ISLAND
12. ASTON BAY
13. CRESWELL BAY
14. PEEL SOUND
15. BARROW STRAIT
16. CUNNINGHAM INLET
17. BOOTHIA PENINSULA
18. BRENTFORD BAY
19. LANCASTER SOUND
20. PRINCE REGENT INLET
21. ADMIRALTY INLET
22. DEVON ISLAND
23. BYLOT ISLAND
24. ECLIPSE SOUND
25. CAPE FANSHAWE
26. CAPE GRAHAM MOORE
27. BAFFIN ISLAND
28. CLARK FIORD
29. PADLOPING ISLAND
30. DAVIS STRAIT
31. FOXE BASIN
32. FROBISHER BAY

FIGURE 2.4-2 *Place-names referred to in descriptions of lower trophic levels.*

TABLE 2.4-2

SEASONAL CHANGES IN PHYTOPLANKTON ABUNDANCE AND DOMINANT SPECIES IN WATERS OF THE NORTHWEST PASSAGE AND DAVIS STRAIT

Location	Date	Depth (m)	Mn. Depth Weighed Cell No./ L x 10⁴	Dominant Organism	Reference
High Arctic					
Barrow Strait	May 8	0-30	6.2*	Nitzschia delicatissima	Thomson et al. (1975)
Brentford Bay	May 2-3	0-25	0.1*	Microflagellates	Thomson et al. (1978)
Bridport Inlet	June 9-14	0-25	2.0*	Nitzschia spp. Navicula spp.	Buchanan et al. (1977)
Wellington Channel	June 2-29	0-25	161.0*	Nitzschia grunowi	Bain et al. (1977)
Resolute Passage	July 5	0-25	7.7	Microflagellates	Bain et al. (1977)
Creswell Bay	Aug. 2	0-50	53.1	Nitzschia seriata	Sekerak et al. (1976b)
Bridport Inlet	Aug. 5-28	0-25	42.7	Chaetoceros socialis	Buchanan et al. (1977)
Assistance Bay	Aug. 25	0-40	83.2	Chaetoceros socialis	Sekerak et al. (1976b)
Peel Sound	Aug. 30	0-50	1.23	Microflagellates	Thomson et al. (1975)
Brentford Bay	Sept. 2	0-40	1.8	Chaetoceros sp.	Thomson et al. (1978)
Lancaster Sound	July 22-25	0-50	306	Chaetoceros socialis	Sekerak et al. (1976a)
	Aug. 2- Sept 1	0-50	294- 164	Chaetoceros socialis	Sekerak et al. (1976a)
	Sept 7-13	0-50	107	Chaetoceros socialis	Sekerak et al. (1976a)
	July 23- Oct. 10	0-50	80	Chaetoceros socialis	Sekerak et al. (1979)
Davis Strait	Feb.	0-50	0.1+	Dinoflagellates	Imperial Oil Ltd., AquitaineCo. Can. Ltd., Canada-Cities Service Ltd. 1978; Esso Resources Canada Ltd., Aquitaine Co. Can. Ltd., and Canada-Cities Services Ltd. 1979.
	April, May	0-50	100+	Chaetoceros spp.	
	July	0-50	14+	Chaetoceros spp.	
	Oct., Nov.	0-50	5+	Diatoms	

* Under-ice **Ice-edge *+Approximate values.*

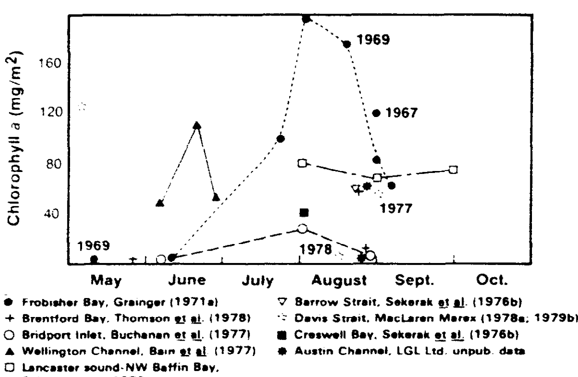


FIGURE 2.4-3 *Mean depth integrated chlorophyll a concentrations from various locations along the Northwest Passage and Davis Strait. (Map locations are shown in Figure 2.4-2).*

of available information is provided in Raymont (1980) or Parsons *et al.*, (1977). This discussion focuses mainly on nitrogen and phosphorus since most work in the Canadian Arctic is confined to these two nutrients.

Nitrogen is frequently the nutrient ion limiting marine phytoplankton growth (Ryther and Dunstan, 1971). Three inorganic forms may occur in seawater, namely nitrate, nitrite and ammonium. Both NO_3^- and NH_4^+ are known to serve as a nitrogen source for phytoplankton though not all species will use both, or uptake of one may be preferential over the other. Nitrate is usually present in greater concentrations than ammonium and both are typically far in excess of nitrite concentrations.

Phosphorus is the other nutrient that may limit phytoplankton growth. In some ways its chemistry in seawater is less complex than that of nitrogen since only one inorganic form (PO_4^{-3}) is used by phytoplankton. Concentrations of phosphate are frequently low in seawater though it is believed to be less likely to limit primary production than does inorganic nitrogen (Alexander *et al.*, 1975; Schell, 1975: Parsons *et al.*, 1977).

Silicon is another nutrient which potentially limits phytoplankton growth, particularly of diatoms which require this element for production of their silicon cell walls. Diatom blooms, such as occur in many oceanic waters in the spring months, frequently lead to a depletion of dissolved silicon. A shortage of silicon may produce successional changes favoring non-diatom components of the phytoplankton.

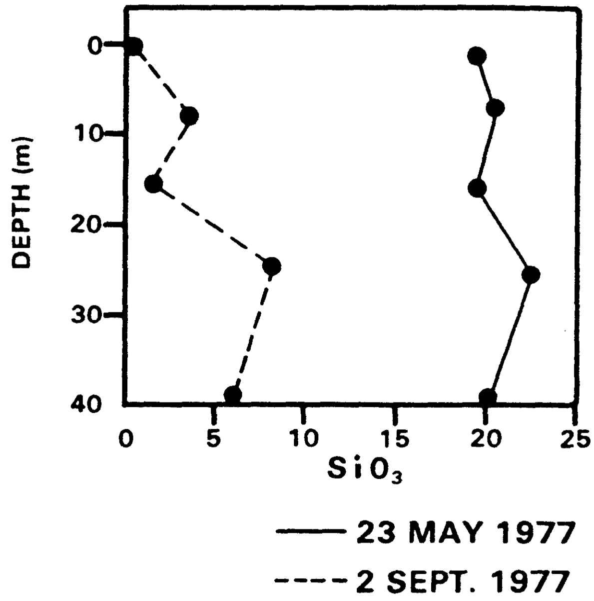
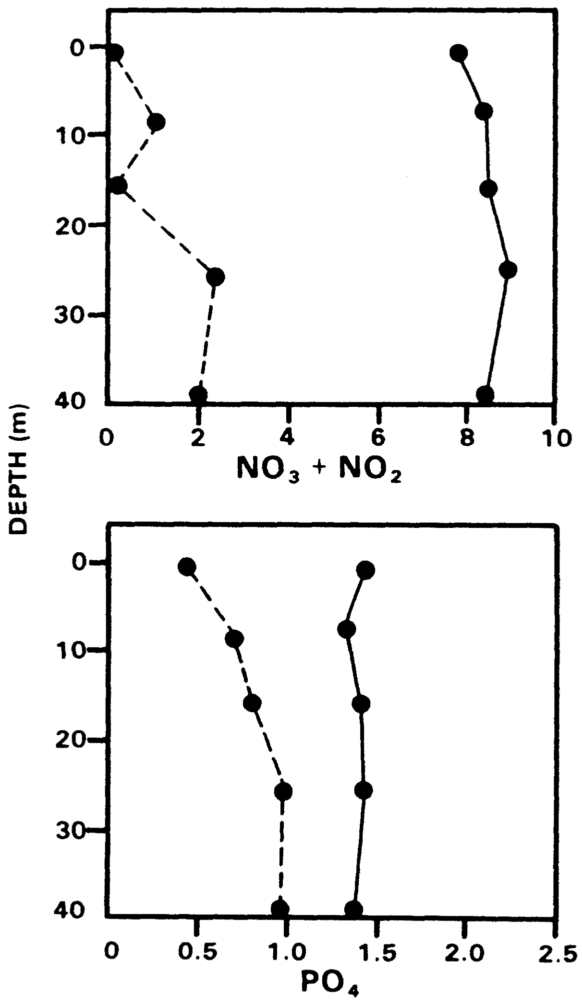


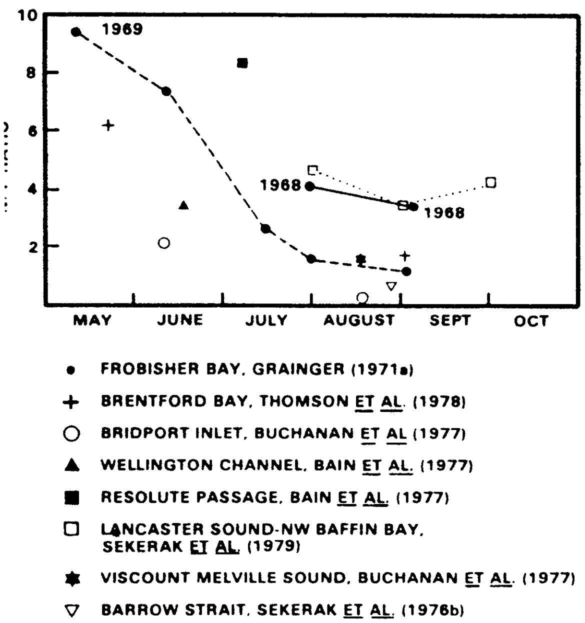
FIGURE 2.4-4 *Nutrient concentrations (µg -at/L) in Brentford Bay, Boothia Peninsula in May and September, 1977 (from Thomson et al., 1978).*

Nitrate/nitrite, phosphate and silicon concentrations in waters of the Northwest Passage are shown in Figures 2.4-4 and 2.4-5. Declines in all three of these nutrients occurred between the May and September samples. Under pre-bloom conditions in May, the combined concentrations of NO_3 and NO_2 exceeded 8 μg-at/L at Brentford Bay (Figure 2.4-3) and declined to less than 0.1 μg-at/L in surface waters in September. Phosphorus concentrations, while lower initially, did not decline to the same extent.



The shortage of inorganic nitrogen relative to phosphorus for plant growth is indicated by the nitrogen to phosphorus ratios in water. This useful index is based on a general requirement by plants for nitrogen and phosphorus in an atomic ratio of approximately 16:1. A decline in the ratio below this value, is indicative of intense biological activity. While such ratios must be interpreted with caution since they do not take into account the dynamics of nutrient cycles, they do suggest, in the case of the waters of the Northwest Passage, that inorganic nitrogen is more rapidly utilized than phosphate and is thus likely to limit phytoplankton production. The N/P ratio in May declines from values approaching 10 to values of 1 to 4 in August and September (Figure 2.4-4).

Depletion of nitrate in the presence of relatively high concentrations of silicate and phosphate have been reported from Bridport Inlet, Melville Island (Buchanan *et al.*, 1977); Assistance Bay, Cornwallis Island (Sekerak *et al.*, 1976b); Brentford Bay, Boothia Peninsula (Thomson *et al.*, 1978); and Davis Strait (MacLaren Marex Inc., 1979b). This further reinforces the suggestion that nitrate is the nutrient which limits phytoplankton production in the waters of the Northwest Passage.



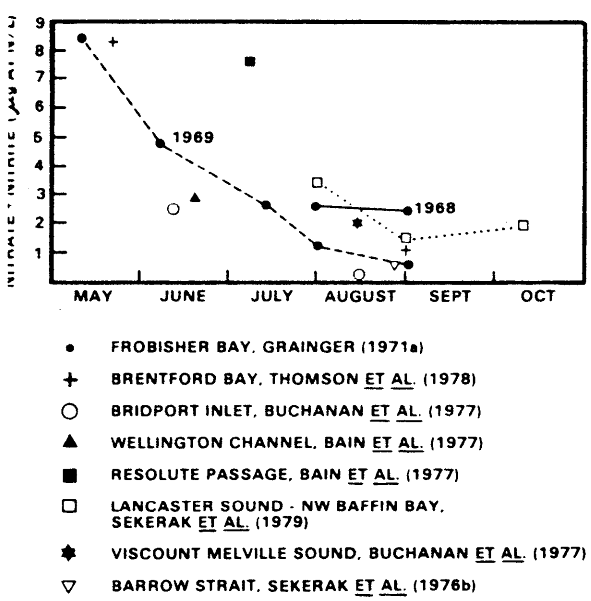


FIGURE 2.4-5 *Mean depth integrated nitrogen concentrations and nitrogen to phosphorus ratios from various locations along the Northwest Passage. (See Figure 2.4-2 for map locations).*

2.4.2.1 Stratification

Some ice free waters of the Arctic become stratified during late spring and summer due to the influence of ice meltwater and freshwater discharge from rivers. This less dense water becomes warmer throughout the summer and strengthens vertical stratification. This leads to a depletion of surface nutrients by phytoplankton growing in the upper, illuminated portions of the water column and eventual curtailment of primary production. While some nutrients are returned to these upper layers by *in situ* excretion by fish or planktonic animals, or by bacterial decomposition of organic matter, a major source of replenishment occurs when winds break down the vertical stratification and deeper, nutrient-rich waters are brought to the surface. An example of this form of near-surface nutrient depletion by phytoplankton is shown in Figure 2.4-4. The combination of low surface nutrient concentrations, stable horizontal stratification, and a short period of adequate illumination are primarily responsible for the low productivity of Canadian Arctic waters (Dunbar, 1970; Platt and Subba-Rao, 1975).

While wind-mixing increases surface nutrient concentrations, upwelling of deep water to the surface may maintain consistently higher levels of nutrients in the photic zone. Such upwelling, which is frequently wind-induced (Smith, 1968), will usually be associated with higher production at all trophic levels given a general increase in primary production. Wind-induced upwelling may occur on a seasonal or shorter time scale, particularly at higher latitudes (Dragesund, 1971).

High productivity has been observed at ice edges (McRoy and Goering, 1974; Bain *et al.*, 1977; Sekerak and Richardson, 1978). Along the Bering Sea shelf, 65% of the annual primary productivity occurs in spring, much of it at the edge of the pack ice in May (Alexander and Cooney, 1979). The bloom may extend 50 km from this ice edge, and the greatest intensity of production is under the pack ice.

Upwelling may be a factor responsible for high productivity at ice edges. Clarke (1978) has shown that wind-driven upwelling at an ice edge is possible, and Buckley *et al.* (1979) have demonstrated its existence near Spitsbergen.

2.4.3 ZOOPLANKTON

Zooplankton, a diverse assemblage of typically small animals, are an important link in oceanic food webs. For the most part they are herbivorous and feed on phytoplankton. The zooplankton, in turn, provide a major source of food for carnivores, notably fish. While the ecology of zooplankton in the Canadian Arctic has only received modest study, their importance can be inferred from numerous studies in other world oceans. They are undoubtedly a mainstay in the diet of many fish, both larval and adult. The size of many fish stocks are directly related to zooplankton production. Other animals also depend on zooplankton. For example, Bradstreet (1976) reported that the dovekie, a small eastern Arctic seabird, sometimes feeds extensively on the planktonic copepod, *Calanus hyperboreus*.

In terms of numbers of species and biomass, copepods are normally the most important component of the zooplankton community throughout the world's oceans (Johnson, 1957). Hopkins (1969) found them to constitute about 80% of the zooplankton biomass in the upper 1,500 m of the Arctic Ocean, and Sekerak *et al.*, (1976a) noted that copepods made up 79% of the zooplankton biomass in the upper 150 m of Lancaster Sound. However, there are many other planktonic species, which are of particular importance to economically important animals in the Arctic. These include ostracods, mysids, amphipods, decapods, cumaceans, euphausiids, combjellies, jellyfish, chaetognaths, and pteropods. In addition, the larvae of numerous benthic invertebrates (e.g. molluscs, echinoderms, polychaetes) are planktonic during the early part of their life cycles. All of these groups occur in the waters of the Canadian Arctic. They may be locally abundant and at times may overshadow the importance of copepods.

Grainger (1965) described the zooplankton of the northwestern Arctic and Beaufort Sea as being composed of three groups (Table 2.4-3). The first group is common and dominant in the surface waters of the Arctic Ocean, the Beaufort Sea and through the Canadian Archipelago to Davis Strait, and as such accounts for the similarity of the zooplankton fauna of these waters (Grainger 1965). The results of more recent work in the Northwest Passage by Mohammed and Grainger (1974), Thomson *et al.* (1975, 1978), Sekerak *et al.* (1976a,b), Bain *et al.* (1977), Buchanan *et al.*, (1977) and Sekerak *et al.*, (1979) have all confirmed this homogeneous nature of the Arctic surface zooplankton. Shih and Laubitz (1978), using a recurrent group analysis, delineated a species assemblage identical to Grainger's (1965) first group. Although characteristic of surface waters, this group is also found in deeper water.

