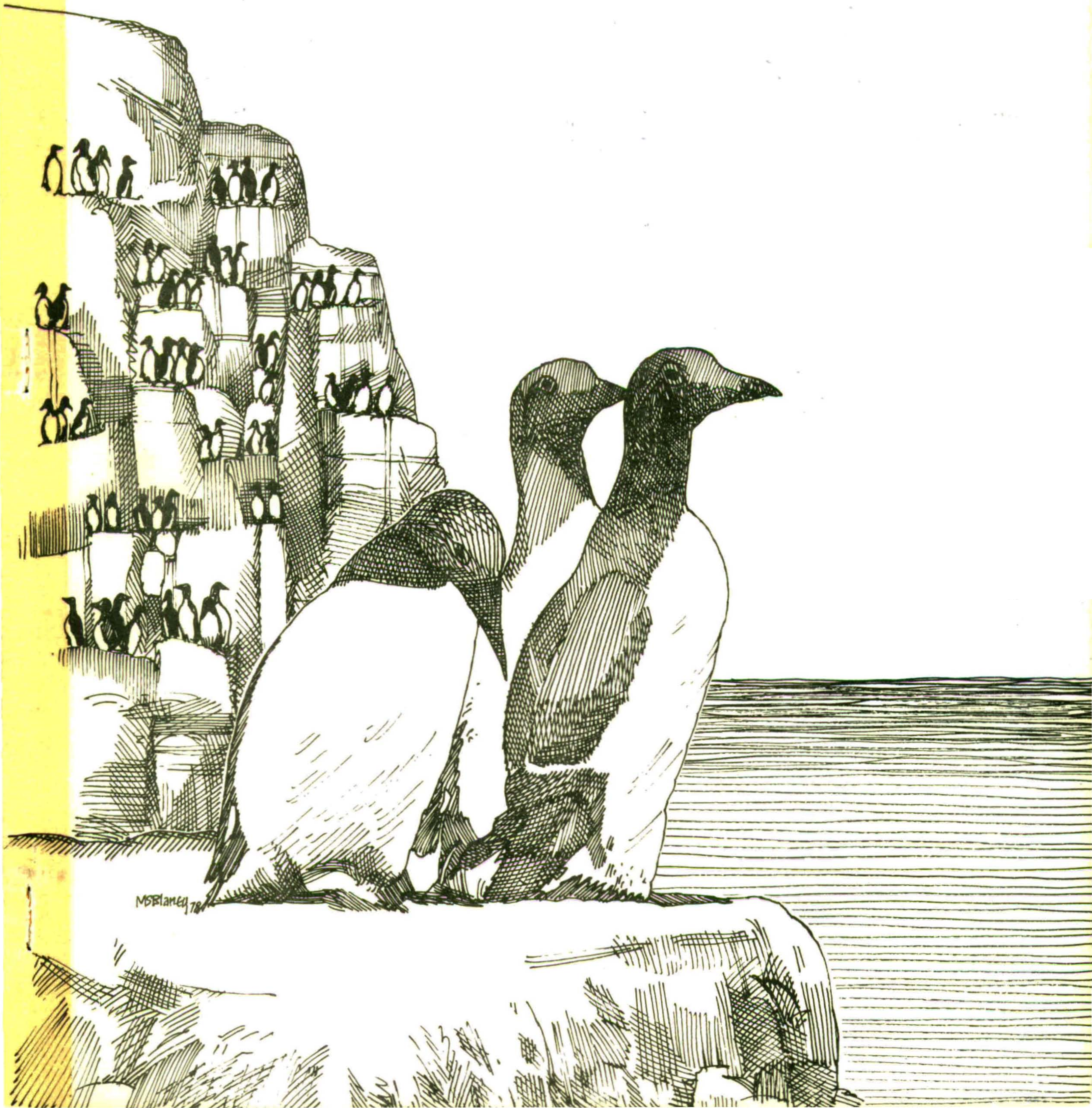
~~Gardner~~ D.P. stone

Offshore Drilling in Lancaster Sound:

Possible Environmental Hazards




Scale of Statute Miles
100
0
500
Scale of Kilometres
100
0
1000
ARCTIC OCEAN
BEAUFORT SEA
Ellesmere Island
Devon Island
Lancaster Sound
BAFFIN BAY
GREENLAND
Davis Strait
Baffin Island
LABRADOR SEA
CANADA
HUDSON BAY
LABRADOR
NEWFOUNDLAND
70°
80°
150°
120°
90°
60°
30°
80°
180°
70°
60°
30°
60°
150°
50°
50°
120°
90°
60°

Possible
Environmental
Hazards

OFFSHORE DRILLING
IN
LANCASTER SOUND

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February, 1978
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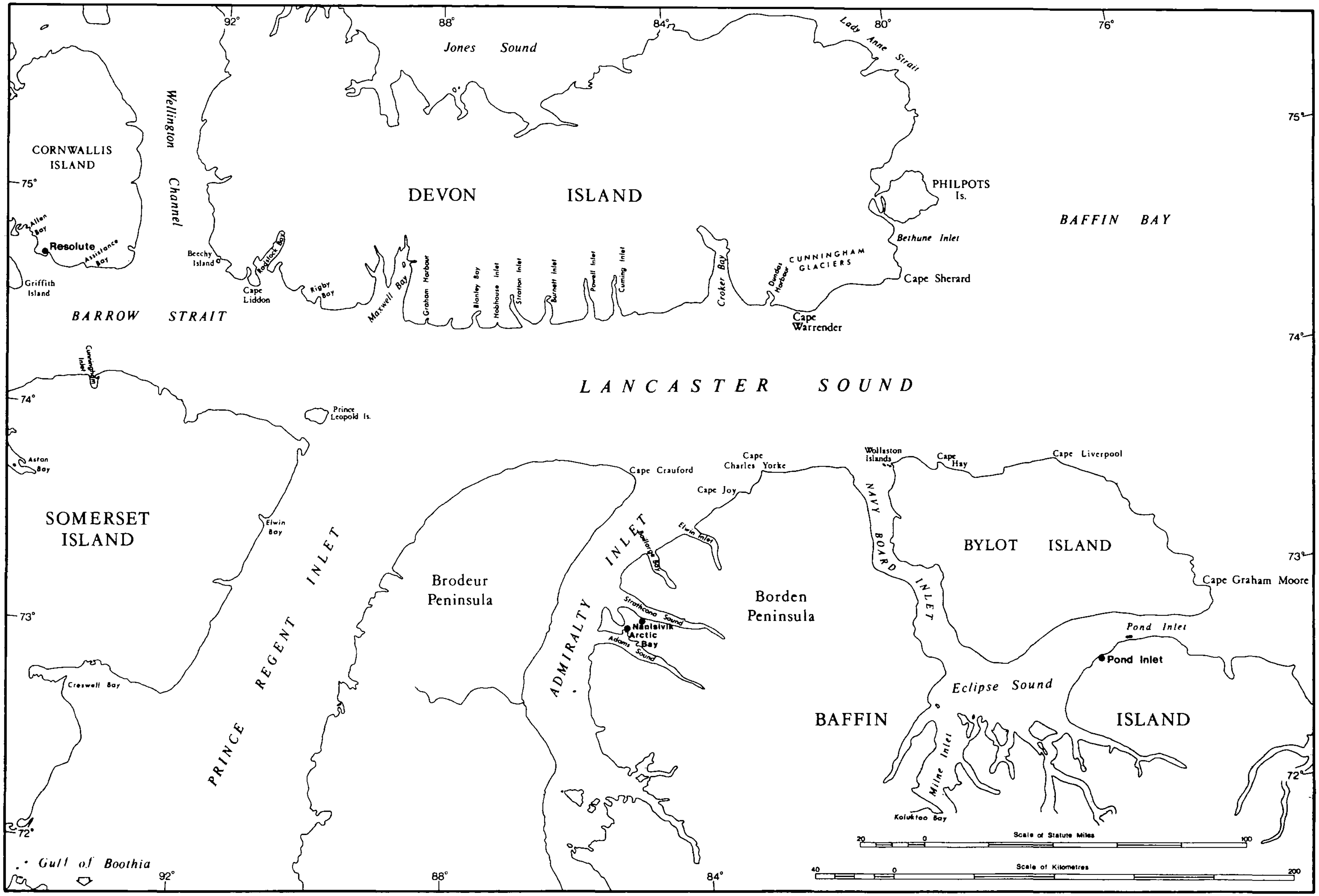
92°
88°
84°
80°
76°
75°
74°
73°
72°
Jones Sound
Lady Anne Strait
Wellington Channel
CORNWALLIS ISLAND
DEVON ISLAND
PHILPOTS Is.
BAFFIN BAY
Allen Bay
Resolute
Assistance Bay
Griffith Island
Beechy Island
Radstock Bay
Cape Liddon
Rigby Bay
Maxwell Bay
Graham Harbour
Blanley Bay
Hobhouse Inlet
Stratton Inlet
Burnett Inlet
Powell Inlet
Cuming Inlet
Croker Bay
Dundas Harbour
CUNNINGHAM GLACIERS
Bethune Inlet
Cape Sherard
Cape Warrender
BARROW STRAIT
Cunningham Inlet
LANCASTER SOUND
Prince Leopold Is.
Aston Bay
SOMERSET ISLAND
Elwin Bay
Creswell Bay
PRINCE REGENT INLET
Brodeur Peninsula
Cape Crauford
Cape Charles Yorke
Cape Joy
Elwin Inlet
Baillarge Bay
ADMIRALTY INLET
Strathcona Sound
Nanisivik
Arctic Bay
Adams Sound
Borden Peninsula
Wollaston Islands
Cape Hay
Cape Liverpool
NAVY BOARD INLET
BYLOT ISLAND
Cape Graham Moore
Pond Inlet
Pond Inlet
Eclipse Sound
BAFFIN ISLAND
Milne Inlet
Koluktoo Bay
Gulf of Boothia
Scale of Statute Miles
20
0
100
Scale of Kilometres
40
0
200

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1. Summary

Petroleum exploration in eastern Lancaster Sound has been proposed by Norlands Petroleum Limited for the open water season in 770 m of water with a dynamically-positioned drillship located near 74°05'N 81°10'W. The frequency of iceberg encounters would undoubtedly present the major environmental hazard to such a drilling program, while an uncontrolled oilwell blowout would constitute the main threat to the marine life of the Lancaster Sound region. Accordingly, scenarios have been developed to consider exploratory drilling hazards in the Lancaster Sound area in light of the world-wide experience in offshore drilling vis-a-vis the specific environmental risks and sensitivities that are peculiar to this section of the Arctic archipelago. Based on world-wide offshore drilling experience, blowout probabilities range from 1 in 1,000 to 1 in 10,000; and in the Lancaster Sound area, the projected blowout would have a 10% probability of attaining a flow rate of 950 m^3 (6,000 bbls) of oil per day.

At the well-site, oilspill countermeasures are expected to be, on average, less than 50% effective during open water months of July, August and September, assuming optimum use of available technology; for the remaining nine months, the effectiveness reduces to zero in sea-ice. Depending on distance from the blowout, up to 55% of the oil evaporates and more progressively disperses into wind whipped seas. Much of the oil drifts with surface currents and sea ice south-eastward into Baffin Bay, leaving on a yearly average, 6% to invade coastlines.

Oil drifting ashore can be stranded on coasts for about 4 months during the open water season. Drift directions predict heaviest oil deposition for the north shores of Bylot Island and the northern mouth on Navy Board Inlet. Less oil pollution is predicted for the coasts of east Bylot Island, Eclipse Sound and south Devon Island.

Unless the blowout stops itself, it could flow for a full year before being stopped by the drilling of a relief well. There is insufficient time in the open-water season, of median duration 109 days, to drill a deep exploratory well and a relief well, should the latter be needed.

Lancaster Sound, a highly productive maritime region within Canada's High Arctic, is judged to be sensitive to oil pollution from a blowout. The Sound's rich waters host, seasonally, over 50% of Eastern Arctic marine birds, one-third of North America's White Whales and, possibly, 85% of North America's Narwhals. These, and their supporting food-web, are at threat from oil in offshore and coastal waters, in sea ice, at ice edges and on shores. The degree of threat to Narwhals, White Whales, Harp Seals, Ringed Seals, Walruses and Polar Bears is unknown. At best, they will avoid oiled areas by shifting feeding and breeding patterns. This may not be possible in restricted high-use regions, such as Navy Board Inlet, Croker Bay, Dundas Harbour and other coastal waters. The long-term consequences of their immersion in oil or ingestion of oil-tainted prey is unknown.

With more certainty, we can predict the impact of oil from the blowout on seabirds. The diving alcids are highly vulnerable, due to their feeding, moulting and migratory habits. The major impact of an oilwell blowout will be on the four largest Thick-billed Murre colonies in Canada's High Arctic. The Murre colony at Cape Hay will probably be destroyed. Populations at Prince Leopold Island, Coburg Island and Cape Graham Moore will be reduced in numbers, possibly to below those necessary for survival. Birds such as Northern Fulmars, Black-legged Kittiwakes, Eiders, Snow Geese and, particularly, the alcids - Dovekies and Black Guillemots - will also die in large numbers. The long-term significance of abrupt population declines is unknown.

The hunting success of Pond Inlet's Inuit may be affected for one or more years by a blowout in Lancaster Sound. Narwhal hunting at ice-edges, Polar Bear and Ringed Seal hunting on sea ice, Snow Geese hunting on Bylot Island and egg-gathering at Cape Graham Moore are at greatest risk.

2. Introduction

2.1 Choices

Lancaster Sound, fed by the waters of the Arctic Ocean and Baffin Bay and flanked by glaciers, cliffs and fjords, is a summer haven for a myriad of seabirds and marine mammals which depend on a bountiful production that has developed since the last glaciation 9,000 years ago. Today, assured markets for petroleum are increasing exploration pressure on Canada's offshore petroleum basins - and Lancaster Sound is one of the more promising ones[2.1].