There is an increasing Atlantic influence towards the

TABLE 2.4-3

ZOOPLANKTON GROUPS FROM THE BEAUFORT SEA AND NORTHWESTERN CANADIAN ARCTIC (AFTER GRAINGER, 1965)

GROUP I. Species common in the upper 20-300 m	**GROUP II. Common nearshore shallow water species**	**GROUP III. Common deep water species**
COPEPODA	COELENTERATA	OSTRACODA
Calanus hyperboreus	Sarsia princeps	Conchoecia maxima
C. glacialis	Euphysa flammea	
Pseudocalanus minutus	Halitholus cirratus	COPEPODA
Microcalanus pygmaeus	Eumedusa birulai	
Pareuchaeta glacialis	Ptychogena lactea	Spinocalanus magnus
Metridia longa		Gadius brevispinus
Oithona similis	AMPHIPODA	Gadius tenuispinus
Oncaea borealis		Heterorhabdus norvegicus
	Hyperoche medusarum	
CHAETOGNATA		CHAETOGNATHA
	COPEPODA	
Sagitta elegans		
	Eurytemora herdmani	Eukrohnia hamata
LARVACEA	Limnocalanus grimaldi	
	Acartia clausi	
	Acartia longiremis	
Oikopleura vanhoeffeni		
Clione limacina		
PTEROPODA		
Limacina helicina		
Fritillaria borealis		
COELENTERATA		
Aglantha digitale		
Aeginopsis laurenti		

southeast. Arctic species are present in Davis Strait; however, *Calanus finmarchicus*, an Atlantic species, is the dominant zooplankter (Imperial Oil *et al.* 1978; Esso Resources Canada Ltd., 1979). In nearshore waters of Davis Strait the zooplankton community is almost wholly Arctic in character with minimal Atlantic influence (Grainger *et al.*, 1980).

Grainger's second group of zooplankton is primarily restricted to shallow (20 m), nearshore waters of the Beaufort Sea and is associated with warm brackish waters. In the Archipelago, *Acartia longiremis* is common in Cunningham Inlet, Brentford Bay, Creswell Bay and other semi-enclosed waters (Mohammed and Grainger, 1974; Thomson *et al.*, 1975, 1978; Sekerak *et al.*, 1976b) but not in the open water of Barrow Strait, Wellington Channel or Lancaster Sound (Thomson *et al.*, 1975; Bain *et al.*, 1977; Sekerak *et al.*, 1979) *Limnocalanus grimaldi*, another copepod, is common in locations with a marked estuarine influence (Mohammed and Grainger, 1974; Sekerak *et al.*, 1976b). A major constituent of this second group are several species of jellyfish (coelenterates).

Grainger's (1965) third group is restricted to the deep Atlantic water layer found in the Beaufort Sea and Arctic Ocean. Sekerak *et al.*, (1979) reported all these species in the deep water of Lancaster Sound (Sekerak *et al.*, 1979). However, they probably do not exist in the shallow waters of much of the Archipelago.

Zooplankton standing crop appears to be lower in the passages of the Canadian Arctic Islands than in Lancaster Sound or Frobisher Bay and much lower than that found in parts of the Atlantic Ocean and Bering Sea (Table 2.4-4). In 1979 the biomass of zooplankton was greater in eastern Lancaster Sound and in nearshore waters of Baffin Bay than in offshore Baffin Bay (Sekerak *et al.*, 1979). The standing crop of zooplankton in Lancaster Sound appears to be greater than that of Frobisher Bay and approaches values found in the relatively productive Bering Sea (Table 2.4-4). This may be due to the previously discussed regional differences in primary production.

Variations in the vertical distribution of zooplankton in Canadian Arctic waters have been reported by a number of workers. In Lancaster Sound, the maxi-

TABLE 2.4-4

COMPARISON OF THE MEAN BIOMASS (mg/m^3) OF ZOOPLANKTON FROM ARCTIC AND SUBARCTIC WATERS

Location	Date	Depth Considered	Mean Biomass (mg/m^3)	Source
Bering Sea	Summer	0-150	402.7	Ikeda and Motoda (1978)
Canadian Arctic Islands				
Foxe Basin	Summer	0-100	55	Grainger (1962)
Assistance Bay, Cornwallis Is.	July-Aug.	0-50	80	Mohammed & Grainger (1974)
Slidre Fiord, Ellesmere Is.	July-Aug.	0-50	84	Mohammed & Grainger (1974)
Creswell Bay, Somerset Is.	July-Aug.	0-50	192	Mohammed & Grainger (1974)
Wellington Channel	June	0-50	156	Bain et al. (1977)
Bridport Inlet	June	0-50	44	Buchanan et al. (1977)
	August	0-50	154	Buchanan et al. (1977)
	August	0-120	34	Buchanan et al. (1977)
Lancaster Sound	July 23 -	0-50	399.9	Sekerak et al. (1979)
	October 10/78	0-150	189.8	
		0-250	156.5	
	July-Sept./76	0-150	171-284	Sekerak et al. (1976b)
Frobisher Bay, Baffin Is.	Summer	0-50	160-330	Grainger (1971b)
Atlantic Ocean				
Labrador Current	Fall	0-200	1072	Be et al. (1971)
Norwegian Sea (temperate)	Yearly	0-100	> 500	Be et al. (1971)
Norwegian Sea (subarctic)	Yearly	0-300	> 100	Be et al. (1971)

mum zooplankton biomass was found in the upper 50 m (Sekerak *et al.*, 1976a, 1979). The most common copepods (Figure 2.4-6) and the herbivorous pteropod *Limacina helicina* (Figure 2.4-7) were concentrated near the surface as were the predaceous *Clione limacina* (Figure 2.4-7), hyperiid amphipods (Figure 2.4-7) and cnidarians (Figure 2.4-8). The waters at

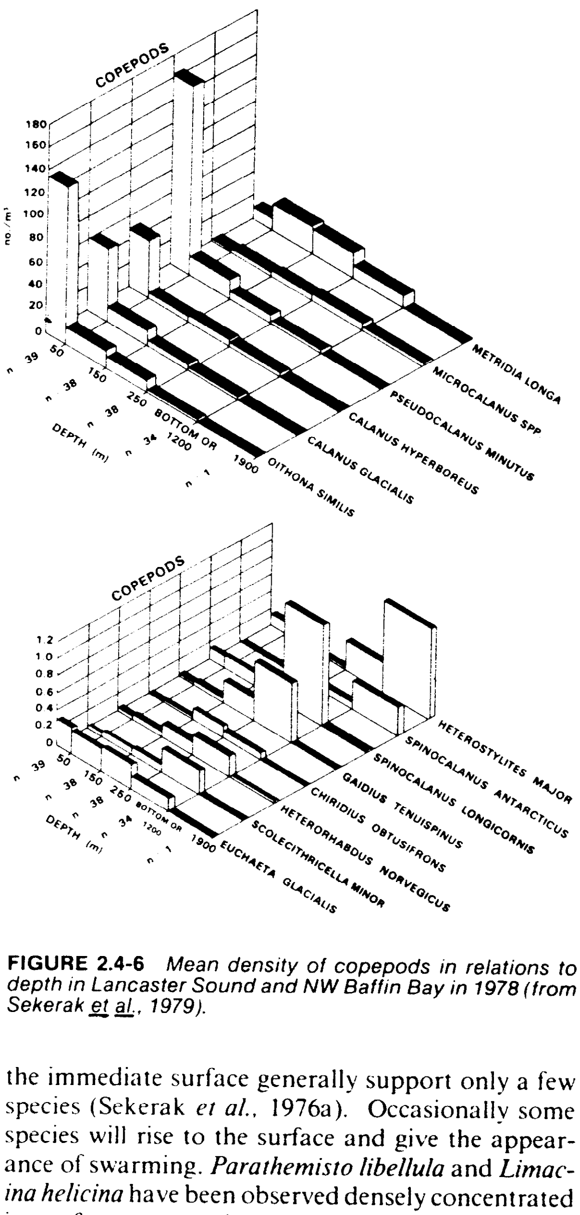


FIGURE 2.4-6 *Mean density of copepods in relations to depth in Lancaster Sound and NW Baffin Bay in 1978 (from Sekerak et al., 1979).*

the immediate surface generally support only a few species (Sekerak *et al.*, 1976a). Occasionally some species will rise to the surface and give the appearance of swarming. *Parathemisto libellula* and *Limacina helicina* have been observed densely concentrated in surface waters (Dunbar, 1946; Sekerak *et al.*, 1976a). Zooplankton concentrated in this fashion may serve as an important source of food for vertebrates.

Major seasonal differences in the abundance and size composition of zooplankton result from timing of reproduction and development. Many herbivorous species such as *Pseudocalanus minutus*, *Calanus glacialis*, and *Limacina helicina* reproduce during the spring and summer, with the result that their young are abundant during the productive period of the year. A few species such as *Calanus hyperboreus* reproduce during the winter, although little development occurs until food becomes abundant in the summer.

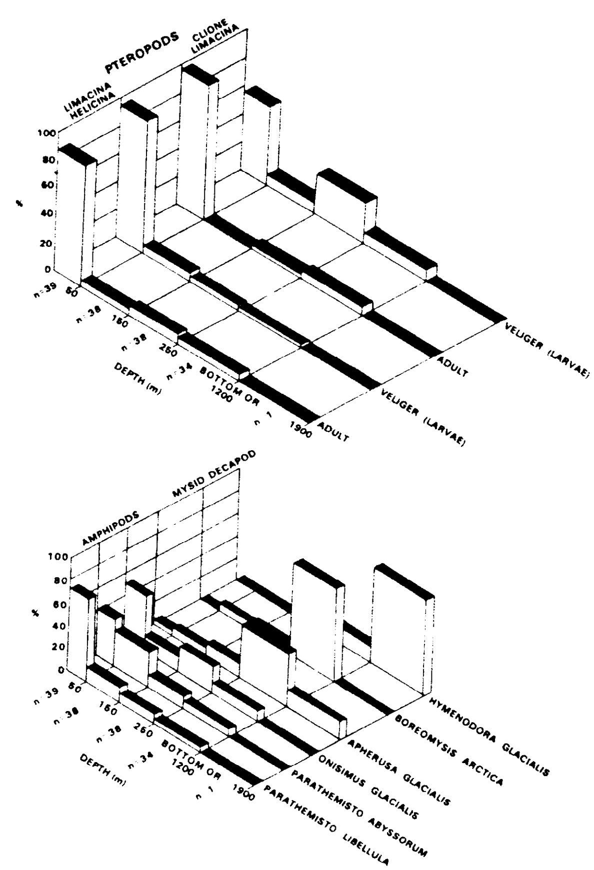


FIGURE 2.4-7 *Percent of mean total numbers of pteropods, amphipods, mysids and decapods in relation to depth in Lancaster Sound and NW Baffin Bay in 1978 (from Sekerak et al., 1979).*

There have been a number of studies on life cycles of Arctic zooplankton (Grainger, 1959, 1971b; Cairns, 1967; Griffiths and Dillinger, 1981). Studies such as these provide the general outline for zooplankton life cycles in Arctic waters.

In the Arctic Islands, *Calanus hyperboreus* exhibits a typical High Arctic life cycle of two years. Adult males and females with attached spermatophores were found in late December, 1978 (Foy, 1978). Development from egg through six naupliar (larval) stages takes approximately three weeks (Grainger, 1959). However, in the Arctic Islands, as in other areas, copepodite I stages were not found in the plankton until June (Figure 2.4-9), indicating that hatching occurs in the spring. Young C. *hyperboreus*

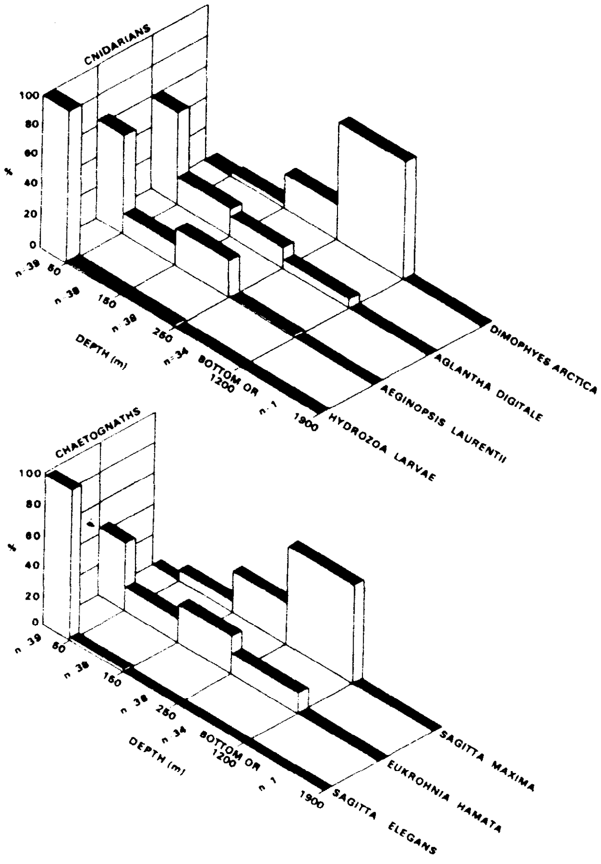


FIGURE 2.4-8 *Percent of mean total numbers of cnidarians and chaetognaths in relation to depth in Lancaster Sound and NW Baffin Bay in 1978 (from Sekerak et al., 1979).*

develop to stage III or IV copepodite during the summer and overwinter in these stages. They metamorphose to stage V during the following summer. Foy (1978) observed metamorphosis of stage V individuals to the adult form in December in Barrow Strait.

Sekerak *et al.*, (1979) found regional differences in the timing of reproduction and duration of life cycles of some herbivorous species throughout the Lancaster Sound and northwest Baffin Bay area. It appeared that large patches of water contained groups of copepods in different stages of development (Figure 2.4-10). Some species, such as *Calanus hyperboreus*, have a two year life cycle throughout most of this study area, but there appeared to be some populations with a one year life cycle.

The length of copepod life cycles appears to be somewhat variable. One to three years may be required for the completion of the life cycles depending on environmental factors such as food availability and temperature. In more northerly regions, more time is normally required for maturation and reproduction although local conditions may over-ride this general trend (Cairns, 1967; Dawson, 1978). Tidmarsh (1973) hypothesized a one year life cycle for some copepods in the 'North Water' of northern Baffin Bay, an unusual area of the High Arctic where open water persists for much or all of the year. Two year life cycles are known from other regions with more typical ice conditions at similar or even lower latitudes (Grainger, 1959; Foy, 1978).

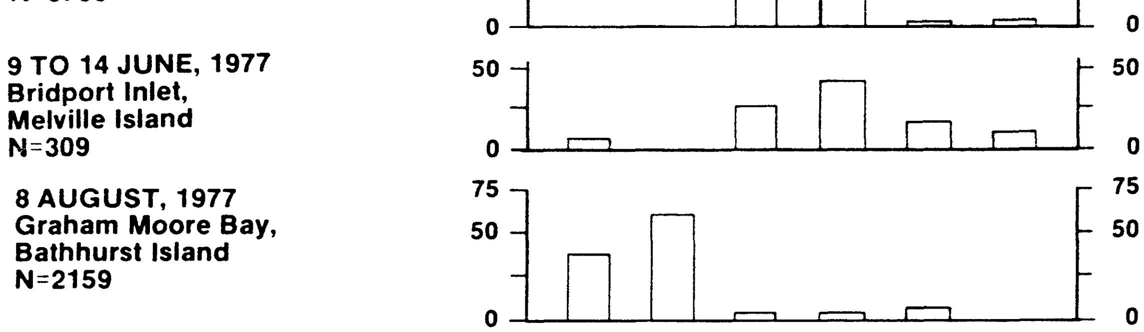


FIGURE 2.4-9 *Life stage frequency distributions of Calanus hyperboreus at different times and locations. N refers to the number of animals examined. (From Foy, 1978). See Figure 2.4-2 for map locations. (cont'd on p. 2.71)*

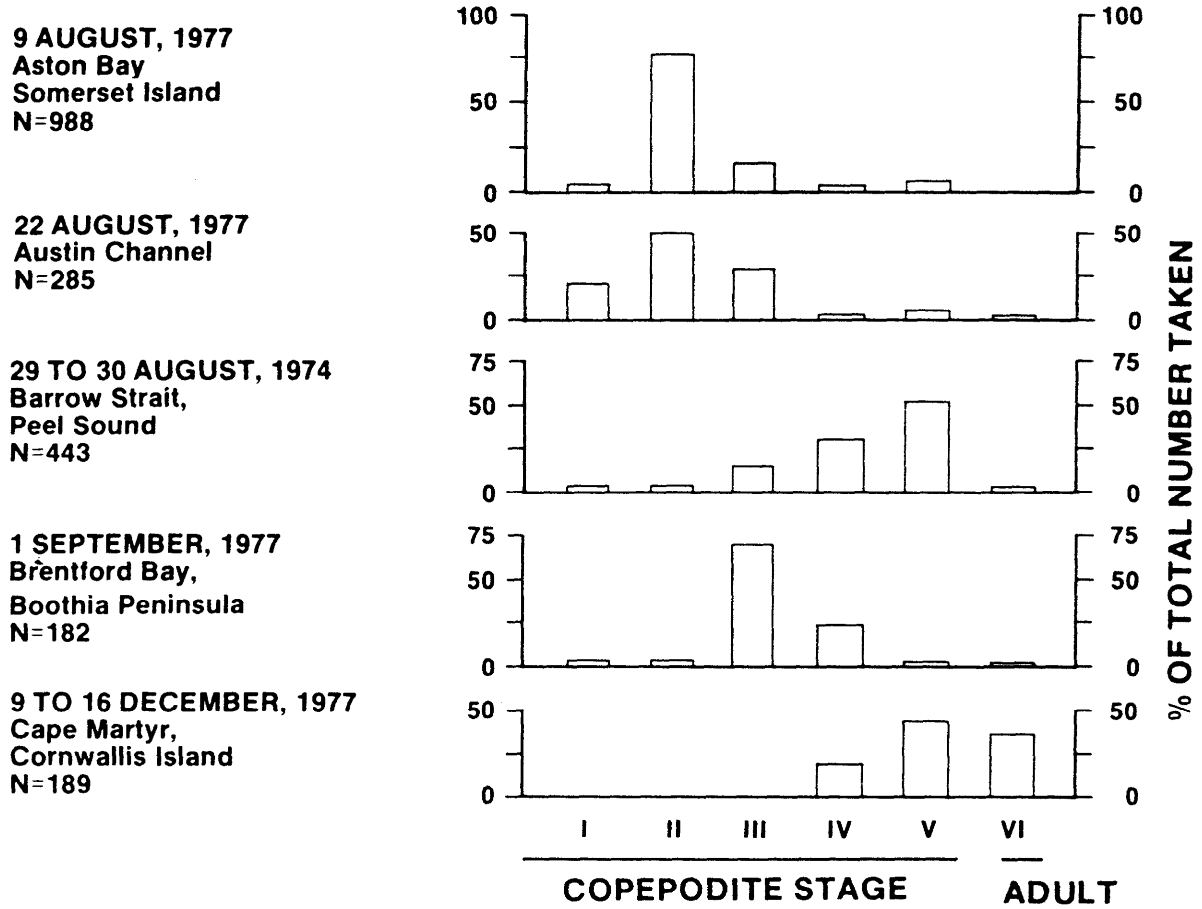


FIGURE 2.4-9 (cont'd)