Conflicts between exploitation, on one hand, and preservation on the other, may be resolved by choices which depend on our perception of costs and benefits. Some important questions determining choices[2.2] are: "Could exploration drilling seriously or irrevocably damage the natural system?" "Is there danger that some species could become extinct?" "Can these dangers be avoided or controlled?" "What are acceptable limits of pollution or damage?"

The purpose of this report is to provide the reader with a review of the most relevant information, pertinent to these choices:

- on the drilling system which might be used;
- on the hazards to offshore drilling;
- on the physical and biological environment;
- on the fate and effects of oil from an assumed oilwell blowout;

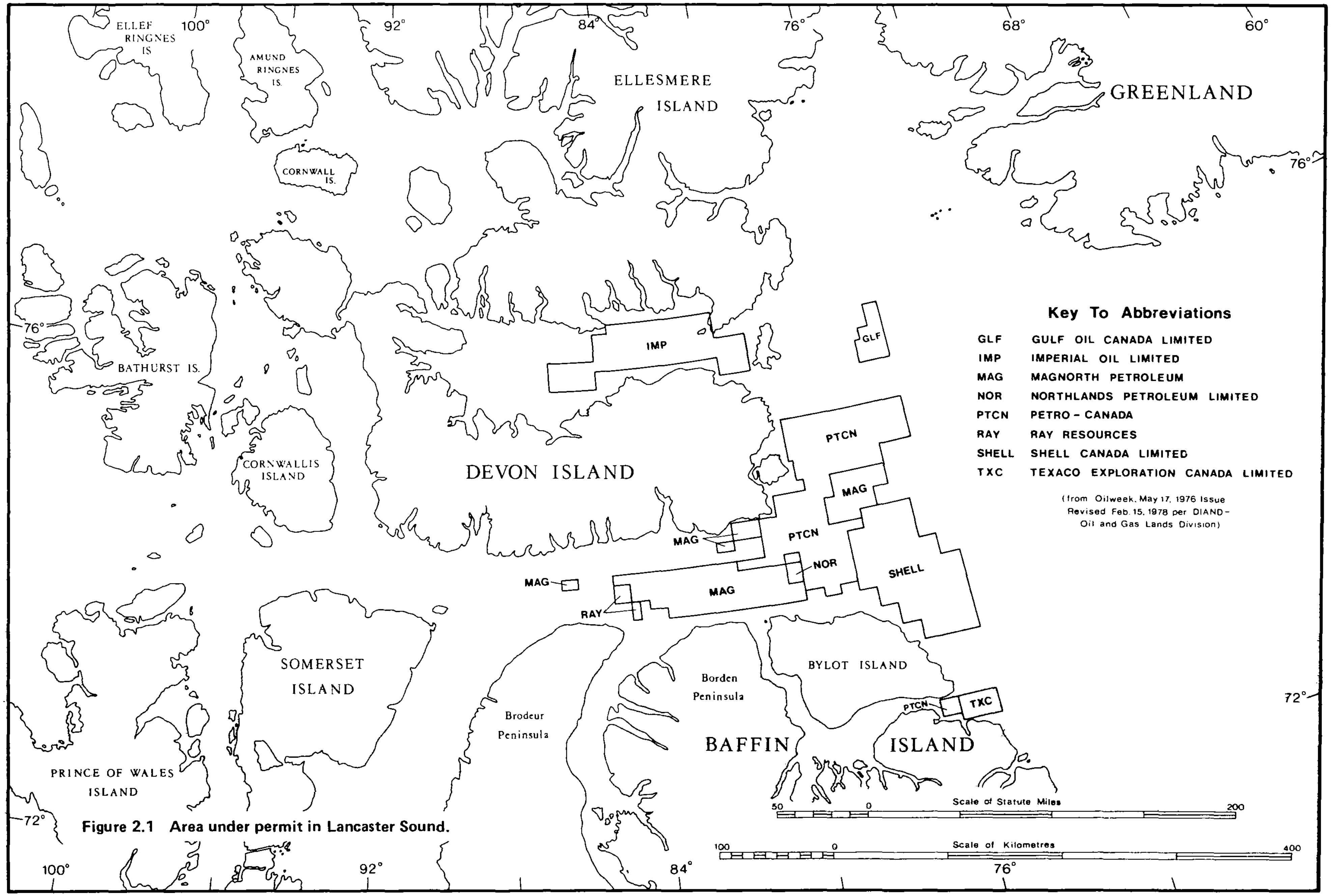

Figure 2.1 Area under permit in Lancaster Sound.

- on the effectiveness of oilspill countermeasures;
- on the effects the oil might have on wildlife.

Not covered, though of equal importance, are:

- the social and economic implications, and possible international problems.

2.2 Offshore Permits

Areas under permit in Lancaster Sound [2.3] (Figure 2.1) are valid for six years and grant exclusive right to the permittee to apply to drill and, later, to lease part of the permit area for petroleum production[2.4]. Guaranty deposits are required of the permittee to ensure that the permit area is effectively evaluated. Permits are granted under the Canada Oil and Gas Land Regulations and, north of 60° latitude, are administered by the Department of Indian and Northern Affairs. At this time, no new permits are being issued, pending revision of the Regulations. The revisions will reflect the need for environmental evaluations in the permit areas in keeping with requirements of the Federal Environmental Assessment and Review Office (FEARO).

2.3 Proposed Exploratory Drilling

Seismic surveys in Magnorth Acreage in eastern Lancaster Sound have revealed a number of sub-seabottom structures which could contain oil. Exploratory drilling - the next logical step to prove-out possible oil reserves - was proposed in an application for "Approval-in-Principle" by Norlands Petroleum Limited, a partner in the Magnorth Consortium, in February, 1974[3.1].

This application, backed up by engineering and environmental data, was reviewed for deficiencies and, in August, 1974, Approval-in-Principle was granted, subject to a number of conditions. A major condition was the requirement to conduct environmental studies in Lancaster Sound to determine the impact that exploratory drilling might have. Extensive baseline studies were completed, but without an evaluation of the possible effects of the proposed exploration program on the natural systems of Lancaster Sound. This report provides that evaluation, and constitutes a major component of an Environmental Impact Statement which the Initiator (the Department of Indian and Northern Affairs) may submit to an Environmental Assessment and Review Panel.

2.4 Escalation to Production

Just as marine seismic surveys precede exploration drilling, exploration drilling precedes development and production. Exploratory wells, coupled with seismic data, prove-out the extent of petroleum reserves. Eventual production then depends not only on proven reserves but also on the economics of production and government policy. The latter reflects, among other factors, environmental concerns.

Exploratory wells are normally abandoned. Production wells would then have to be drilled, with their oil feeding into sea-bottom pipelines - for transfer to bulk storage tanks at shore-bases. The oil would likely be delivered south, year-round, by ice-breaking tankers.

In deep water, well-heads may not have to be buried; however iceberg scouring of the sea-bottom occurs where pipelines emerge from the depths. Tunnelling from shore to depths of over 300 metres may be necessary to contain pipelines below iceberg keels.

The history of oil field development and production shows that, up to 1975, offshore oil production accounted for between 1.7% and 4.0% of the oil pollution in the world's oceans[2.5]. Transportation of oil accounts for most of it, with estimates ranging between 43% and 46%. Although the contributions from producing oil-fields are small, the effects can be magnified by their proximity to sensitive flora and fauna.

Various estimates have been made of the oil spillage from producing offshore fields. For example, an estimated 0.03% of the oil produced in Cook Inlet, Alaska, was spilled where there are offshore wells, a tanker terminal and a refinery[2.6]. Even if the percentage loss was as low as 0.001%, its chronic effects could be significant. If exploratory drilling occurs in Lancaster Sound, and extensive reserves of oil are discovered, it is certain that production will follow.

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2.2 Dunbar, M.J. *"Are Arctic Ecosystems Really as Fragile as Everyone Assumes?"*, Science Forum, pp. 26-29, August, 1977.

2.3 Land Map: Eastcoast Offshore and Greenland Concessions, from *Oilweek, January, 1977.*

2.4 *"Offshore Exploration - Information and Procedures for Offshore Operators"*, 6th Issue, Resource Management and Conservation Branch, Department of Energy, Mines and Resources, Ottawa, January, 1977.

2.5 *"Environment Impacts from Offshore Exploration and Production of Oil and Gas"*, Environmental Committee, Organization for Economic Cooperation and Development, Paris, January, 1976.

2.6 Kinney, P.J., D.K. Button and D.M. Schell, *"Kinetics of Dissipation and Biodegradation of Crude Oil in Alaska's Cook Inlet"*, In proceedings Joint Conference on Prevention and Control of Oilspills, December 15-17, 1969.

3. OFFSHORE DRILLING IN LANCASTER SOUND

3.1 Exploratory Drilling

Exploratory drilling is the next logical step following marine seismic surveys, in providing proof of the existence of oil and gas, and delineating the extent of petroleum reservoirs. The necessary geophysical information needed to identify different strata is obtained by well-logging. This is done, usually in the deepest part of the well, by running different kinds of detectors through the well-bore. The data obtained from logging is a prime reason for drilling exploratory wells. Seldom, if ever, will an exploratory well be used as a producing well.

3.2 The Drilling System Proposed

According to an "Application for Approval-in-Principle" from Norlands Petroleum Ltd., dated February 6, 1974,[3.1] a dynamically-positioned drillship of the *Havdrill* class was proposed for exploratory drilling in the deep water of eastern Lancaster Sound (Figure 3.1). Specifications for *Havdrill* are as follows:

Overall length	150 m
Beam	21 m
Depth	12 m
Maximum draft	7 m
Deadweight	6,600 tonnes
Speed	25 km/h (14 kts)
Ice Class	1A1 Ice B
Self-sufficiency	100 days
Power	17,000 HP.
Main propulsion	6,000 HP.
Complement	98

Drilling from dynamic-positioned, ice-strengthened ships appears to be most suited for Lancaster Sound. The deep water of this Sound precludes the use of jack-up rigs and, although semi-submersible rigs provide better heavy-weather drilling platforms than drillships, they would not be sufficiently mobile in ice. Lancaster Sound is accessible for drilling long before the ice clears from Baffin Bay, and from the many overwintering havens in the region of eastern Lancaster Sound.

Dynamic-positioning* has the advantage over anchoring in iceberg-infested eastern Lancaster Sound, where frequent moves off location may be required (Section 4.1.1.5).

3.3 Experience in Deep-water Drilling

Proposed drilling in Lancaster Sound is in water 770 m deep. To place this proposal in its proper perspective[3.2], a review of world experience up to mid-1977, in deep-water exploration drilling, is given in Tables 3.1 and 3.2.

Shell extended the water-depth record beyond 600 m in 1973 and again in 1974, using the drillship *Sedco 445* off Gabon. The current water depth record of 1,054 m was established by Esso in the Andaman Sea off Thailand[3.3]. Seven rigs are now capable of drilling in 1,000 m of water or more. A capability to 1,500 m is planned in 1980 for rigs now under construction.

Drilling comparable to that which has been proposed for Lancaster Sound occurred off West Greenland in the summer of 1977[3.3]. No reports are available of iceberg avoidance experience in that location; however, well-developed techniques for iceberg avoidance were used during exploratory drilling off Labrador in recent years.

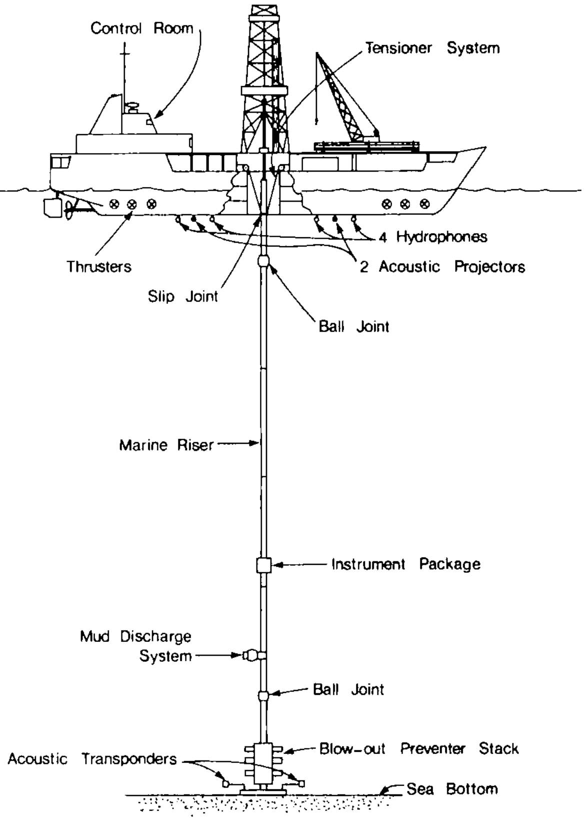


Figure 3.1 Deep-water Drilling System

A deep-water drillship costs over $50 million and, in southerly latitudes, operating costs are now more than $100,000 per day[3.3].

3.4 Components and Operation of a Deep-water Drilling System

When drilling on land, or offshore, formation pressures are balanced as the well is drilled. A pressure balance is accomplished by carefully adjusting the weight of a column of drilling-mud in the well-bore. Too low a mud-weight will permit formation fluids to enter the well-bore; too high a weight forces mud into formations, possibly fracturing them. A well is progressively lined with casing, which can resist well-bottom pressures should mud-weight be lost. Also a set of blowout preventer valves (BOP) is attached to the surface-casing, at the well-head, to close off the well. The BOP is designed to close under a variety of conditions, in order to secure a well.

3.4.1 Dynamic-Positioning

Station-keeping is achieved by countering wind, wave and current stresses with thrusters and main propellors (Figure 3.1). The thrusters and propellors act in response to signals from an acoustic positioning system keeping the vessel's position within a circle of diameter less than 6% of the water depth and holding its heading within ± 2 degrees. For example, the drillship *Pelerin* is capable of maintaining these limits in 4.9 m significant wave-heights, concurrent with 83 km/h winds gusting to 120 km/h and a 100 cm/sec current[3.4].