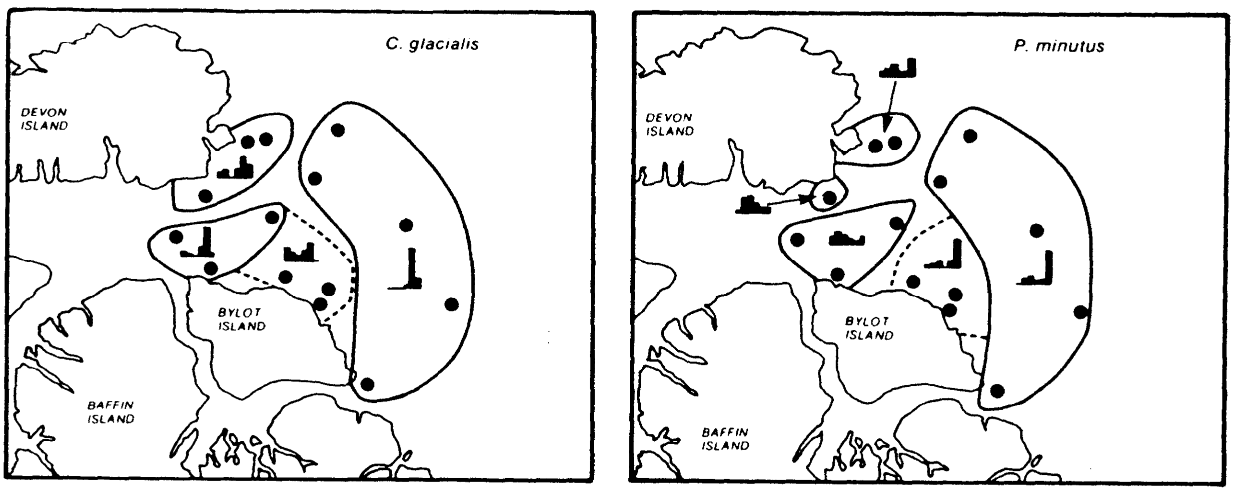


FIGURE 2.4-10 *Identification of similar areas of water in Lancaster Sound and NW Baffin Bay through the use of stage frequencies of the copepods Pseudocalanus minutus, Calanus glacialis and C. hyperboreus. Stage frequencies (as a percent) associated with each area are illustrated by histograms, each of which show averages of frequencies at all stations in the area sampled between July 23 and August 4, 1975. Possible subareas are designated by a dashed line. (From Sekerak et al., 1979). (Continued.)*

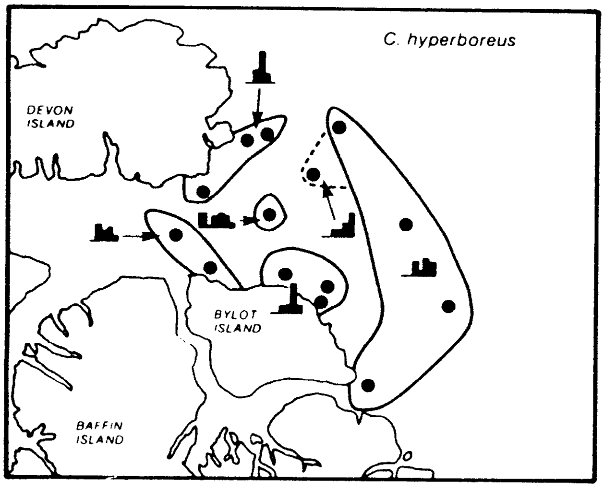


FIGURE 2.4-10 *(Cont'd.)*

2.4.4 UNDER-ICE COMMUNITIES

The undersurface of sea ice supports a complex community of plants and animals living within the bottom few centimetres of the ice and on the under-ice surface. Under-ice biota are believed to play an important role in the ecology of high latitude ecosystems. This is because they make a significant contribution to the annual production of organic matter and by extending the period during which this matter is available to other organisms (Usachev, 1949; Apollonio, 1961; Meguro *et al.*, 1966; Dunbar, 1968; Alexander, 1974; McRoy and Goering, 1974, 1976; Horner, 1976, 1977). The concentration of macroscopic herbivores on the undersurface of the ice, probably with less protective cover than exists on the sea floor, may also expose them to larger carnivores such as fish and seals, although this remains to be demonstrated.

2.4.4.1 Ice Flora

(a) Species Composition

Microalgae are present in low abundance throughout sea ice from the time it forms (Horner, 1977) and may occur between layers of clear ice (Plate 2.4-1) (Usachev, 1949; Bursa, 1961). However, the highest concentration of microalgae occurs 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). This epontic community is dominated by diatoms, primarily pennate forms, both motile and sessile, that occur as colonies within brine cells in the interstices of vertically oriented ice crystals (Meguro *et al.*, 1967; Horner and Alexander, 1972b). Any of the pennate diatom species *Nitzschia frigida, N. cylindrus, N. grunowii, Navicula pelagica, N. marina, N. quadripedis and Achnanthes taeniata* can dominate the community. The dominant species can vary from year to year or from week to week at a given location; or over relatively short distances at a given time; or remain relatively constant, both in time and space. Cross (1980) found that one of two species of *Nitzschia* predominated in 39 of 41 samples collected from May 12 to July 2, 1979, at a number of stations in Pond Inlet.

Centric diatoms usually constitute only a small part of the epontic diatom community. However, some species occur regularly in small numbers (e.g. *Chaetoceros* spp., *Thalassiosira* spp. as noted by Buchanan *et al.*, 1977; Horner, 1977; Thomson *et al.*, 1978) or occasionally in relatively high numbers (e.g. *Melosira* spp. in Hsiao, 1979). Dinoflagellates, flagellates and cryptomonads form the remainder of the epontic microalgal community.

The overall composition of this algal community varies throughout the year. Horner (1976) reported that flagellates were always the most abundant algae in new ice forming in autumn, whereas Meguro *et al.*, (1966, 1967) observed only pennate diatoms in sea ice cores taken during July.

(b) Standing Stocks

The available data on standing stocks of under-ice algae from samples taken in the Northwest Passage and adjacent areas are summarized in Table 2.4-5. The abundance of microalgae is seen to vary considerably, both seasonally and spatially.

Cross (1980) found significant variations in microalgal densities in Pond Inlet among-stations, and a large decrease in densities from 22.3 x 10^6 cells/L to 6.2 x 10^6 cells/L between May and June. Standing stocks reported for late June in Pond Inlet were similar to values recorded elsewhere in the central eastern Arctic in late May and early June by Buchanan *et al.*, (1977) and Thomson *et al.*, (1978).

Extremely low standing stocks of ice microalgae were found during March in Eclipse Sound (Hsiao, 1979, 1980). No further data are available on pre-bloom algal densities in the Northwest Passage. It is likely, however, that the slow increase from January to April reported at Point Barrow, Alaska (Alexander *et al.*, 1974; Horner, 1977), also occurs in the central and eastern Arctic.

Concentrations of chlorophyll *a* in the undersurface of the Davis Strait ice pack in April and May were much lower than those recorded for other polar regions (MacLaren Marex, 1979a; Table 2.4-5), and were approximately equal to values from the Gulf of St. Lawrence (Dunbar and Acreman, 1980).

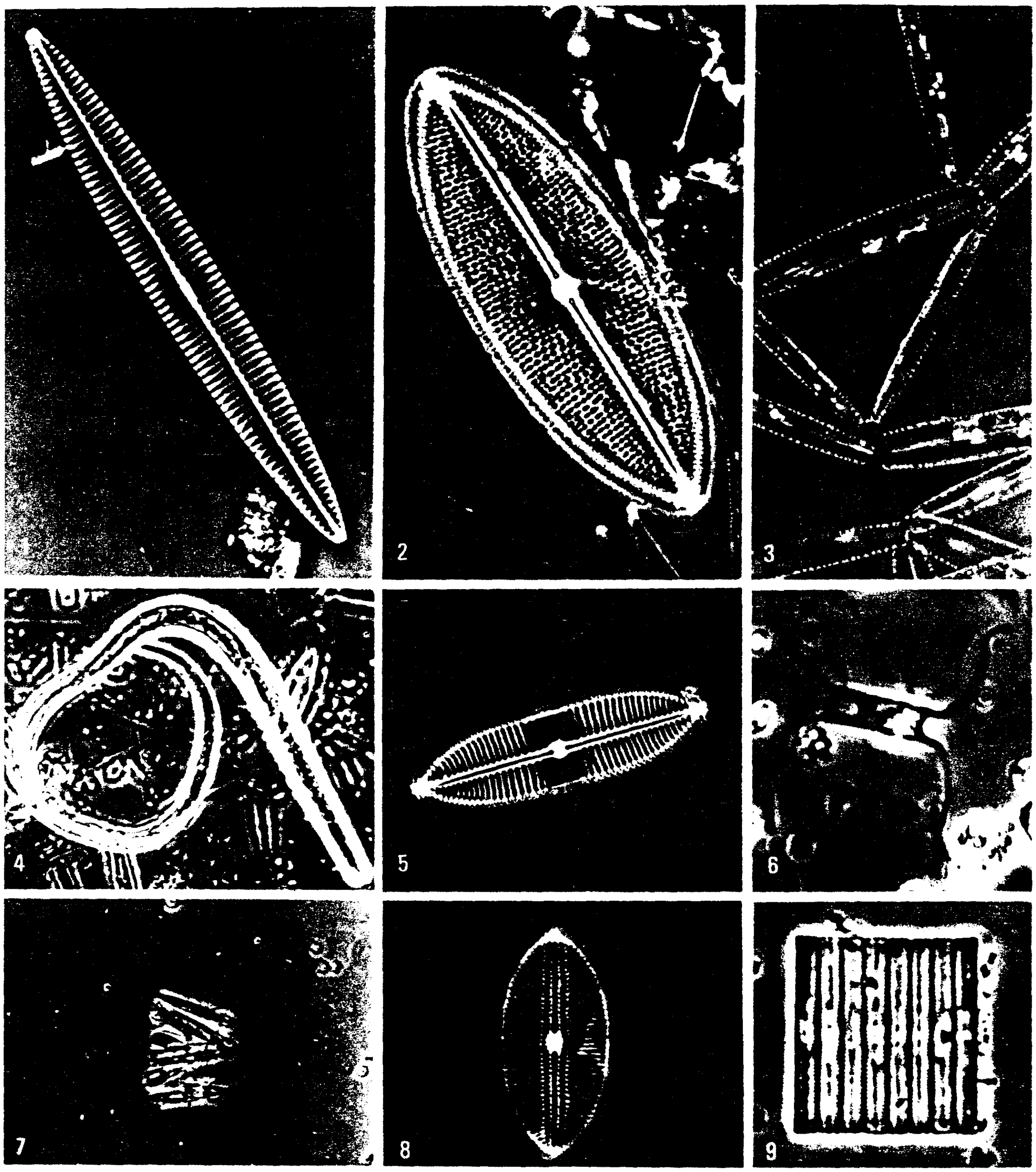


PLATE 2.4-1 *Typical group of epontic microbiota found in or under the ice in the Arctic. Sub photos 1, 2, 3, 5, 7, 9 show pennate or rod-shaped diatoms, which generally dominate the community. Chaetoceros, a centric diatom is shown in 6 and a nematode worm is illustrated in 4. (Courtesy, Arctic Laboratories Ltd.).*

(c) Primary Productivity

Production rates of epontic microalgae based on laboratory or *in situ* incubation of samples collected with a SIPRE corer (expressed as mg $C/m^3/h$) and those based on diver-operated *in situ* incubations (expressed as mg $C/m^2/h$) are summarized here.

Based on the data from 1973 (Alexander *et al.*, 1974) and certain assumptions about diel regimes and the seasonal productivity curve (Alexander, 1974), an annual epontic productivity of 5 g C/m^2 (25 to 30% of total annual primary productivity) was estimated for coastal regions near Barrow, Alaska (Alexander, 1974). Grainger (1975) estimated annual epontic productivity in Frobisher Bay at 1 to 10 g C/m^2. In comparison, Grainger (1975) estimated phytoplankton productivity in Frobisher Bay at 40 and 70 g

TABLE 2.4-5

BIOMASS (EXPRESSED AS mg chl a/m³ and /m²) & STANDING STOCK (CELLS/L) OF EPONTIC ALGAE DETERMINED FROM SAMPLES TAKEN IN THE CANADIAN ARCTIC

		Biomass (mg chl a/m³)			Biomass (mg chl a/m²)			Standing Stock (cells/L x 10⁶)				
Location	**Dates**	**Mean**	**Max.**	**n**	**Mean**	**Max.**	**n**	**Mean**	**Max.**	**n**	**Method**	**Authority**
S. Melville Island	7-13 June 77	—	—	—	—	—	—	4.95	12.19	13	2	Buchanan et al. (1977)
Barrow Strait	8,13 May 73	—	—	—	15.2	22.0	15	—	—	—	?	Welch & Kalff (1975)
Austin Channel/ Barrow Strait	1-14 May 74	—	—	—	10.9	12.4	3	—	—	—	1	Thomson et al. (1975)
N.E. Boothia Pen.	22-27 May 77	—	—	—	—	—	—	5.10	7.13	6	2	Thomson et al. (1978)
Jones Sound	4-13 June 61	409.6	645.0	9	15.5*	23.0*	7	—	—	—	1	Apollonio (1965)
	16-27 June 61	82.3	196.0	6	—	—	—	—	—	—	1	Apollonio (1965)
	11 May - 12 June 63	646.4	1460.0	18	10.7*	23.0*	17	—	—	—	1	Apollonio (1965)
Eclipse Sound	15-27 May 76	—	—	—	—	—	—	72.77	160.23	9	1	Hsiao (1979)
	21 March 77	—	—	—	—	—	—	0.03	0.04	3	1	Hsiao (1979)
Pond Inlet (fast ice)	2-20 May 79	556.9	2344.8	44	(111.3)	(469.0)	44	22.31	44.14	12	1,2	Cross (1980)
	18 June - 2 July 79	259.3	818.7	46	(51.9)	(163.7)	46	6.19	16.15	14	1,2	Cross (1980)
(ice edge)	2-9 May 79	315.3	1149.2	44	(63.1)	(229.8)	44	—	—	—	1	Cross (1980)
	18 June - 2 July 79	10.7	49.3	46	(2.1)	(9.9)	46	1.39	6.71	15	1.2	Cross (1980)
Frobisher Bay	9 Jan - 23 Mar 70	16.0	44.1	3	—	—	—	—	—	—	1	Grainger (1971a)
	27 May, 13 June 69	37.4	66.9	2	—	—	—	—	—	—	1	Grainger (1971a)
	21 May - 13 June 70	39.7	141.5	4	(4.0)	4.6*	4	—	—	—	1	Grainger (1971a)
	27 April - 16 June 71	162.0	300.6	7	(16.2)	9.1*	7	—	—	—	1	Grainger (1971a)
Davis Strait	20-28 April 78	4.9	40.9	58	(0.3)	(2.5)	58	—	—	—	1	MacLaren Marex Inc. (1979a)
	4-17 May 78	11.3	160.4	152	(0.7)	(9.6)	152	5.91	30.37	25	1	MacLaren Marex Inc. (1979a)

Biomass: * data given as mg/m³ and mg/m² -method of conversion not stated. ( ) indicates conversion of mg/m³ (first column) to mg/m² of ice surface by multiplying by core length (m).

Method: 1: SIPRE CORER 2: Diver-operated corer.

C/m² in 1968 and 1969, respectively.

Other workers have also measured primary productivity of epontic algae. Andersen (1977) estimated annual productivity of ice algae at 0.15 g C/m² under thin new ice off the coast of west Greenland. This was only 0.2% of total planktonic production, and was apparently related to a small algal standing crop. Welch and Kalff (1975) estimated the annual productivity of epontic algae at 15 g C/m²/year offshore from Resolute, Cornwallis Island. They estimated that this comprised approximately 33% of the total annual primary production.

In summary, in some areas, spring epontic primary production may represent a considerable fraction of the total annual primary production in the water column. However, many of the available estimates of epontic production are extrapolated from few data and are based on assumptions that need to be tested further.

2.4.4.2 Epontic Fauna

A variety of microscopic fauna have been reported in the soft bottom layer of sea ice. At Barrow, Alaska, heliozoans, hypotrichous ciliates and nematodes are common (Plate 2.4-1) while turbellarians, polychaete larvae and harpacticoid copepods occurred sporadically (Horner and Alexander, 1972 a,b; Horner *et al.*, 1974). The epontic fauna in Austin Channel and West Barrow Strait was made up of ciliates, nematodes and cyclopoid copepods (Thomson *et al.*, 1975) while ciliates and nematodes were found on the undersurface of ice in Bridport Inlet, Melville Island by Buchanan *et al.*, (1977). Data reported by Thomson *et al.*, (1978) for Brentford Bay, Boothia Peninsula indicated that copepods made up 79% of the total metazoa. Nematodes and polychaete larvae were also abundant. MacLaren Marex Inc. (1979a) reported ciliates, nematodes and harpacticoid copepods from the outer edge of the Davis Strait ice pack.

Gammarid amphipods are the most commonly occurring macroinvertebrates on the undersurface of the ice (Plate 2.4-2). Of these, *Gammarus setosus, G. wilkitzkii and Gammaracanthus loricatus* are the largest (up to 50 mm long, 1.5 g in weight) and are dominant in some inshore communities in spring (Golikov and Averincev, 1977; Thomson *et al.*, 1978). *Gammarus setosus and G. loricatus* were common near the ice in Resolute Bay in December (Green and Steele, 1975). An unidentified species, probably one of these two, was present in small cavities in the undersides of icebergs in Resolute Bay during August (Emery, 1973). In the Beaufort Sea, *Gammaracanthus loricatus* occurred on the underside of ice cakes during break-up of landfast ice (Divoky, 1978). These species are often associated with ice cracks, stalactites (under-ice extensions of brine drainage channels), 'chimneys' and pockets, as well as being evenly distributed on flat under-ice surfaces. Previous reports have described *Gammarus setosus* and *Gammaracanthus loricatus* as littoral and intertidal species (MacGinitie, 1955; Steele and Steele, 1970) and *G. wilkitzkii* as being associated with old ice (Green and Steele, 1975). However, recent information indicates that the distribution of these species under ice cover is less specific than previously reported.

The smaller gammarid amphipods of the genus *Onisimus* (Plate 2.4-2) are abundant and widespread. They are found singly or in groups in small holes in the ice undersurface. Others are scattered on the ice undersurface. Large swarms of *Onisimus litoralis* have been observed both on and just under the ice undersurface. This species was numerically dominant at nearshore locations in Brentford Bay and Bridport Inlet in spring and was abundant in December in Resolute Bay (Green and Steele, 1975). *Onisimus glacialis* dominated offshore samples from Aston Bay (northeast Somerset Island), and Bridport Inlet in spring even though its abundance was greatly underestimated because most individuals were within the ice (Thomson *et al.*, 1978). It was also dominant under fast ice near Cornwallis Island in July (LGL Ltd., unpubl. data).

Another amphipod, *Apherusa glacialis*, was the dominant amphipod at offshore stations in Pond Inlet (Cross, 1980) but was not a prominent member of the spring epontic community under fast ice in Bridport

PLATE 2.4-2 *Gammarid amphipods, as shown here, are the most commonly occurring macroinvertebrates on the undersurface of the ice. These were photographed from under the ice near Pond Inlet. (Courtesy, W.E. Cross, LGL Ltd.).*

Inlet, Brentford Bay or Aston Bay. This species occurs on the ice surface and in small holes, both in fast ice and pan ice (W.E. Cross, pers. comm.). It was extremely abundant under ice floes in August near Barrow, Alaska (MacGinitie, 1955), particularly under multi-year ice cakes (Divoky, 1978), and also under pan ice in the Canadian Arctic (Emery, 1973; Thomson *et al.*, 1978; Cross, 1980). It was not, however, reported by MacLaren Marex Inc. (1979a) under the outer edge of the Davis Strait ice pack in April or May.

Other amphipod species have been collected from the under-ice surface in small numbers, often at single locations. These include *Anonyx nugax* (Thomson *et al.*, 1975), *Atylus carinatus* (Buchanan *et al.*, 1977), *Boeckosimus edwardsi, Anonyx laticoxae* (Thomson *et al.*, 1978), *Parapleustes* sp. (MacLaren Marex Inc., 1979a), and *Eusirus holmi* (Cross, 1980). These less common species may have occurred in the near-ice plankton rather than on the ice (see Thomson *et al.*, 1978). They might also dominate the epontic community in other locations though no currently available data support this possibility.

Mysids *(Mysis litoralis, M. oculata, M. polaris)* occur in small numbers on the under-ice surface, and at times have been observed in large swarms just under the ice in spring (Thomson *et al.*, 1978). Mysids were also observed hovering beneath the larger icebergs present in Resolute Bay in August (Emery, 1973).

The epontic community depends not only on the photosynthetic production of the microalgae but also on the heterotrophic activity of a number of microscopic organisms including bacteria, fungi, colorless flagellates and ciliated protozoans (Horner, 1976, 1977). The abundance of bacteria (Horner, 1976) and their uptake of labelled organic substrates (Horner and Alexander, 1972a) indicate the existence of an active microbial population which may be important food for small animals of the epontic community. Horner and Alexander (1972a) have observed that flagellates ingest diatoms while ciliated protozoans graze on diatoms, bacteria and other small organic particles.

The epontic flora provide the food for a diverse group of larger underice metazoans including amphipods, copepods and worms. Evidence for this comes from direct observations of amphipods feeding under fast ice (Apollonio, 1961, 1965; Horner, 1972, 1977; Welch and Kalff, 1975; Buchanan *et al.*, 1977) and from the presence of partially digested ice diatoms in the digestive tracts and feces of amphipods, copepods and worms (Horner and Alexander, 1972a, 1972b; Buchanan *et al.*, 1977; Bradstreet and Cross, 1980). Bradstreet and Cross (1980), for example, demonstrated that *Apherusa glacialis* and *Onisimus glacialis*, two major species of under-ice amphipods, fed solely on ice microalgae. Apollonio (1961) suggested that young amphipods may find their first food on the bottom of the ice. This was later confirmed by diver observations and fecal pellet examination (Buchanan *et al.*, 1977).

Various predator species probably depend, to some extent on the herbivores of the epontic community. For example, *Gammaracanthus loricatus* preys on *Gammarus setosus* (Green and Steele, 1975) and *Onisimus glacialis* will attack herbivorous animals (W. Griffiths, pers. comm.). The importance of these predatory relationships to energy flow in the epontic community has not been demonstrated.

The extent to which epontic biota are food for higher trophic levels (fish, birds and mammals) is also not clear (see Sekerak and Richardson, 1978). 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, 1980). They were also fed upon by Arctic terns, Sabine's gulls and red phalaropes during the landfast ice and general ice break-up periods at Cooper Island, Alaska (Divoky, 1978). Under-ice amphipods may be important in the diet of ringed seals, at least during the haulout season (Finley, 1978). Arctic cod *(Boreogodus saida)* are thought to feed in part on epontic biota (Andriashev, 1970; McAllister, 1975) although few quantitative data are available. The diets of cod collected under the ice in Pond Inlet contained some under-ice amphipods, but were dominated by planktonic copepods (Bradstreet and Cross, 1980).

The Arctic cod, in turn, is important in the diet of a variety of sea birds including kittiwakes, murres, guillemots, and at times fulmars in the eastern and central Arctic (Bradstreet 1976, 1977). Kittiwakes, ivory gulls, Ross gulls and apparently Arctic terns and guillemots in the eastern Chukchi and Beaufort Seas also prey on Arctic cod (Divoky 1978). Various marine mammals including ringed seals, white whales, harp seals and narwhals also use Arctic cod as food (McLaren, 1958; Finley, 1978; Davis and Finlay, 1979; Davis *et al.*, 1979).

Thus, the epontic community seems to be of some importance to animals with actual or potential economic importance. However, not all production in the epontic community is utilized *in situ*. Meguro *et al.*, (1966, 1967) indicated that some of the algal biomass inhabits the ice above a layer of clear, hard ice which apparently restricts grazing. Some of the ice algae are also sloughed off into the water (Horner, 1976, 1977; Cross, 1980). As the bloom of ice microalgae terminated, chlorophyll *a* content of the water column increased, although a corresponding increase in productivity was not observed (Clasby *et* *al.*, 1973). This suggests that ice algae sloughed off into the water column do not continue to grow, nor do they become a viable part of the benthic microalgal community (Mathebe and Horner, 1974). They may provide a source of food for planktonic or benthic detritivores (Alexander, 1974; Horner, 1977). These algae probably are also decomposed and serve as a source of regenerated nutrients.

2.4.5 BENTHIC COMMUNITIES

The benthic (bottom-living) communities of Canadian Arctic waters have been the subject of studies which are reviewed in this section. The larger algae (macroalgae) and the invertebrate animals are considered.

2.4.5.1 Macrophytic Algae

Leè (1973) reports 175 species of marine macrophytes (seaweeds) from the Canadian Arctic, with most being of temperate Atlantic origin. Most grow wherever a suitable substrate is available within the euphotic (sunlit) zone. The more protection an area has from waves and currents, the less stringent the substrate requirements become (Lee, 1973).

In general, the standing crop of macroalgae decreases from east to west in the North American Arctic with the north coast of Alaska being almost barren of macrophytic algae (Mŏhr *et al.*, 1957; Lee, 1973). This change in abundance is related to a westward increase in the proportion of the bottom that is covered by soft sediments and a decrease in the period of open water. However, luxuriant stands of kelp and other algae are found in western locations that have a rocky seabed (MacGinitie, 1955; Mŏhr *et al.*, 1957; Buchanan *et al.*, 1977; Dunton and Schonberg, 1979). In all areas the intertidal and barren zones are sparsely populated by macrophytes, primarily due to the effects of ice on the substrate in this zone.

The commmunity composition and zonation of macrophytes is about the same as that along the Canadian east coast and southern Baffin Island, but in the High Arctic each zone begins at a deeper depth (Thomson *et al.*, 1978). On the Canadian east coast and on southern Baffin Island, *Fucus* is found in the intertidal zone with the kelp zone beginning in the low intertidal. In the High Arctic, *Fucus* is found in the barren zone and the kelps are generally not found shallower than a depth of 3 to 5 m. However, in a few protected locations in the High Arctic, *Fucus, Enteromorpha* and some other macrophytes are found in the intertidal zone.

The barren zone in Brentford Bay, Boothia Peninsula, was colonized by clumps of *Fucus distichus* and scattered patches of *Sphacelaria arctica, S.plumosa, Chaetomorpha* spp. and *Rhizoclonium riparium* (Thomson *et al.*, 1978). Bottom coverage by these plants at 3 m was 15.8%. At Cape Hatt, northern Baffin Island, these understory species formed an almost continuous mat at 3 m with a mean biomass of 739 g/m^2 (Cross and Thomson, 1981). Dominant species were *Pilayella littoralis, Dictyosiphon foeniculaceous and Stictyosiphon tortilis.*

The highest biomass and greatest diversity of plants is found immediately below the barren zone (Wilce, 1973). Kelps, especially *Laminaria solidungula, L. saccharina, L. longicruris, Agarum cribrosum and Alaria grandifolia,* are the most important species in this *Laminaria* zone, which extends to a depth of 10 m (Wilce, 1973; Thomson *et al.*, 1978; Thomson and Cross 1980). The biomass of kelp at 5 and 10m in Lancaster Sound and Northwest Baffin Bay was quite high. Values over 1 kg/m^2 were recorded in 8 of 12 locations sampled. The distribution of kelp on the bottom was generally patchy. The biomass of the smaller macrophytes was highest at locations with little or no kelp canopy (Thomson and Cross, 1980). The most common of these species, which also form the understory in kelp beds were *Neodilsea integra, Desmarestia aculeata, Halosaccion ramentaceum and Phyllophora truncata.*

Below this, extending from 10 to 50 m, is a zone dominated by *Agarum cribrosum.* Within this depth range the biomass and number of species decreases rapidly with depth as light decreases (Wilce, 1973). A considerable diversity of understory species also occurs in this zone (Wilce, 1973). Below 50 m the vegetation consists primarily of a few encrusting species of algae.

Recent work on the productivity of Canadian Arctic *Laminaria* (Chapman and Lindley, 1980) indicates that growth is governed by concentrations of dissolved inorganic nitrogen. During the ice free period nitrate concentrations and growth rates were low. Most of the annual growth took place in winter and spring under the ice when nutrient concentrations were high. This growth pattern, which is similar to that found on the Canadian east coast (Mann, 1972), appears to be unhindered by thick ice cover (Chapman and Lindley, 1980).

In general, macrophytic algae will establish themselves wherever substrate, ice, and other environmental conditions permit. Where the algae are well developed, they provide a diverse habitat for marine animals including fish (Mŏhr *et al.*, 1957; Thomson *et al.*, 1975; Bain *et al.*, 1977). Much of the production of macrophytic algae, which may be very high, enters the detritus food web (Mann, 1972; Miller and Mann, 1973).

2.4.5.2 Benthic Animals

Benthic animals are closely associated with the seabed and can be grouped into three categories: infauna, epibenthos and epifauna.

Infauna are the animals living in or on soft substrates and include bivalves (clams), polychaetes (worms), ophiuroids (brittlestars) and some amphipods. They are typically filter feeders or derive their food from bacteria associated with ingested organic matter in sediments (Wildish, 1970).

Epibenthic animals are active swimmers which remain close to the seabed. This group includes mysids and decapods (crabs), as well as some amphipods and isopods. Decapods feed on detritus and phytobenthos (Squires, 1968). Isopods are scavengers but may feed on plant material or living animals (Bray, 1962). Arctic mysids feed primarily on phytoplankton while amphipods, as a group, feed omnivorously.

Animals of the epifauna live more or less permanently attached to the substrate and include barnacles, hydroids, anemones, bryozoans and mussels. Most are filter feeders that feed on phytoplankton, detritus, suspended sediment or small zooplankters from the water.

(a) Infauna

In the Canadian Arctic Islands, ice scour and variations in temperature and salinity render the upper few metres of the seabed uninhabitable to plants and infaunal animals (Ellis, 1960). In the Arctic Islands and along northern Baffin Island this 'barren zone' extends to a depth of 2 to 5 m (Ellis, 1960; Thomson *et al.*, 1978; Thomson and Cross, 1980). In Lancaster Sound the barren zone reaches a depth of 15 m or more (Thomson and Cross, 1980), probably a result of heavy waves acting on pan ice and increasing the depth of ice scour. The sole infaunal species consistently found in the barren zone is the tunicate *Rhizomolgula globularis* (Thomson and Cross, 1980).

Benthic animals of the infauna reach their greatest abundance between the lower edge of the barren zone (where it exists) and a depth of 50 to 100 m. At these depths bivalves are the principal group of infaunal animals and the Arctic *Macoma* community is the dominant assemblage (Plate 2.4-3). The nature of this community varies with substrate and location. In Lancaster Sound and northwest Baffin Bay, Thomson and Cross (1980) found a deep water (to 100 m) *Macoma* community dominated by the bivalve *M. calcarea* and a shallow community characterized by *M. moesta*. At Cape Hatt in Eclipse Sound the community structure at 7 m was spatially consistent and was characterized by *M. calcarea* (Cross and Thomson, 1981). However, in Creswell Bay, Somerset Island, Sekerak *et al.*, (1976b) noted three variations of the *Macoma* community within the outer portion of the bay (Table 2.4-6). In most areas under the influence of Arctic water *M. calcarea* is rare and *M. moesta* is the dominant species of *Macoma* (Ockelmann, 1958). In these areas the shallow water infauna is often dominated by the clam *Astarte borealis* (Buchanan *et al.*, 1977).

This shallow water *Macoma* community does not occur under certain conditions. A community characterized by the bivalve *Portlandia arctica*, is often found in areas with fine silt off streams and rivers (Ellis, 1960). This bivalve is usually the only dominant species in such areas and reaches densities of 2,866 /m^2 (Buchanan *et al.*, 1977). These workers noted that *P.arctica* dominated the benthos off the Mecham River in Bridport Inlet, Melville Island but that it was progressively replaced by *Astarte borealis* with increasing distance from the river (Figure 2.4-11).

Marine worms were the dominant group of infaunal animals below a depth of 50 to 100 m in Barrow Strait and Peel Sound (Thomson *et al.*, 1975). In Lancaster Sound and northwest Baffin Bay polychaetes were dominant at depths greater than 55 to 100 m (Figure 2.4-12). In Davis Strait, however, bivalves dominate to a depth of 900 m (MacLaren Marex Inc., 1978b).

(b) Epibenthos

The epibenthic animals are active swimmers living in close association with the bottom. The main epibenthic animals found on the seafloor change as a function of depth from the intertidal zone to the deep ocean.

In the High Arctic the intertidal area is covered by fast ice for much of the year and is continually scoured by ice during the summer. This, coupled with wide fluctuations in salinity, results in an intertidal zone nearly devoid of the epibenthic animals typical of more southerly latitudes (Ellis and Wilce, 1961).