Positional accuracy (about 1% depth) depends upon the acoustic telemetry. The maximum offset of 6% triggers a red alarm, while a 4% offset triggers a warning yellow-alarm. Experience off Labrador in 1973 and 1974 was that maximum offsets did not exceed 3% of depth for 93% of the operating time, while heading variations remained within 4° for 94% of the time.

* In the shallow shelf-waters of the Beaufort Sea, drillships are anchored in order to maintain off-vertical tolerances for marine-risers.

Table 3.1 Number of Wells in Water Depths more than 180 m, by Locations and Years.

Years	68	69	70	71	72	73	74	75	76	77
Locations										
Gulf of Mexico								10	25	4
California	4	7	7	8	3			1	4	2
Far East					3	1		1	10	
North Sea					1	1	4	3	4	3
North Africa							2	4	1	2
Spain & Portugal								3	5	1
E. Canada							3	4	2	
Australia						2		4	1	3
W. Africa					1		1	1		2
Red Sea									2	1
W. Greenland										1
Other					1	2			4	
Totals:	4	7	7	8	9	6	10	31	58	19

Table 3.2 Number of Wells in various Depths and Locations

Locations	Depth, m.		
	180-300	300-600	Greater than 600
Gulf of Mexico	20	19	0
California	37	1	0
North Sea	12	4	0
Far East	4	4	7
N. Africa	5	3	1
E. Canada	7	2	0
Other			7

3.4.2 The Riser System

Marine drilling differs from land-based drilling by having the drill-rig on a ship and the well-head and the BOP stack on the sea bottom instead of just under the drill platform. The marine riser completes the link from the top of the BOP stack to the drill platform and acts as a flexible extension of the surface-casing to contain drilling mud, the drill-string and, at times, the casing being set into the well.

In deep water, the larger diameter riser required will be subject to high water current stresses. Maintenance of mud circulation is more difficult as the volume of mud in the riser compared to that in the well-bore increases. This problem is sometimes solved by using a booster pump and line connected above the BOP to increase the circulation rate of mud and cuttings. Long risers require increased mud storage, typically double that of conventional drillships.

Riser design is specific to a drilling location, depending on water depth and currents. This would also apply to the vessel which could drill a relief well in the event of a blowout. Riser bending stress is relieved by the use of ball joints at both ends. Its weight is supported by a multiple riser tensioning system on the ship providing a constant lift while the ship heaves. Bouyancy members are often used to provide a fraction of the axial lift; however, these add horizontal drag and are subject to leakage. Anti-drag fairings are sometimes used where currents of 150 cm/sec, or more, are anticipated. Today, the trend is to apply large axial tensions with no bouyancy-lift or anti-drag fairings, as in *Pelican* and the newer *Pelerin*. Recent designs incorporate stress sensors on risers, and a mud discharge feature which releases mud to the sea floor, if required in well-control procedures.

3.4.3 Blowout Preventer and Receiver-Plate Assembly

A drillship may be forced off location by an iceberg, sea-ice or a severe storm, and must be able to shut-in the well at any stage of its operation, and move off quickly. This is done by actuating the BOP and Lower Receiver-Plate Assembly. For example, on *Pelerin*, several automatic disconnect and shut-sequences can be initiated,[3.4] including a rapid 30-second sequence and a slower 56-second sequence. The slower (56-second) sequence permits retention of all mud within the hung-off riser, which can be a considerable volume in deep water. If necessary, there is a 12-second emergency disconnect and shut-in sequence, which shears the drill-pipe. Communication between the drillship and the BOP and receiver-plate assembly on the bottom, through hundreds of metres of water, is achieved using multiplexed electrical signals, backed up by an independent acoustic system. Power to perform a variety of functions is provided at the sea-floor by stored fluid pressure in accumulators. The BOP stack is a set of hydraulically-operated valves, or rams, designed to stop fluid-flows at formation pressures. Drill-mud is circulated down the drill-pipe, then up in the annulus between the drill-pipe and the well-bore, through the BOP and up the marine riser. The BOP can shut-off flow in this annulus; it can hang-off a drill-string and close shear-rams above it, and it can shear drill-pipe and casing. Depending on the lead-time required for a move-off location, drill-pipe would be landed in the pipe-rams before operating the shear-rams. More lead-time for departure enables drilling to be resumed faster.

In Lancaster Sound, an ice and iceberg alert system is necessary to give advance warning of possible collisions. An effective system ensures that hours are available to decide on types of operations not to start, or to terminate. If a large iceberg is predicted to collide with a drillship, a cement plug will likely be set in the upper well-bore, prior to closing BOP rams and hanging-off the marine riser. This ensures that the well remains closed if the BOP stack is pushed off the well-head by the iceberg's keel.

Reconnection of the hung-off riser to the BOP stack (or the lower riser stab assembly) on the sea-bottom is aided by the dynamic-positioning system and by underwater television. The hanging riser must be placed within 0.6 m, which is easily done with the ship's positioning system; however, the ship's heave must be less than 1 m.

3.4.4 The Preliminary Stages of Deep-water Drilling

Initially, a base plate with a funnel on top, complete with acoustic transponders is placed on the sea floor. The drill string enters the funnel and drills a hole to a depth of between 100 and 150 m for the conductor casing. At this stage, salt water is usually used to clear cuttings. After the conductor casing is cemented in place, drilling proceeds for setting the surface casing to a depth of about 300 m. This is done using the marine riser and drilling mud. An option is to drill with or without the BOP stack in place during this stage. Procedures will vary, depending on whether there could be sub-sea permafrost, gas hydrates, or both. Relict sub-sea permafrost, in the deep water of Lancaster Sound probably does not exist, but gas hydrates are almost certain to exist in sediments (Section 4.3).

On land or in shallow water, permafrost can be preserved by drilling with refrigerated mud and the use of an insulated conductor casing. So far, deep water drilling through sub-sea permafrost has not been done. Other design alternatives, other than those used in shallow water, may have to be devised if permafrost exists[3.2].

Hydrates can decompose on warming to form gas, possibly causing a "kick" in a well. Control is maintained by ensuring that the mud temperature during drilling, remains below the temperature required for hydrate decomposition. Gas hydrates can bond sea bottom sediments to form a layer impervious to free gas beneath the layer. Anticipation of possibilities such as this determines the design of the drilling program.

When the upper part of the hole is being drilled for surface casing, a diverter is placed on top of the marine riser to direct any gas from a well-kick to a separator or flare line. This ensures that high gas pressures do not develop at the bottom of the conductor casing possibly fracturing the surrounding formations and permitting gas to flow outside the casing through the sea floor. At the early stages of drilling, a BOP is not necessarily in place, nor would it ensure well-control without the surface casing in place.

3.4.5 Drilling to Depth

Well-control below the shoe of the surface casing, at about 300 m, depends on the prediction and monitoring of drilling conditions and on the design of the well-casing. Monitoring ensures the detection of small volumes of fluids entering the well-bore which, if undetected, could precipitate a blowout if no controls are initiated. The "kick" which tends to lift mud out of the hole, is countered by increasing the mud density. If this procedure fails, a second line of defence is to close the BOP and circulate the fluid safely to the surface through a "choke" line bypassing the BOP, meanwhile regaining the required mud column in the hole.