Amphipods, chiefly *Gammarus setosus* and *Onisimus litoralis*, are the only common inhabitants of the High Arctic intertidal zone and are sometimes abundant (Tables 2.4-7 and 2.4-8). Neither species is widespread in the Arctic, probably because of the irregular distribution of preferred habitats. Thomson and Cross (1980) noted that *Onisimus litoralis* tended to be found on sand and pebble substrates, while *Gammarus setosus* frequented areas with large rocks. At some locations *Onisimus litoralis* is more abundant in the barren zone than in the intertidal zone (Table 2.4-7). *Gammarus setosus* is taken only rarely

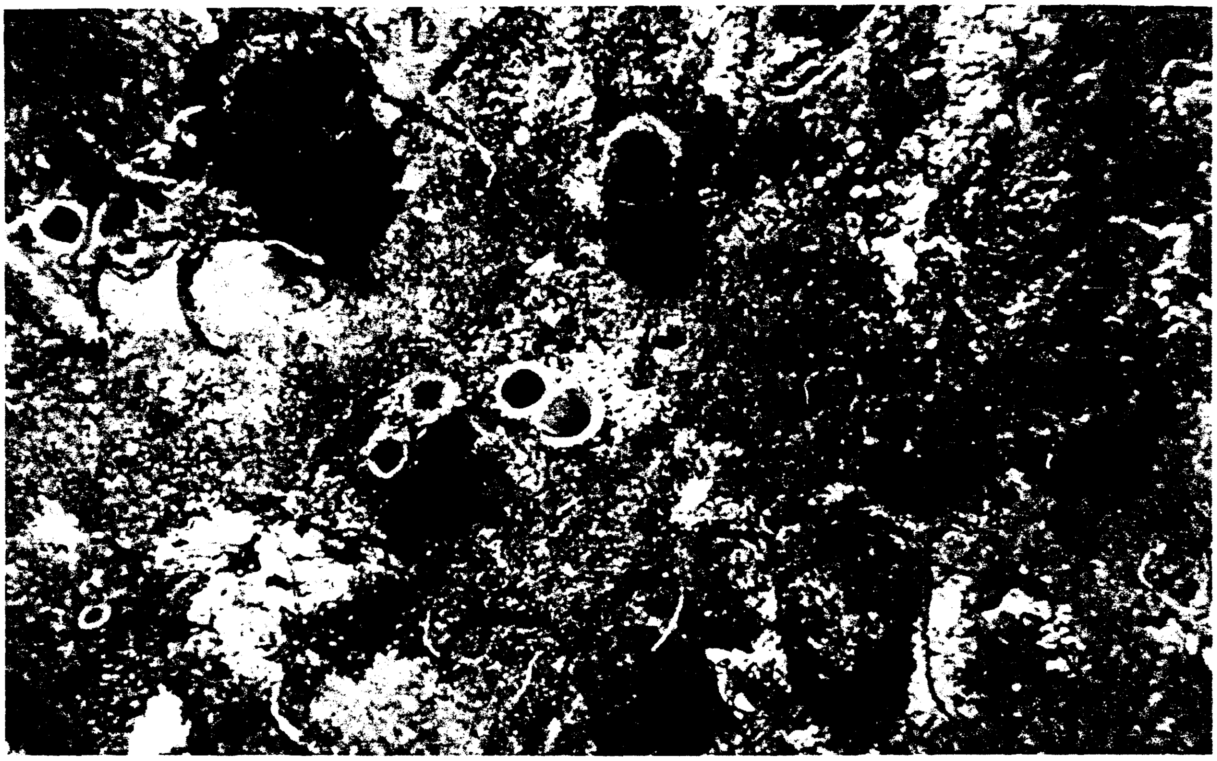


PLATE 2.4-3 *Bivalves (clams) are the main group of infauna or animals that live buried in the seafloor. This underwater photograph shows the siphons of two kinds of clams extending to or above the seafloor at Cape Hatt on northern Baffin Island. (Courtesy. W.E. Cross. LGL Ltd.).*

TABLE 2.4-6
SPECIES COMPOSITION (INDIV./m^2) OF THE MACOMA COMMUNITY AND ITS VARIATIONS IN CRESWELL BAY, SOMERSET ISLAND (FROM SEKERAK ET AL. 1976b)

	Macoma community	Owenia fusiformis zone	Serripes groenlandicus zone
Depth range (m)	16 to 88	36 to 49	10 to 50
Macoma calcarea	43	23	24
M. moseta	98	23	14
Astarte borealis	6	0	19
A. montagui	0	0	0
Mya truncata	41	10	13
Serripes groenlandicus	42	0	44
Hiatella arctica	10	50	42
Ophiocten sericeum	26	19	10
Owenia fusiformis	57	1890	85
Cistenides granulata	0	19	3

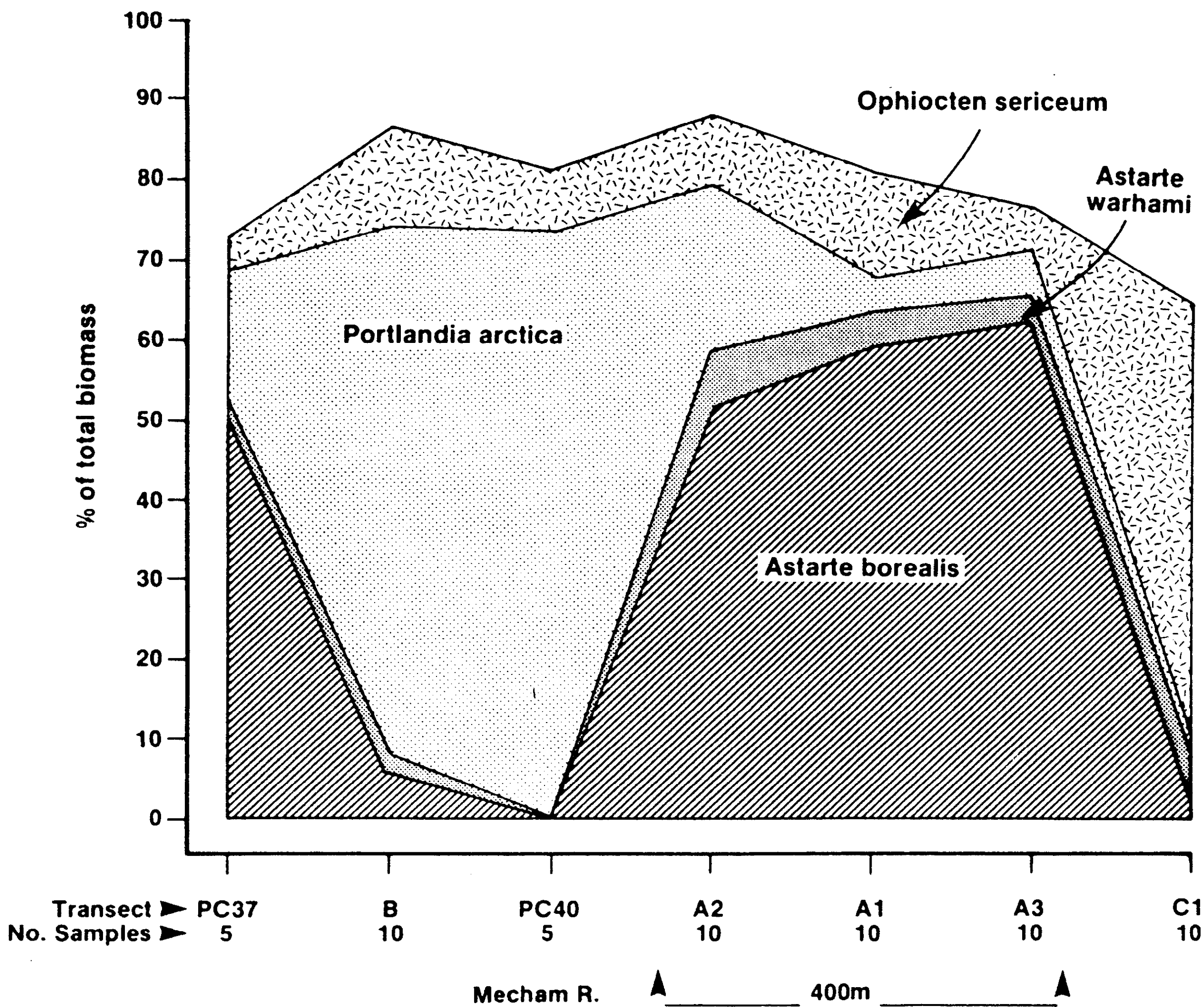


FIGURE 2.4-11 *Composition of the infaunal community by transect in Bridport Inlet, Melville Island. The distance between PC37 and C1 was approximately 12 km. Only airlift samples from depths of 3 to 15 m were considered (from Buchanan et al., 1977).*

in the barren zone (Thomson *et al.*, 1978; Thomson and Cross, 1980; Cross and Thomson, 1981). However, when the intertidal zone becomes inaccessible due to ice, *Gammarus setosus* moves to the shallow water next to the ice (Thomson and Cross, 1980).

Many of the epibenthic animals of the intertidal zone form an important source of food for char that forage there during high water, as well as for shorebirds and Arctic terns (Alliston *et al.*, 1976; Sekerak *et al.*, 1976b).

The barren zone is usually dominated by amphipods, chiefly *Onisimus litoralis, Paroediceros lynceus, Atylus carinatus*, or where estuarine conditions prevail, *Pontoporeia affinis* (Sekerak *et al.*, 1976b; Thomson *et al.*, 1978; Thomson and Cross, 1980).

In shallow water, mysids *(Mysis litoralis, M. oculata)* may form dense shoals along the shoreline. In Brentford Bay, Thomson *et al.*, (1978) observed such a shoal extending for several hundred metres in 2 m of water. The shoal was composed almost entirely of 8 to 11 mm long juveniles of both species. In deeper water dense concentrations of large individuals, to 30 mm long, were found under the fronds of kelp. *Mysis oculata* was more abundant in deep water than was *M. litoralis.*

Epibenthic animals in various parts of the Arctic Archipelago have been surveyed and abundances determined in some areas. Much emphasis has been placed on amphipods, however, other groups have also received some attention. In Resolute Bay, Brentford Bay and Bridport Inlet, decapods are common epibenthic animals at depths of 30 m or less, with *Sabinea septemcarinata, Lebbeus groenlandicus, and L. polaris* being most abundant (Squires, 1968; Bain *et al.*, 1977; Buchanan *et al.*, 1977; Thomson *et al.*, 1978). Buchanan *et al.*, (1977) and Thomson *et al.*,

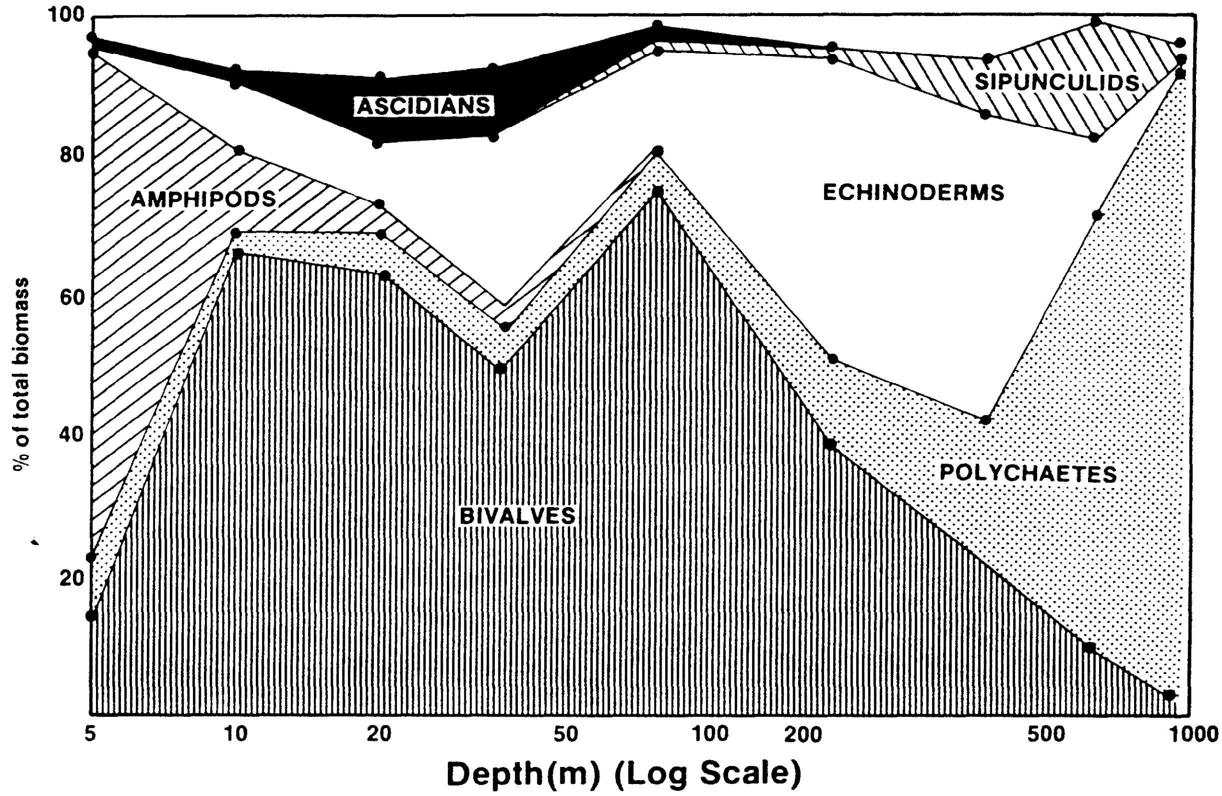


FIGURE 2.4-12 *Relative composition of the infaunal benthos of Lancaster Sound and NW Baffin Bay as a function of depth. Mean % of total biomass of each of 9 depth ranges is plotted (from Thomson and Cross, 1980).*

TABLE 2.4-7

MEAN ABUNDANCE (No./m² ± SD) OF ONISIMUS LITORALIS IN FOUR DEPTH INTERVALS AT FIVE ARCTIC AREAS. NUMBERS OF SAMPLES ARE IN PARENTHESES.

		Depth Range (m)		
Area	**Intertidal**	**1 to 2**	**3 to 5**	**6 to 12**
Phoenix Head Glacier[1] (S Devon Island)	6 ± 8 (22)	700 ± 503 (5)	1021 ± 1106 (4)	48 ± 27 (6)
Navy Board Inlet[1] (N Baffin Island)	3 ± 3 (11)	1 to 50 (4)	71 ± 38 (3)	Not sampled
Outer Creswell Bay[2] (E Somerset Island)	240 (40)	147 ± 138 (4)	16 ± 29 (8)	19 ± 38 (4)
Brentford Bay[3] (NE Boothia Peninsula)	58 (15)	109 ± 157 (4)	9 ± 15 (4)	0 (8)
Bridport Inlet[4] (S Melville Island)	0 (21)	Not sampled	6 ± 10 (12)	2 ± 6 (37)

[1] From Thomson and Cross (1980).
[2] From Sekerak et al. (1976b) and Alliston et al. (1976).
[3] From Thomson et al. (1978).
[4] From Buchanan et al. (1977).

SD = Standard Deviation

TABLE 2.4-8

ABUNDANCE AND BIOMASS OF INTERTIDAL ANIMALS FROM THREE ARCTIC AREAS.

Location	Sample size	Amphipods (No./m² ± SD)	Total abundance (No./m² ± SD)	Total biomass (g/m² ± SD)
EAMES Study Area[1]	83	172 ± 519	317 ± 722	2.9 ± 13.3
Philpots Island	13	32 ± 65	32 ± 65	0.5 ± 0.9
Phoenix Head Glacier	25	433 ± 883	436 ± 889	8.2 ± 23.5
Croker Bay	8	24 ± 26	27 ± 30	0.1 ± 0.1
Navy Board Inlet	14	3 ± 3	10 ± 10	0.1 ± 0.1
Eclipse Sound	23	125 ± 191	635 ± 907	1.4 ± 2.1
Brentford Bay, N.W.T.[2]	15	149 ± 164	245 ± 188	7.9 ± 9.4
Bridport Inlet, N.W.T.[3]	21	300 ± 791	1624 ± 3251	13.1 ± 27.7

[1] Thomson and Cross (1980).
[2] Thomson et al. (1978).
[3] Buchanan et al. (1977).

SD = Standard Deviation

(1978) collected averages of 32 and 10 decapods per 10 minute trawl, respectively, in waters less than 30 m deep. Thomson and Cross (1980) collected less than 1 decapod/10 min tow in water depths ranging from 20 to 660 m in Lancaster Sound, suggesting that decapods are most abundant in shallow areas. Other epibenthic animals may be quite abundant in some areas. The large epibenthic isopod *Mesidotea* has been found in abundance at a few locations in the Arctic Islands , notably along the Brooman Peninsula of Bathurst Island (LGL Ltd., unpubl. data). The sea urchin, *Strongylocentrotus drobachiensis* (Plate 2.4-4), a widely distributed epibenthic species, has been found as deep as 600 m in Lancaster Sound (Thomson and Cross, 1980) and is quite abundant in shallow water. Thomson and Cross (1980) recorded a mean density of 7.91 urchins/m^2 in the 55 m^2 area surveyed by divers in northwest Baffin Bay and Lancaster Sound, and Cross and Thomson (1981) recorded a mean density of 2.32 urchins/m^2 in the 450 m^2 area surveyed at Cape Hatt in Eclipse Sound. Urchins were rare in Bridport Inlet. Differences in abundance of sea urchins were related to the abundance of macrophyte algae (Buchanan *et al.*, 1977).

Epibenthic mysids and amphipods are important in the diets of Arctic char, shorebirds, some seabirds and ringed seals (McLaren, 1958; Alliston *et al.*, 1976; Sekerak *et al.*, 1976b). Decapods are fed upon by bearded seals (LGL Ltd., unpubl. data) and white whales (Sergeant, 1973). The position of the ubiquitous and abundant urchin in the High Arctic food web is unknown.

(c) Epifauna

Most stable rock surfaces below the barren zone support an abundance of epifaunal animals (Plate 2.4-5). The barnacle *Balanus crenatus,* the limpet *Acmaea rubella,* the chitons *Tonicella* spp., the polychaetes *Spirorbis* spp. and bryozoans were the common animals found on cobbles and rocks along the south coast of Cornwallis Island (Sekerak *et al.*, 1976b). In Clark Fiord on northern Baffin Island, Thomson and Cross (1980) also found, in addition to the above, the bivalves *Hiatella arctica and Musculus discors* and sea cucumbers attached to the rock substrate. No quantitative studies on epifauna of the Canadian Arctic are available. In Labrador, Barrie *et al.*, (1980) found the biomass of the epifauna on rock to be more than four times greater than the biomass from adjacent soft substrates. The ecological significance of this group of animals remains to be established.