Should insufficient casing be installed to line the well-bore, a kick and associated loss of mud volume could transfer deep formation pressures to the shallower shoe of the casing. This could fracture the surrounding shallower formation causing an underground blowout; although serious, fluids would not spill into the sea.

3.4.6 Abandonment

Deep-water exploration wells are generally abandoned as follows: All the casing is left in place with a mud-column filling the hole, topped by a concrete plug about 30 m long, starting 10 m below the sea-bottom. The BOP stack is then removed.

3.5 Hazards to Drillships from Blowouts

There is an established Canadian Government principle of requiring "same-season" relief well drilling capability, based on having a back-up drilling system nearby. This implies that a drillship would be too severely damaged after a blowout to drill a relief well on its own. Therefore, it is worth examining the respective hazards to a dynamically-positioned drillship in deep water in the event of either a gas or gas-and-oil blowout.

A gas-well usually flows considerably more gas than an oilwell. The gas from an oilwell is only the volume which comes out of solution from the oil. For example, from a 950 m^3 per day flow of oil (assumed in the hypothetical blowout in section 5), the gas flow at the sea-surface could be 3 m^3 per second, while gas-well blowouts flowing from 10 to 100 m^3/second of gas at the sea-surface are common. In the deep, cold water of Lancaster Sound, it is likely that a large fraction of the gas – perhaps more than one-half of it – would form gas hydrates (Section 5.1.3). The movement of the gas in the water column, due to the currents, would tend to remove the surface bubbles from the drillship's location over the well.

The hazards to the drillship from oil on the sea are low compared to the presence of large volumes of gas. Gas in a bubble-plume reduces the bouyancy of a ship, and creates a serious fire-hazard. Both of these hazards diminish in deep water. In shallow water, gas bubbles-up in the "moon pool" and washes water on to the ship's deck. One drill vessel has sunk from deck-water flowing into open hatches. Model tests, and experiences with gas blowouts by modern drillships show that some stability can be lost, but sinking does not occur.

The most severe hazard is fire; however, a dynamically-positioned drillship can drift with currents or move under power away from the fuel source. A gas blowout which may result in a fire, can occur in two ways. Gas can vent through the sea floor, or come up through the riser. If gas vents through the sea floor, rig engines would be shut down to prevent ignition of the gas, the riser would be released and the vessel allowed to drift off. If gas vented through the riser, for example from a kick while drilling to set the surface casing, the diverter would be closed to shut off the fuel supply. In drilling deeper wells, the BOP rams and the diverter would be closed to limit the fuel supply.

Fire has destroyed or severely damaged four floating drilling rigs. In each case, the moorings fixed the rigs over the blowout, allowing fires to rage unchecked.

3.6 Blowout Possibilities

Exploratory drilling is more risky than production drilling, and could contribute a significant fraction of the oil lost in the development of a large offshore field. Questions are: How probable is an offshore blowout of any kind?; How probable is an oilwell blowout?; How much oil is likely to flow from an oilwell blowout?; Are relief wells always required?. Answers to these questions are unsatisfactory because no two blowouts have been alike in offshore fields. One cannot say that one component or procedure has failed consistently; however, human mistakes emerge as the common thread in the fabric of accidents.

Available data for 20,373 wells drilled offshore[3.5], from 1952 to 1972, show that 47 of these had blowouts of various kinds, or about 2 in every 1,000 wells drilled. Sixty-three per cent of these ceased flowing independently due to the well-bore "bridging" with debris, seventeen per cent were eventually killed by circulating heavy mud and the remaining twenty per cent required the drilling of relief wells to stop the flow by the insertion of cement into the oil bearing formation. From this data, it is seen that about one well in 3,300 blew oil, for a total of six oilwell blowouts. The dates, locations and estimates of volumes of oil spilled for these wells are as follows:

1969, Santa Barbara Channel	18,500 -	780,000 barrels
1970, Gulf of Mexico	53,000 -	130,000 barrels
1970, Gulf of Mexico		30,500 barrels
1969, Gulf of Mexico	2,500 -	3,000 barrels
1971, Gulf of Mexico	400 -	500 barrels
1964, Gulf of Mexico		500 barrels

This list shows the wide range in volumes of oil escaping through blowouts, depending on access to the well, natural bridging, and a myriad of other factors.

The Canadian Arctic record is no better. In the two wells drilled by Canmar in 1976 in the Beaufort Sea, one had minor, uncontrolled waterflows — hardly classified as a blowout — and the other had an underground gas blowout. This initial blowout score is, at least, 50%. Up to 1975, 475 wells had been drilled on land in the High Arctic Islands, of which two Panarctic wells blew gas — a blowout score of over 4 in 1,000. Statistically, oilwell blowouts have occured five times more frequently offshore than on land. Should this factor of five be applied to Lancaster Sound, the blowout rate would be 20 in 1,000. It is evident that the manipulation of past scores to predict future accidents soon becomes meaningless. In any new enterprise, there is a "learning curve" applying to proper procedures, as well as to drillcrew training and government regulations. Therefore, imprecise as it may be, we assume that the probability of an oilwell blowout in Lancaster Sound is somewhere between 1 in 1,000 and 1 in 10,000.

3.7 Logistic Support for Offshore Drilling

For exploratory drilling in offshore Lancaster Sound, using drillships, the following support is required: (1) shore support base camp(s) to stage equipment and personnel, to store emergency drilling supplies, to serve as a communication centre, and to harbour and possibly overwinter drillships and supply vessels; (2) marine and air transportation to ferry personnel and equipment from ship to shore; and (3) a ship-based support system for ice and iceberg surveillance and avoidance.

Generally, the shore support base camp consists of living accommodation for 100 people, water treatment and sewage disposal plants, garbage incineration, loading facilities and wharf or gravel spit for marine transportation of drill-pipe, casing, drill-mud and other drilling materials, an airstrip for C130-type cargo aircraft, roads, storage area for bulk fuel, and gravel borrow sites. The complexity of these support facilities may vary with the level of drilling activity, design and operation of the drillships,[3.4] and government safety regulations concerning weather and ice prediction and oilspill countermeasures.

With the exception of a major pollution event, such as an oil blowout, the environmental hazards associated with land-based facilities and logistics are greater than those of the drilling operation itself. At present, there is no detailed plan which outlines the facilities and logistics proposed for Lancaster Sound in support of offshore drilling; however, it is possible that a lead-zinc mine site, called Nansivik, situated on the south shore of Strathcona Sound, could provide the above-mentioned requirements. The incremental environmental consequences of a base camp at an established mining site may or may not be within acceptable limits.