2.4.5.3 Regional Variations in Abundance

Within the North American Arctic, regional differences in abundance and biomass are evident (Tables 2.4-9 and 2.4-10). Of the areas studied, the biomass of benthic animals was generally highest in Lancaster Sound and Davis Strait; lowest in the Beaufort Sea; and intermediate in bays and inlets of the central Arctic Islands and in northern Baffin Island.

The geographical distribution of benthic biomass

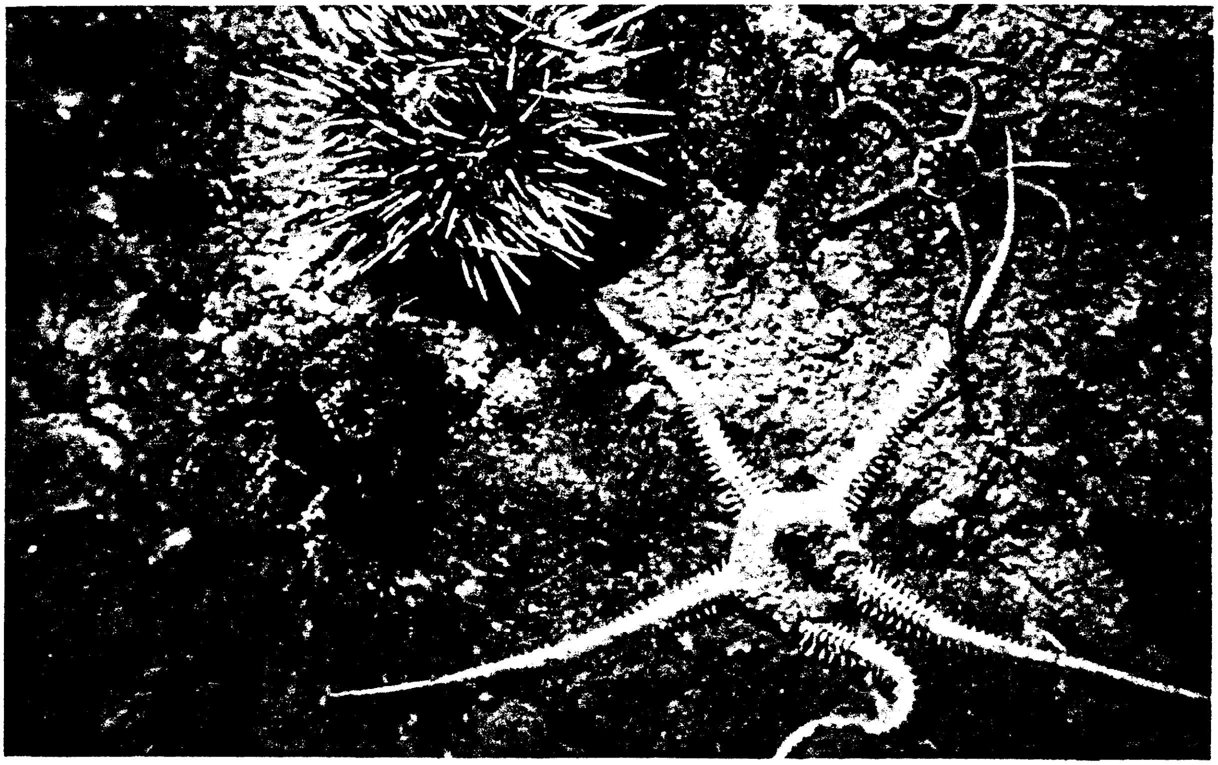


PLATE 2.4-4 *Sea urchins (upper left) are the most widely distributed epibenthic species and have been found as deep as 600 m in Lancaster Sound. Also shown in this underwater photo are brittlestars. (Courtesy, W.E. Cross, LGL Ltd.).*

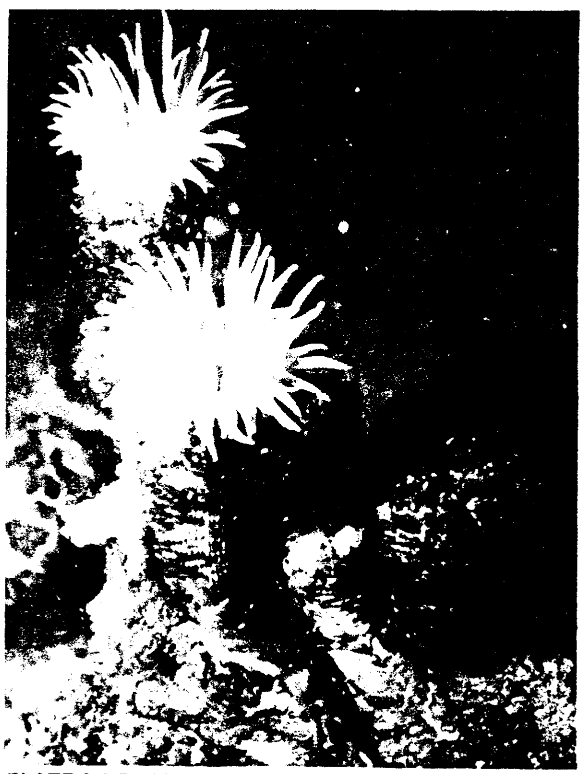


PLATE 2.4-5 *Most stable surfaces below the barren zone support an abundance of epifaunal animals. This underwater photo taken at Cape Hatt near Pond Inlet shows a clump of attached anemones as well as some coralline algae (lower left) and shrimp (lower centre). (Courtesy, W.E. Cross, LGL Ltd.).*

follows the same general pattern noted previously for primary productivity and zooplankton. It is highest in the southeast, decreases to the north and west, and is lowest in the Beaufort Sea (Table 2.4-11).

The biomass of benthic animals in all Arctic seas tends to be very high and considerably greater than that of temperate and tropical seas, but lower than that found in the subarctic (Thomson and Cross, 1980). This high abundance in Arctic waters may reflect relatively limited use of benthic fauna by carnivores since growth rates are likely to be low (Dunbar, 1968). Recent work in western Greenland suggests that the productivity to biomass ratio for benthic animals in that area may be 10% or less of the value found in temperate seas (Curtis, 1977; Petersen, 1978). Comparable studies in the Canadian Arctic will be required to interpret available data.

In the Canadian Arctic the highest abundance and biomass of benthic animals is found below the barren zone at depths of 50 m in protected bays and inlets, and at depths of 100 m along exposed coastlines. Below these depths there is a progressive decrease in abundance and biomass with depth (Table 2.4-9 and 2.4-10; MacLaren Marex Inc., 1978b; Thomson and Cross, 1980).

The standing crop of benthic animals is usually higher at shallower depths in bays and inlets than it is

TABLE 2.4-9

COMPARISON OF THE MEAN INTEGRATED BIOMASS (g/m²) OF BENTHIC INFAUNAL ANIMALS FROM ARCTIC AND SUBARCTIC AREAS. ONLY THE DEPTH RANGE FROM 5 TO 50 m IS CONSIDERED

Location	Sample Size	Mean Biomass (g/m²)	
Alaskan Beaufort Sea	131	41	Carey (1977)
Bridport Inlet, Melville Is.	78	94	Buchanan *et al.* (1977)
Brentford Bay, Boothia Pen.	21	188	Thomson *et al.* (1978)
EAMES study area (Lancasters)	110	319	Thomson and Cross (1980)
Northern Baffin Is.	51	200-438	Ellis (1960)
Labrador coast (infauna only)	94	346	Barrie *et al.* (1980)
Newfoundland banks	6	1455	Nesis (1965)

TABLE 2.4-10

MEAN BIOMASS (g/m² ± SD) OF BENTHIC ANIMALS FROM ARCTIC MARINE AREAS. SAMPLE SIZE IS SHOWN IN PARENTHESES.

Area	Depth Range (m): 5 to 10		15 to 25		26 to 52		53 to 105	
EAMES Study area[1]								
Lancaster Sound	53 ± 58	(13)	787 ± 650	(9)	519 ± 87	(3)	1094 ± 277	(6)
Northern NW Baffin Bay	34 ± 65	(24)	292 ± 253	(10)	376 ± 297	(18)	402 ± 221	(9)
Eclipse Sound	427 ± 528	(13)	596 ± 144	(2)	61 ± 45	(2)	53 ± 23	(2)
Southern NW Baffin Bay	45 ± 25	(5)	105 ± 31	(2)	92 ± 84	(7)	68 ± 126	(11)
All Areas	137 ± 302	(55)	504 ± 481	(25)	303 ± 277	(30)	394 ± 442	(28)
Central Canadian Arctic								
Bridport Inlet, Melville Is[2]	255 ± 233	(35)	163 ± 166	(11)	53 ± 32	(4)	-	
Brentford Bay, Boothia Pen.[3]	268 ± 23	(11)	85 ± 67	(5)	143 ± 152	(5)	-	
Beaufort Sea[4]	21	(30)	51	(35)	43 ± 29	(66)	100 ± 53	(15)
Disko Is., W. Greenland[5]	173	(74)	-		47	(14)	112	(14)

Area	Depth Range (m): 106 to 250		251 to 500		501 to 750		751 to 1100	
EAMES Study area[1]								
Lancaster Sound	180 ± 40	(4)	153	(1)	33 ± 36	(7)	-	
Northern NW Baffin Bay	184 ± 138	(12)	49 ± 24	(8)	26 ± 26	(5)	46 ± 22	(7)
Eclipse Sound	134 ± 234	(7)	24 ± 12	(3)	-		-	
Southern NW Baffin Bay	17 ± 12	(8)	104	(1)	-		4.2 ± 1.4	(3)
All Areas	129 ± 152	(31)	55 ± 40	(13)	30 ± 31	(12)	33 ± 27	(10)

(Cont'd)

Area	Depth Range (m) 106 to 250		251 to 500		501 to 750		751 to 1100	
Beaufort Sea[4]	92 ± 70	(22)	41 ± 34	(20)	63 ± 50	(8)	-	
Disko Is., W. Greenland[5]	69	(5)	-		-		-	
Davis Strait[6]	234	(22)	19	(15)	25	(32)	33	(11)

[1] Thomson and Cross (1980).
[2] Buchanan *et al.* (1977).
[3] Thomson *et al.* (1978).
[4] Carey (1977).
[5] Ellis (1960).
[6] MacLaren Marex Inc. (1978b).

(Table 2.4.10 Cont'd)

TABLE 2-4.11

MEAN DENSITY (no./m^2 ± SD) OF BENTHIC ANIMALS FROM ARCTIC MARINE AREAS. SAMPLES SIZES ARE SHOWN IN PARENTHESES

Area	Depth Range (m) 3.5 to 7.5	7.6 to 12.5	12.5 to 25	26.52	53 to 105
EAMES study area[1]					
Lancaster Sound	1533 ± 871 (7)	2957 ± 1414 (6)	3560 ± 1596 (9)	3387 ± 1370 (3)	4564 ± 1709 (6)
Northern NW Baffin Bay	1133 ± 1190 (14)	3639 ± 3229 (10)	3582 ± 3635 (10)	5502 ± 4006 (18)	2525 ± 1055 (9)
Eclipse Sound	1196 ± 442 (2)	1953 ± 1461 (11)	5384 ± 1460 (4)	2309 ± 679 (2)	813 ± 619 (2)
Southern NW Baffin Bay	6193 ± 344 (2)	4731 ± 780 (3)	1642 ± 156 (2)	1730 ± 1092 (7)	1681 ± 1389 (11)
All Areas	1655 ± 1693 (25)	2994 ± 2286 (30)	3707 ± 2629 (25)	4198 ± 3555 (30)	2509 ± 1741 (28)
Central Archipelago					
Bays and Inlets[2]	2164 ± 1845 (26)	1980 ± 1502 (40)	1735 ± 1252 (24)	963 ± 778 (16)	-
Passages and exposed coasts[3]	169 ± 189 (7)	656 ± 444 (10)	826 ± 1191 (12)	1380 ± 1001 (9)	1174 ± 820 (4)
All Areas	1740 ± 1830 (33)	1715 ± 1455 (50)	1432 ± 1290 (36)	1113 ± 868 (25)	1174 ± 820 (4)
Beaufort Sea					
Carey (1977)	1593 (15)	4456 (15)	2593 (35)	1808 ± 885 (66)	1986 ± 1257 (15)
	Depth Range (m) 106 to 250	**251 to 500**	**501 to 750**	**751 to 1100**	**1101 to 2600**
EAMES study area[1]					
Lancaster Sound	1797 ± 931 (4)	1896 (1)	857 ± 320 (7)	-	-
Northern NW Baffin Bay	1983 ± 1141 (12)	988 ± 509 (8)	638 ± 266 (3)	1222 ± 1910 (7)	-
Eclipse Sound	2487 ± 1758 (7)	936 ± 448 (3)	-	-	-
Southern NW Baffin Bay	867 ± 572 (8)	1482 (1)	-	231 ± 42 (3)	-
All Areas	1785 ± 1271 (31)	1084 ± 514 (13)	765 ± 307 (12)	925 ± 1632 (10)	-

(Cont'd)

Central Archipelago	Depth Range (m) 106 to 250	251 to 500	501 to 750	751 to 1100	1101 to 2600
Passages and exposed coasts[3]	469 ± 299 (15)	-	-	-	-
All Areas	469 ± 299 (15)	-	-	-	-
Beaufort Sea					
Carey (1977)	2260 ± 947 (22)	2502 ± 1784 (20)	3441 ± 1625 (8)	-	

[1] Thomson and Cross (1980).

[2] Inner Creswell Bay, Sekerak *et al.* (1976b); Cunningham Inlet, Thomson *et al.* (1975); Bridport Inlet, Buchanan *et al.* (1977); Brentford Bay, Thomson *et al.* (1978).

[3] Barrow Strait-Peel Sound, Thomson *et al.* (1975); Outer Creswell Bay and Assistance Bay, Sekerak *et al.* (1976b).

(Table 2.4-11 Cont'd)

in exposed passages. In Eclipse Sound maximum biomass was found at depths less than 25 m. Below that point the standing stock decreases with increasing depth (Table 2.4-10). Similar trends exist in bays and inlets of the Archipelago (Table 2.4-9) and Frobisher Bay (Wacasey *et al.*, 1980). In Frobisher Bay, the maximum standing crop is found at 40 m, and at 80 m it is approximately one third of the maximum. In the passages and exposed coasts of the Archipelago, Lancaster Sound and Baffin Bay, a relatively high standing crop is found to depths of 100 m (Tables 2.4-9 and 2.4-10). In Davis Strait, nearshore shallow water biomass reaches approximately 400 to 750 g/m^2 wet weight (Wacasey *et al.*, 1980). Biomass at 106 to 250 m in offshore waters is also relatively high (234 g/m^2; Table 2.4.-9).

Although the fauna of the High Arctic has some similarity from east to west, there are important differences in the southern part of Baffin Bay (see Den Beste and McCart, 1978). South of Padloping Island there is no barren zone. There is also a transition from High Arctic to subarctic faunal and floral assemblages in the intertidal zone (Ellis, 1955). These changes reflect, among other things, a reduced impact of ice and the intrusion of Atlantic water.

The intertidal fauna south of Padloping Island consists of a group of exclusively intertidal organisms such as the barnacle *Balanus balanoides* and the periwinkle *Littorina saxatilis,* and another group of generally shallow water animals that range into the intertidal zone (Ellis, 1955). The existence of an intertidal flora along southern Baffin Island *(Fucus* spp. for example) and of Laminariales (Kelp) subtidally, (Den Beste and McCart, 1978) at depths that are barren in the High Arctic, undoubtedly increases the capacity of the area to support benthic fauna.

In Davis Strait, the shallow water fauna has many components of the High Arctic and includes an increasing number of Atlantic species (see MacLaren Marex Inc., 1978b; Wacasey *et al.*, 1980). Biomass reaches a maximum between depths of 20 and 80 m (Wacasey *et al.*, 1980) and the Atlantic influence increases with increasing depth.

2.5 RESOURCE USE

Nine species of marine mammals are harvested regularly and several other species are harvested occasionally or in limited areas of the main eastern shipping corridor. The estimated annual harvests of marine mammals in Parry Channel, Baffin Bay and Davis Strait are shown in Table 2.5-1. This information was obtained from various sources including Hudson's Bay Co. records, Greenlandic and Canadian government trade records, compilations by individual researchers (e.g. Kemp *et al.*, 1977: Finley and Miller, 1980) and, in Canada, records formerly kept by R.C.M.P. officers which are now compiled by the Department of Fisheries and Oceans from local game officers' reports. However, these sources provide only a minimum estimate of the animals harvested in most cases. Trade records for example, do not reflect numbers of animals used locally and in only a few cases do the estimates include animals killed but not recovered. Losses of seals, walruses and whales through sinking can approach 50% of the

TABLE 2.5-1

APPROXIMATE ANNUAL HARVEST OF MARINE MAMMALS IN PARRY CHANNEL, BAFFIN BAY AND DAVIS STRAIT.[1]

Species	Canada[2]	Western Greenland[3]
Ringed seal	20,000-30,000	55,000
Harp seal	1,000-1,500	5,000-10,000
Hooded seal	<20	2,200
Bearded seal	300-400	500-1,000
Harbour seal	<20	100
Walrus	100-150	150-250
White whale	100-200	500-1,000
Narwhal	300-400[2]	200-800
Harbour porpoise	0	620-1,250
Minke whale	0	250
Other large whales	0	<20
Polar bear	125-150	<70
Arctic fox	2,000-9,000	2,000-5,000

[1] Estimates for all but polar bear and Arctic fox are probably low because sinking losses are not included.
[2] Based primarily on Usher (1975), Smith and Taylor (1977), Kemper (1980) and unpublished government reports.
[3] Based on Kapel and Petersen (1979).

total number killed (McLaren, 1958; Mansfield, 1973; Smith and Taylor, 1977; Davis *et al.*, 1980; Finley *et al.*, 1980). The only species for which Canadian (but not Greenlandic) records are probably accurate is the polar bear, since few are lost or used locally in Canada and the hunt has been regulated on a community quota system since 1967. Further information on the resource harvesting patterns of the Inuit is provided in Volume 5 of the Environmental Impact Statement.