By water, Nanisivik is about 190 km distant from the proposed drilling area in mid-eastern Lancaster Sound (Figure 1.1). From mid-September to mid-July, ship traffic will encounter landfast ice of varying amounts in Strathcona Sound and Admiralty Inlet. Any vessels overwintered in Strathcona Sound will require heavy ice-breaking support if drilling commences in early July. In the future, Dundas Harbour and Croker Bay, along south Devon Island, may be considered as potential land-base and overwintering sites because of their close proximity to drilling operations, and their deep water, protected characteristics.

3.8 Operating Conditions proposed for Lancaster Sound in 1974

In August, 1974, Norlands Petroleum Limited was granted Approval-in-Principle[3.6] for the drilling system described in their application[3.1] of February, 1974. This expired in August, 1977, but was subject to a number of conditions. The main ones concerning drilling operations are paraphrased as follows:

- The drillship, a *Havdrill* class vessel, or equivalent, must comply with Arctic Waters Pollution Prevention Regulations.
- Two ice-breaking workboats of Arctic Class 2, or higher, are required, both of which must comply with Arctic Waters Pollution Prevention Regulations.
- A weather, sea-state, and ice-prediction system was required to be in operation, similar to that supporting drilling operations in the Beaufort Sea.
- A relief-well drilling schedule was required. (This was to be approved by the "designated authority" but did not prescribe, specifically, a "same-season" schedule).
- Another drillship, with compatible equipment, and meeting the same specifications as the original vessel, was to be available to drill a relief-well within an acceptable time period.
- An oilspill contingency plan was required.
- A plan for a support base and operational scheduling was required.

3.9 Summary: Drilling in Lancaster Sound

- Exploratory drilling defines the extent of petroleum resources.
- Exploration wells seldom become production wells.
- A dynamically-positioned *Havdrill* class drillship, or equivalent, would be used.
- Drilling would take place in water over 750 m deep.
- Drilling in waters over 1,000 m deep has occured once, in October, 1976. Fifteen wells have been drilled in waters over 600 m deep. In the Arctic, non have been drilled in waters over 600 m deep.
- An ice and iceberg surveillance and warning system will be required in eastern Lancaster Sound.
- A well, under the predicted path of a large iceberg, would be sealed, with a cement plug before the drillship

moves off location. This would leave the well safe should an iceberg push the BOP stack off the well-head.

- A modern drillship can shut-in the well, disconnect and hang-off its marine-riser in as little as 12 seconds, in an emergency.
- An abandoned well will be permanently sealed with a long, cement plug, set within the well casing.
- A gas blowout, especially in deep water, will not significantly reduce a drillship's stability.
- The fire hazard from a gas blowout is substantially reduced when using dynamic-positioning.
- The probability of an oilwell blowout in Lancaster Sound is somewhere between 1 in 1,000 and 1 in 10,000 wells drilled.
- Government policy requires a "same season" relief well drilling capability.
- It is likely that the same drillship that drilled a wild-well will be available to start a relief well.
- A logistic support base and its infrastructure is likely to produce more environmental disturbance than offshore drilling, provided an oilwell blowout does not occur.

References

3.1 *"Lancaster Sound Exploratory Well Proposal - Approval-in-Principle Submission"*, Norlands Petroleum Limited., 717 - 7th Avenue, S.E. Calgary, Alberta, T2P 0Z3, February, 1974.

3.2 Potts, H.L., *"A Review of Deep Water Exploratory Drilling Techniques with particular reference to the Eastern Arctic Area of Canada"*, Unpublished Memorandum, Oil and Gas Engineering Division, Department of Indian and Northern Affairs, Ottawa, Ontario. K1A 0H4, October, 1977.

3.3 Snyder, L.J., *"Deep Water Drilling has its own Technology"*, Offshore, pages 315-322. May, 1977.

3.4 Robertson, R.,*"Perelin uses Dynamic-Positioning to Drill in 3,046 feet of Water"*, Offshore, pages 116-123, May, 1977.

3.5 *"Energy under the Oceans"*, University of Oklahoma, Technology Assessment Group, Norman: University of Oklahoma Press, 1973.

3.6 *"Approval-in-Principle"*, Attachment I in a Letter from the Assistant Deputy Minister, Northern Affairs Program, Department of Indian and Northern Affairs to Norlands Petroleum Limited, August 1974.

4. HAZARDS AND CONSTRAINTS TO DRILLING

The question here is, "What could disrupt drilling operations and help to cause a blowout?". The drillship, its drilling technology and support system, are designed to cope with assumed weather, waves, ice, currents, sea bottom and other conditions in Lancaster Sound. If design assumptions do not adequately account for the real environment, then a breakdown of planned procedures and perhaps a loss of well control could result, increasing the possibility of an oilwell blowout.

The purpose of this section is to illuminate known and possible environmental constraints and hazards that offshore drilling may be confronted with in Lancaster Sound, thereby avoiding the unexpected.

4.1 Sea Surface and Atmospheric Problems

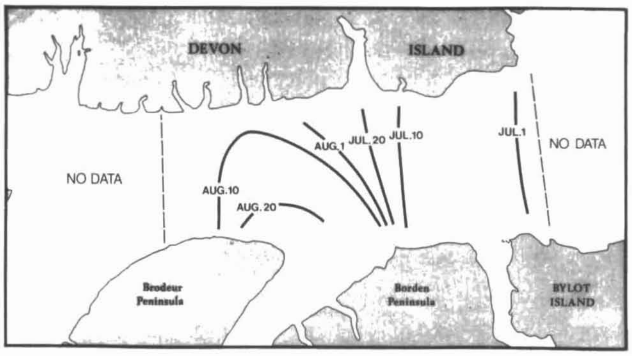
The sea surface and the atmosphere are inextricably linked in the growth, decay and movement of ice and in producing wind waves, surface currents, obscured visibility and structural icing, all of which, to some degree, affect drilling platform safety, its ability to be resupplied and to remain on station.

4.1.1 Ice Climate

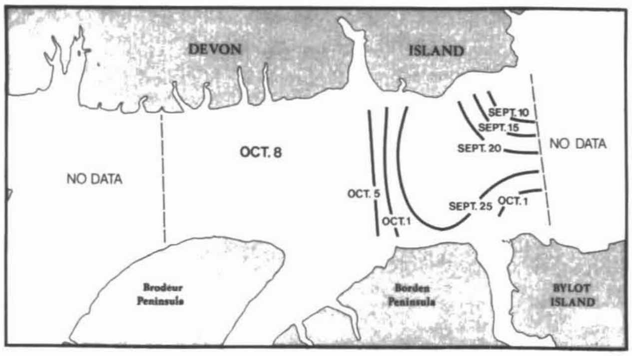
4.1.1.1 Operating Season

The ice cover determines the duration of the summer's operating season for drillships. This season could encompass not only exploratory drilling but could include time to deploy a second drillship and to complete a relief-well in the event of a blowout. Not considered, but important, are added constraints to drillships entering and leaving Lancaster Sound. Assuming drillships can operate in early summer ice concentrations of 3/10ths or less, and in the fall can move in new ice of thickness of 15 cm or less, the season extends from about early July until mid-October – about 109 days[4.1] for central Lancaster Sound between 81°W and 82°W, assuming one 3-day ice intrusion.