Inuit hunting patterns changed as outpost camps were abandoned, people moved into permanent settlements and, in some cases, entered the wage economy. Nevertheless, subsistence hunting remains important as a source of protein, cash (through the sale of animal products) and cultural identity. The core areas used for hunting in recent years tend to be centred on the communities, although much larger areas are used during occasional hunting trips and during pursuit of wide ranging species. In addition, some Inuit, supported by government policy, have recently returned to permanent outpost camps where they are highly dependent on subsistence hunting. Well established camps along the eastern shipping corridor are located on Allen Island seaward of the Hall Peninsula, in Eclipse Sound and at Eglinton Fiord, north of Clyde.

The core hunting area of Resolute consists of central Barrow Strait, southern Wellington Channel and southern McDougall Sound (Figure2.5-1). In the more detailed discussion of Resolute Inuit hunting patterns given in Volume 5, Chapter 12, it is pointed out that coastal areas are of greatest importance while the offshore ice that forms in central Barrow Strait is used as a travel route to gain access to hunting areas on Prince of Wales and Somerset Islands. Although polar bears are hunted throughout this area, other species are hunted primarily in the northern half of Barrow Strait (Kemp *et al.*, 1977). People from Arctic Bay hunt mainly in Admiralty Inlet, with occasional trips to Prince Regent Inlet to hunt polar bears (Bissett, 1967; Freeman, 1976). Residents of Pond Inlet hunt primarily in Eclipse Sound, Pond Inlet, Navy Board Inlet and along southeast Bylot Island (Bissett, 1967; Treude, 1977). The more extensive but less often used hunting areas of these three communities include all of Parry Channel west to western Bathurst and Prince of Wales islands and the adjacent channels (Freeman, 1976; Figure 2.5-2).

Hunting areas of communities bordering Baffin Bay and Davis Strait are restricted by the winter-long presence of unstable pack ice. The core hunting areas of eastern Baffin Island communities are mainly on the landfast ice within about 100 km of the communities (Figure 2.5-3) (Haller *et al.*, 1967). The extended hunting area includes the landfast ice along most of the Baffin Island coast as well as relatively small portions of the pack ice of Baffin Bay and Davis Strait (Figure 2.5-4) (Freeman, 1976).

There is little available information on areas hunted by residents of Greenland. However, over 90% of the population of western Greenland live south of Disko Bay and is supported mostly by commercial fishing. There is little or no landfast ice south of Disko Bay and marine mammals are hunted from boats all year. North of this area, the landfast ice along the coast provides areas for winter and spring hunting, mostly close to the settlements. Haller (1978) found that few hunters travelled more than a few kilometres beyond the coastal islands except in Melville Bay. In the latter area dog teams are used to cross the heavy pack ice during polar bear hunts.

2.5.1 HARVESTED SPECIES.

2.5.1.1 Seals

The ringed seal is the species of marine mammal taken most frequently along the eastern shipping corridor. The total estimated annual harvest ranges from 75,000 to 85,000 animals (Table 2.5-1). This is the most economically important species in all areas except southern Greenland where it ranks second to the hooded seal (Kapel, 1975). Ringed seals are hunted throughout the year, but effort increases during the period from March to June. The fur of the young 'silver jars' is particularly valuable and they are taken mainly during May and June (Smith, 1973).

Canadian Inuit harvest ringed seals for their pelts, and this species also provides a major source of protein in some settlements. In Greenland, seals pro-

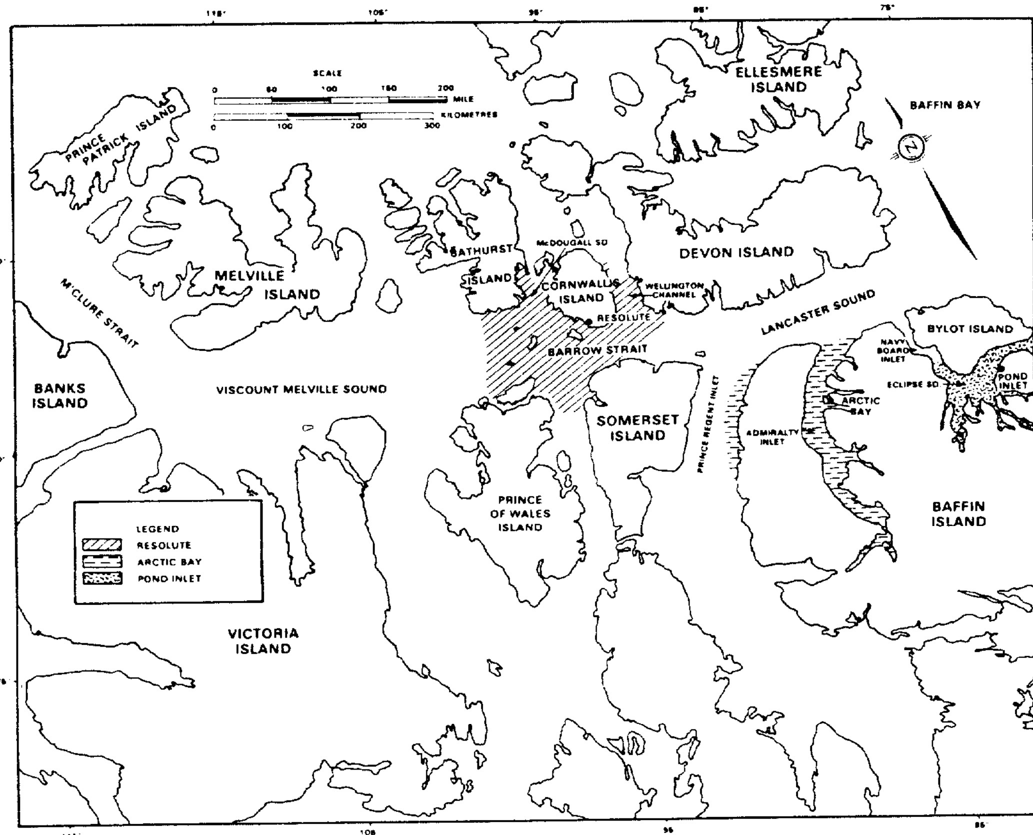


FIGURE 2.5-1 *Core hunting areas of communities along Parry Channel (from Bissett, 1967; Kemp et al., 1977; and Treude, 1977).*

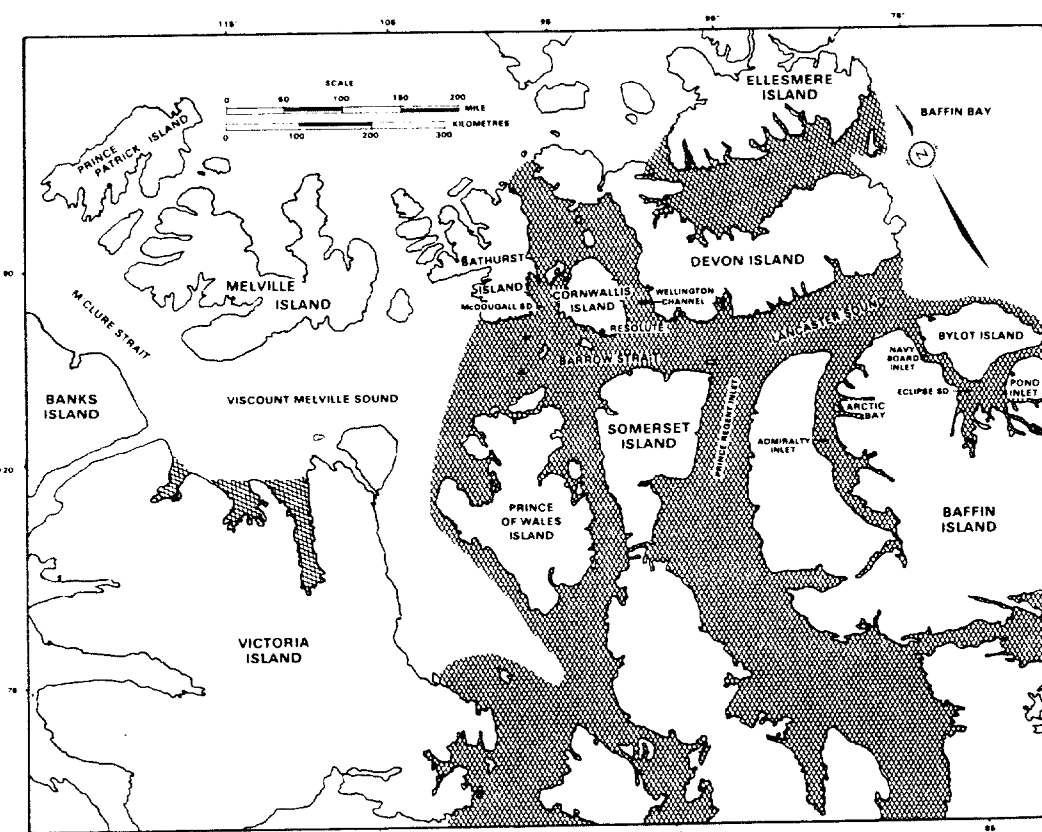


FIGURE 2.5-2 *Full extent of hunting areas of communities along Parry Channel (from Freeman, 1976).*

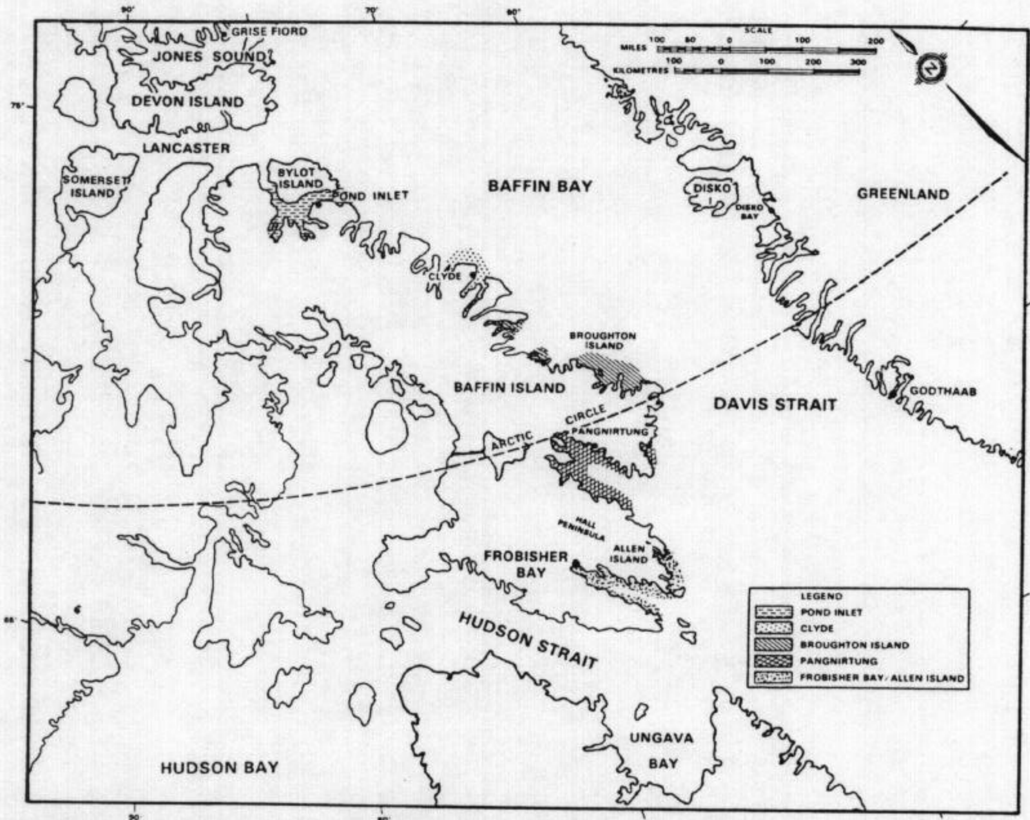


FIGURE 2.5-3 *Core hunting areas of Canadian communities along Baffin Bay and Davis Strait (from Bissett, 1967; Haller et al., 1967; Meldrum, 1975; Kemp, 1976; and MAL, 1978).*

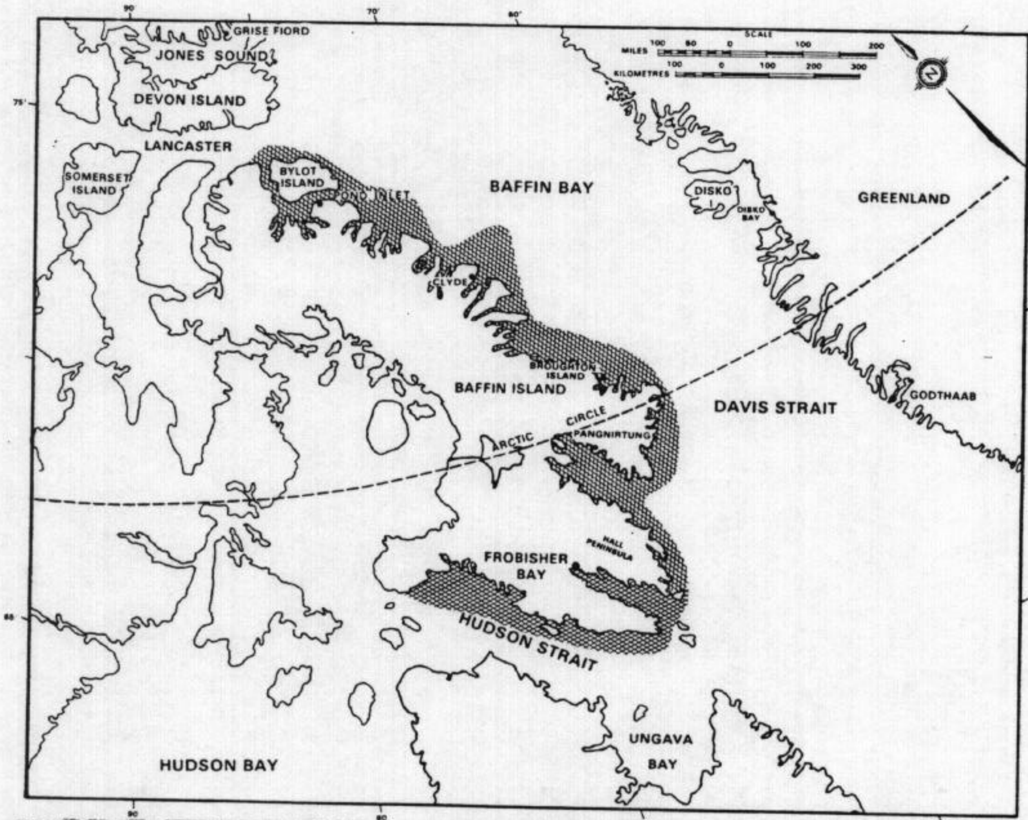


FIGURE 2.5-4 *Full extent of hunting areas of Canadian communities along Baffin Bay and Davis Strait (from Freeman, 1976).*

vide the major food for dog teams. They are not used much for dog food in Canada because of the much greater use of snowmobiles (Smith, 1973).

The number of harp seals harvested by communities along the shipping corridor ranks second to ringed seals, although this species is not commonly taken by residents of most Canadian settlements (Table 2.5-1). Large numbers of harp seals migrate into Canadian Arctic waters during the open water season, but few are harvested, probably because they are not particularly abundant in coastal areas near most communities. Most of the reported catch in Canada is taken off southeastern Baffin Island, mainly at Pangnirtung and Frobisher Bay. About 75% of the harp seals harvested in Greenland are taken between 67° 30' and 75°N and the remainder are taken primarily in southwest and south Greenland (Kapel, 1975).

Along the corridor, hooded seals have a much more limited distribution than most other seals and a few are taken infrequently in Canada (Table 2.5-1). Probably fewer than 20 hooded seals are taken each year in Canadian settlements (mainly Pond Inlet), although the annual catch by Greenland is about 2,200 animals. In southern Greenland, hooded seals are the most economically important marine mammal, comprising 46% of the seals harvested annually (Kapel, 1975).

An estimated 800 to 1,400 bearded seals are harvested annually. This species is widely distributed and is taken along every part of the corridor. Bearded seals are prized for their strong hides which are used to make rope. Since virtually all of the harvested animals are used locally, bearded seals contribute little to the cash economies of the settlements. The majority of the 100 to 120 harbour seals taken annually along the shipping corridor are harvested in southwest Greenland, although a few are also taken at Frobisher Bay (Table 2.5-1).

2.5.1.2 Walrus

The annual harvest of walruses by residents of communities along the eastern shipping corridor is estimated to range from 250 to 400 animals (Table 2.5-1). Walruses were formerly used for dog food, but with the increasing use of snowmobiles the harvest has decreased. In Canadian portions of the corridor, the majority are taken along southeastern Baffin Island from Frobisher Bay and Pangnirtung, while in western Greenland, most are taken in the Thule District (Kapel, 1975).

2.5.1.3 White Whale

The estimated annual harvest of white whales along the shipping corridor ranges from 600 to 1,200 (Table 2.5-1). About 95 white whales were being taken yearly from the Cumberland Sound stock of white whales. However, Fisheries and Oceans Canada has suggested a quota of 40 animals for this stock. The High Arctic stock, which is believed to be genetically isolated from the Cumberland Sound stock, winters off southwest Greenland and summers in the Canadian High Arctic and off north Greenland (Davis and Finley, 1979). Most of the harvest of about 500 to 1,000 whales annually from the High Arctic stock, occurs along the west coast of Greenland (Kapel, 1977), and only about 50 are taken annually in Canada.

In Canada, most white whale products are used locally, although a small industry has been established to distribute excess muktuk from the Cumberland Sound harvest.

2.5.1.4 Narwhal

Approximately 500 to 1,200 narwhals are taken annually by residents of communities along the corridor (Plate 2.5-1). About 84% of the 300 to 400

PLATE 2.5-1 *Approximately 500 to 1,200 narwhals are taken annually along the shipping corridor. In Canada, about 84% of the 300 to 400 harvested annually are taken near Pond Inlet and Arctic Bay. (Courtesy, Northwest Territories Wildlife Service).*

narwhals harvested annually in Canada are taken near Pond Inlet and Arctic Bay on northern Baffin Island (Finley *et al.*, 1980; Kemper, 1980). The Canadian narwhal harvest is regulated under a quota system administered by the Canadian Department of Fisheries and Oceans. Narwhal ivory is sold as whole tusks or made into handicrafts, and sales provide considerable cash income for the communities of Arctic Bay and Pond Inlet. Although muktuk (whale fat) is eaten locally, the meat is not often consumed.

2.5.1.5 Other Whales

There are several other species of whales taken along the west coast of Greenland (Table 2.5-1), but the numbers harvested are very small in most cases. The largest annual harvests include about 500 to 1,000 harbour porpoises and 250 minke whales taken by native Greenlanders (Kapel, 1977, 1979). The International Whaling Commission has set a five year (1981-1985) quota of 1,778 minke whales for west Greenland with no more than 444 to be taken in any one year. Minke whales within the quota but not taken by Greenlanders are harvested by Norwegian commercial whalers. Although humpback whales are protected by the International Whaling Commission, an aboriginal quota of 10 per year is allowed off western Greenland (IWC, 1980).

2.5.1.6 Polar Bear

Polar bears are taken regularly by residents of northwestern Greenland and all Canadian communities along the eastern shipping corridor (Table 2.5-1). No polar bear quotas are imposed in Greenland. This species occurs infrequently in all areas except north Greenland and the annual harvest there is less than 70 animals. In Canada, the hunt is regulated under a community quota system administered by the N.W.T. government. The largest annual harvests are from the communities of Clyde and Resolute, where about 45 and 35 polar bears are taken, respectively (Plate 2.5-2). The remaining Canadian communities along the shipping corridor take a combined total of 45 to 55 bears per year. Although the number of polar bears taken is relatively small in comparison with the numbers of other marine mammals harvested, bear pelts are valuable and result in significant income for Inuit communities in Canada. In northern Greenland, however, a higher proportion of the pelts are used locally to make clothing.

2.5.1.7 Arctic Fox

Arctic foxes from coastal populations along the eastern shipping corridor are trapped during winter and spring when they forage on the sea ice (Macpherson, 1969). The total annual estimated catch for all corridor communities ranges from 4,000 to 14,000 animals, presumably depending on the stage of the fox population cycle (Sec. 2.1.4). Foxes are taken mostly for the sale of their pelts. The proportion of skins used locally for handicrafts and clothing is relatively small.

PLATE 2.5-2 *Polar bears are taken regularly by residents of northwestern Greenland and all Canadian communities along the shipping corridor. Approximately 35 are taken per year by Resolute and 45 per year by Clyde. (Courtesy, Northwest Territories Wildlife Service).*

2.6 SPECIAL AREAS

Three regions adjacent to the eastern shipping corridor have legal status as protected areas in Canada. These areas are Auyuittuq National Park on eastern Baffin Island, the Banks Island Federal Migratory Bird Sanctuary No. 2, and the Bylot Island Federal Migratory Bird Sanctuary (Figure 2.6-1). The Banks Island Sanctuary protects major moulting habitats of brant and lesser snow geese, while the Bylot Island Sanctuary protects large nesting colonies of thick-billed murres (two colonies), black-legged kittiwakes (two colonies) and greater snow geese.

Several additional areas along the eastern corridor have official recognition, but at present no legal sta-

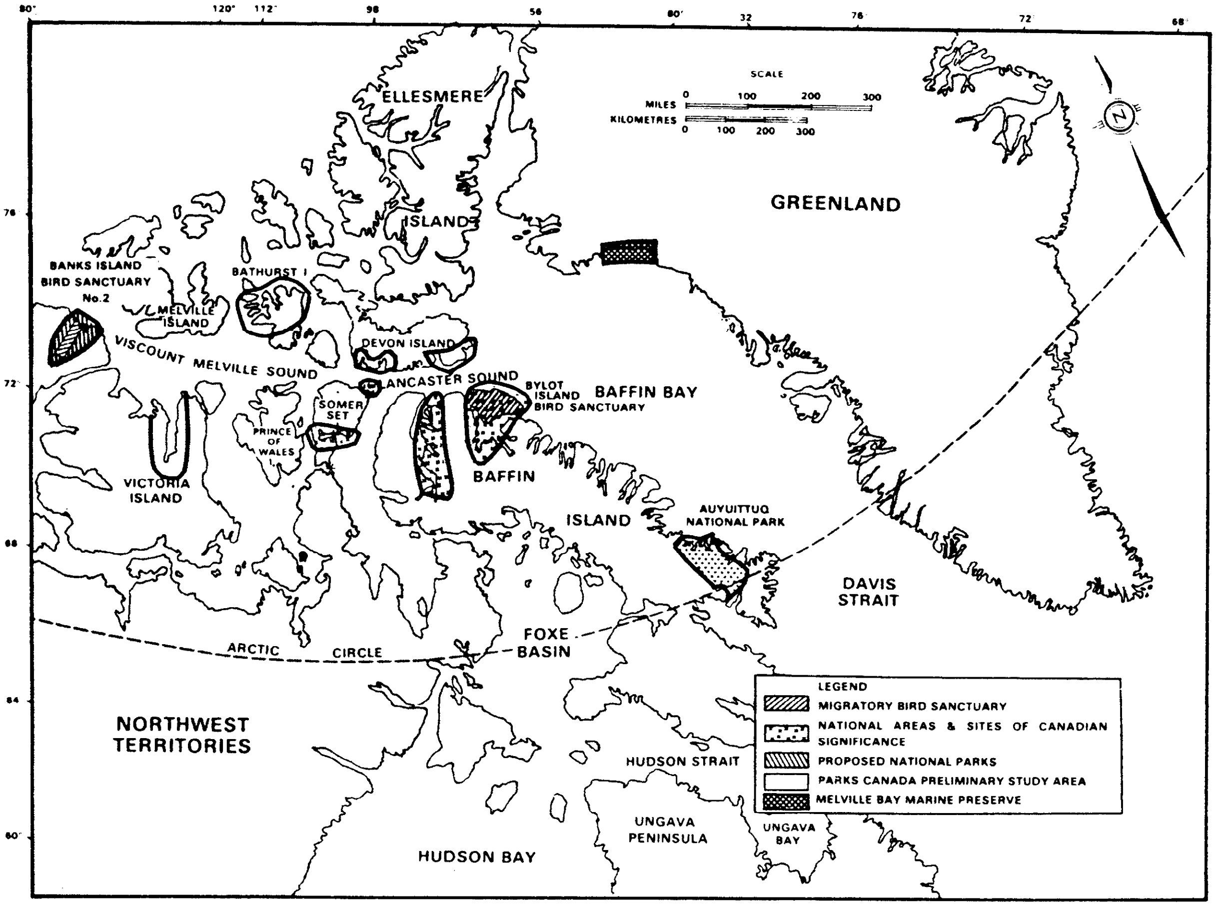


FIGURE 2.6-1 *Special areas along the eastern shipping corridor.*

tus. These are the proposed National Park that would include part of northern Banks Island, four 'Natural Areas (or Sites) of Canadian Significance' which may eventually become National Parks, and 23 International Biological Programme (IBP) ecological sites (Table 2.6-1, Figure 2.6-2). In addition, UNESCO has suggested that all of Lancaster Sound become a World Heritage Area (R. Beardmore, pers. comm.). The World Heritage Program which is administered in Canada by Parks Canada, identifies and attempts to gain legal protection for areas which are considered of world-wide ecological significance. Greenland established a marine reserve in northern Melville Bay in 1977. No hunting is permitted and there are travel restrictions in portions of the reserve.

TABLE 2.6-1

IBP ECOLOGICAL SITES IN THE ARCTIC ISLANDS (SOURCE: ADAPTED FROM NETTLESHIP AND SMITH 1975)

SITE AND NUMBER	AREA (km^2)	FEATURES	PROTECTIVE STATUS
Victoria Island			
Prince Albert Sound (3-4)	4725	Primarily terrestrial; a representative low Arctic site with a high diversity of vegetation types within a small area.	None
Minto Inlet (3-3)	6000	Highly diverse vegetation. Peregrine falcon nesting area. Possible polar bear migration route. Stable ice for ringed seal pupping.	None
Melville Island Bailey Pt. (1-9)	850	Primarily terrestrial. Rich vegetation for a High Arctic location. Very large muskox population.	None
Ibbett Bay to McCormick Inlet (1-4)	2450	Occurrence of extremely dense Arctic willow communities. Muskox and caribou habitat. Large wolf and Arctic fox population.	None
Bathurst Island Bracebridge-Goodsir Inlets (1-2)	2960	Walrus haul-out sites. Polar bear migration route and occasional denning area. Rich vegetation. Diverse avifauna. Large populations of muskoxen, caribou and Arctic foxes.	Withdrawn from development by Order-in-Council
Somerset Island Cunningham Inlet (1-8)	155	White whale calving area. Polar bear maternity denning area.	None
Prince Leopold Island and Adjacent Cape Clarence (1-5)	5680	Multi-species seabird colony: northern fulmar 62,000 pairs; thick-billed murre 86,000 pairs; black-legged kittiwake 29,000 pairs; black guillemot 2000 pairs; glaucous gull 200 pairs.[1]	None
Stanwell-Fletcher Lake (1-3)	3000	Diverse vegetation with several species near the northern limits of their ranges. Supports the only muskox herd on Somerset Island.	None
Bellot Strait (1-6)	520	Open water present all winter. Concentration area for waterbirds and marine mammals.	None
Devon Island Cape Liddon (2-15)	3760	± 5000 pair northern fulmar colony.[2] Year-round use by polar bears. Summer concentrations of white whales.	None
Hobhouse Inlet (2-16)	4240	35,000 pair northern fulmar colony.	None
Lancaster Sd. Marine Area (2-14)	6100	Major feeding area for seabirds in Lancaster Sound and western Baffin Bay (used in summer by ± 130,000 pairs northerb fulmars; ± 300,000 pairs thick-billed murres; ± 80,000 pairs black-legged kittiwakes). Used by up to 1.3 million dovekies during spring migration.[2] Migration route of walrus, harp seal, narwhal, white whale and bowhead.	None
Cape Sparbo (2-5)	870	Unusually dense vegetation for high Arctic location. Diverse fauna.	None
Coburg Island (2-12)	4025	± 160,000 pairs thick billed murres and ± 1000 black-legged kittiwakes nests.[3] Adjacent to the North Water.	None

TABLE 2.6-1 (Cont'd)

IBP ECOLOGICAL SITES IN THE ARCTIC ISLANDS (SOURCE: ADAPTED FROM NETTLESHIP AND SMITH 1975)

SITE AND NUMBER	AREA (km^2)	FEATURES	PROTECTIVE STATUS
Bylot Island (7-5)	17920	Seabird colonies: ± 160,000 thick-billed murre pairs;[3] ± 53,000 black-legged kittiwake pairs. Nesting greater snow geese (7500 pairs). (H. Boyd in C.W.S. 1972 indicated a population of 20,000). Polar bear denning. Concentrations of ringed seals, narwhals, bearded seals.	Bylot Island Migratory Bird Sancturary
Baffin Island Baillarge Bay (7-7)	1555	Northern fulmar colony (at least 25,000 pairs). Feeding area for several species of seabirds and marine mammals.	None
Buchan Gulf (7-11)	2180	At least 25,000 pairs of nesting northern fulmars.	None
Scott Inlet (7-8)	2575	At least 25,000 pairs of nesting northern fulmars.	None
Clyde Foreland (7-2)	260	Primarily terrestrial. Extensive vegetative cover supports a diverse flora and fauna.	None
Cape Searle (7-6)	3790	At least 10,000 breeding pairs of northen fulmars in two colonies.	None
Reid Bay (7-9)	1940	10,000 breeding pairs of northern fulmars in three colonies; 200,000 breeding pairs of thick-billed murres in two colonies.	None
Padle-Kingnait Fiord (7-3)	1390	Primarily terrestrial. Rich and diverse flora and avifauna.	Part of the site is within Auyuittuq National Park
Ogac Lake (7-1)	580	Unique population of Atlantic cod living in a submerged saltwater layer maintained by spring tides. Unusual associations of plant species.	None
'Hantzsch' Island, Resolution Island Group (7-10)	1040	Multi-species seabird colony: 50-75,000 pairs thick-billed murres, 3000 pairs black-legged kittiwakes, smaller numbers of glaucous gulls and herring and/or Thayer's gulls.	None
Button Islands (6-8)	410	Breeding colonies of glaucous gulls, black-legged kittiwakes and black guillemots. Feeding area for thick-billed murres and northern fulmars.	None

1 Estimates of breeding pairs based on Nettleship and Gaston (1978).
2 Estimates of numbers based on Johnson et al. (1976), McLaren and Renaud (1979) and McLaren (1980).
3 Estimates of breeding pairs based on Gaston (1980).

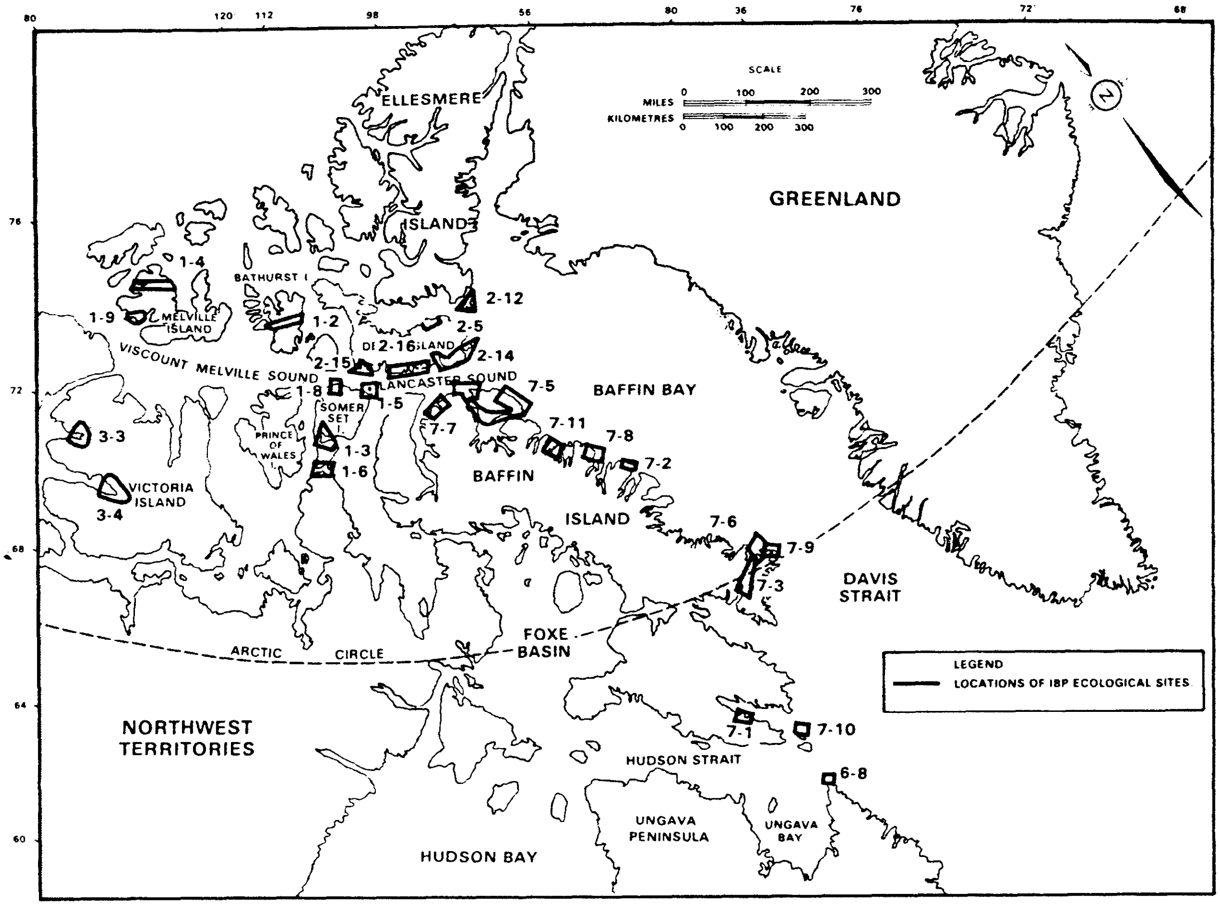


FIGURE 2.6-2 *IBP ecological sites. Twenty-three International Biological Programme (IBP) sites have been identified along the shores of the eastern shipping corridor. Table 2.6-1 summarizes the key features of each of these areas.*

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