Compared to the southeastern Beaufort Sea[4.2], the variation in the summer's drilling season, from year to year and from one location to another is far less in Lancaster Sound. Markham[4.1], using ice observations in the 17 summers between 1960 and 1976, shows that, for central channel locations in Lancaster Sound extending from 80°W to 87°W, the median operating season, which varies with longitude, ranges between 126 and 90 days (Table 4.1). Figure 4.1, derived from columns 7, 8 and 9 in Table 4.1, shows isochrones representing most probable dates for the beginning and end of the drilling season in Lancaster Sound. Excluded are the two worst ice years in the 17 years of data.



START OF SEASON



END OF SEASON

Figure 4.1

During summer, intrusions of multiyear ice from northern Baffin Bay, sometimes in concentrations of 3/10th or more, are common at the eastern end of the Sound. However, time lost from these intrusions could be compensated for by an earlier season's beginning. The

Table 4.1 Drillship Operating Season based on Ice Observations in 17 Summers in Lancaster Sound (1960 to 1976).

(1) Longitude Intervals in Lancaster Sd.		(2) Beginning*			(3) End*		(4) Operating Period Days (Referred to Medians)	(5) Ice Intrusions	(6)	(7) Most probable beginning and end dates, excluding two worst ice years	(8)	(9)
	Earliest	Median	Latest	Earliest	Median	Latest		Total No. in 17 yrs.	No. of years affected	Beginning	End	Location
80-81W	June 18	June 18	July 09	Sept 17	Oct 22	Oct 29	126	22	13	July 02 July 02	Sept 10 Oct. 01	N S
81-82W	June 18	June 25	July 30	Sept 10	Oct 15	Oct 29	112	13	11	July 02 July 09	Sept 24 Sept 24	N S
82-83W	June 18	June 25	Aug 20	Sept 24	Oct 22	Oct 29	119	8	8	July 09 July 09	Sept 24 Sept 24	N S
83-84W	June 18	July 02	Aug 20	Oct 08	Oct 22	Oct 29	112	9	9	July 23 Aug 13	Oct 08 Oct 08	N S
84-85W	June 18	July 02	Sept 03	Oct 01	Oct 15	Oct 29	105	5	4	Aug 06 Aug 20	Oct 08 Oct 08	N S
85-86W	June 18	July 09	Sept 03	Oct 01	Oct 15	Oct 29	98	3	3	Aug 13 Aug 20	Oct 08 Oct 08	N S
86-87W	June 18	July 16	Sept 03	Sept 17	Oct 15	Oct 29	90	5	5	Aug 06 Aug 06	Oct 08 Oct 08	N S

* At latitude 74°10'N, approximately one-half way across the Sound.

** 'S' is at latitude 74°00'N, and 'N' is at latitude 74°20'N.

duration of the intrusions is unknown but these could occur for a few days at a time in locations along the centre of the Sound. Near the southern shore, they could be more disruptive. The most operating days likely occurs at the centre of the Sound, between 82°W and 83°W, just west of the proposed exploratory drilling site. Here, there were 8 ice intrusions in 8 years of ice observations, or one per year, resulting in a median operating season of 116 days (assuming single 3-day disruptions). Although these statistics are useful, the timing of a drilling operation would have to rely on the prediction of ice conditions from satellite imagery and ice reconnaissance flights. Possible disruptions from icebergs and wind waves will be described later (sub-sections 4.1.1.5 and 4.1.2.2).

4.1.1.2 Sea Ice break-up and freeze-up patterns

Overwintering of drillships, access to supply bases and strategies for ice avoidance depend on seasonal patterns of breakup, movement and freeze-up. These patterns also determine the fetch in which wind waves develop.

Lancaster Sound is a major eastern exit for water moving southward from the Arctic Ocean through the Queen Elizabeth Islands. At its eastern end, its surface waters are influenced by the southward-moving surface water from northern Baffin Bay[4.3]. Deep water intrusions from Baffin Bay into Lancaster Sound provide heat in winter which, combined with the easterly surface water flow, prevents landfast ice from forming over Lancaster Sound.

Figure 4.2 illustrates two typical patterns in the seasonal dynamics of ice in Lancaster Sound[4.4]. Satellite infra-red imagery shows that the western end of Lancaster Sound in late winter is similar to the "North Water" in Northern Baffin Bay, having open water and thin ice east of a landfast ice-edge. From this ice-edge, growing ice drifts eastward in company with ice from adjoining inlets. These inlets become progressively blocked as their ice becomes landfast. By early January, ice stops moving through Barrow Strait and Wellington Channel, but Prince Regent Inlet contributes ice to the Sound until April. This progressive blocking of channels creates stationary ice edges — the main one being at the western end of Lancaster Sound. By May ice growth stops and clearing begins from the ice edges and progresses eastward. This is followed by the break-up of the fast ice and its eastward drift in band-like floes. Ice then resumes its drift into Lancaster Sound from Barrow Strait, Wellington Channel and Prince Regent inlet. By summer, the Sound is virtually ice free.

The outstanding wintertime feature of the ice in Lancaster Sound is the landfast ice-edge across the western end of the Sound usually forming before mid-January. In 1975, this edge struck N.E. across the Sound from Prince Leopold Island (its more usual position) but, in 1976, the edge stabilized across western Barrow Strait, near Griffith Island, south of Resolute Bay. The Sound to the east of this edge becomes a source for new ice which gradually thickens as it drifts eastward. To a lesser extent, Prince Regent Inlet acts as another source of new ice until a second landfast ice-edge forms at its exit by April. The formation of these ice plugs profoundly affects thicknesses, concentrations and drift-speeds of ice in the Sound during late winter and early spring.

While Lancaster Sound may clear early and freeze late, adjacent bays and inlets, suitable for shore bases and overwintering sites, can remain clogged at the season's start, or become inaccessible at its end.

4.1.1.3 Ice types, concentrations and thicknesses

Ice types and concentrations, in late winter and early spring, are often like those shown in Figure 4.3. In some years, the open water just east of the ice edge of Prince Leopold Island can extend to the exit of the Sound by mid-March[4.5]. In the west, where fast ice grows, its thickness is similar to that of ice off Resolute Bay**; and the first-year ice thickness off Arctic Bay is similar to that in Admiralty Inlet[4.6] (Figure 4.4). Neither will typify ice thicknesses in Lancaster Sound, east of the fast ice edge. After January, this part of the Sound continually grows and exports ice; consequently, ice thickness will be less than for Resolute and Arctic Bay, and thinnest just east of the ice edge. Knowledge of this ice thickness is absent in the ice climate of Lancaster Sound but is of no consequence to drilling operations in summer. The only available ice measurements are from the *S.S. Manhatten* in 1970 (Figure 4.5) in the eastern end of the Sound. These are not typical since 1970 appeared to be an anomously heavy ice-year (according to the Atmospheric Environment Service Ice Charts of May 21 and 28, 1970).

** There will be considerably more variation in the thickness of first-year ice offshore, due to rafting of young ice and variation in snow cover. Pounder and Stalinski[4.7] describe first-year ice thickness variations in Barrow Strait.

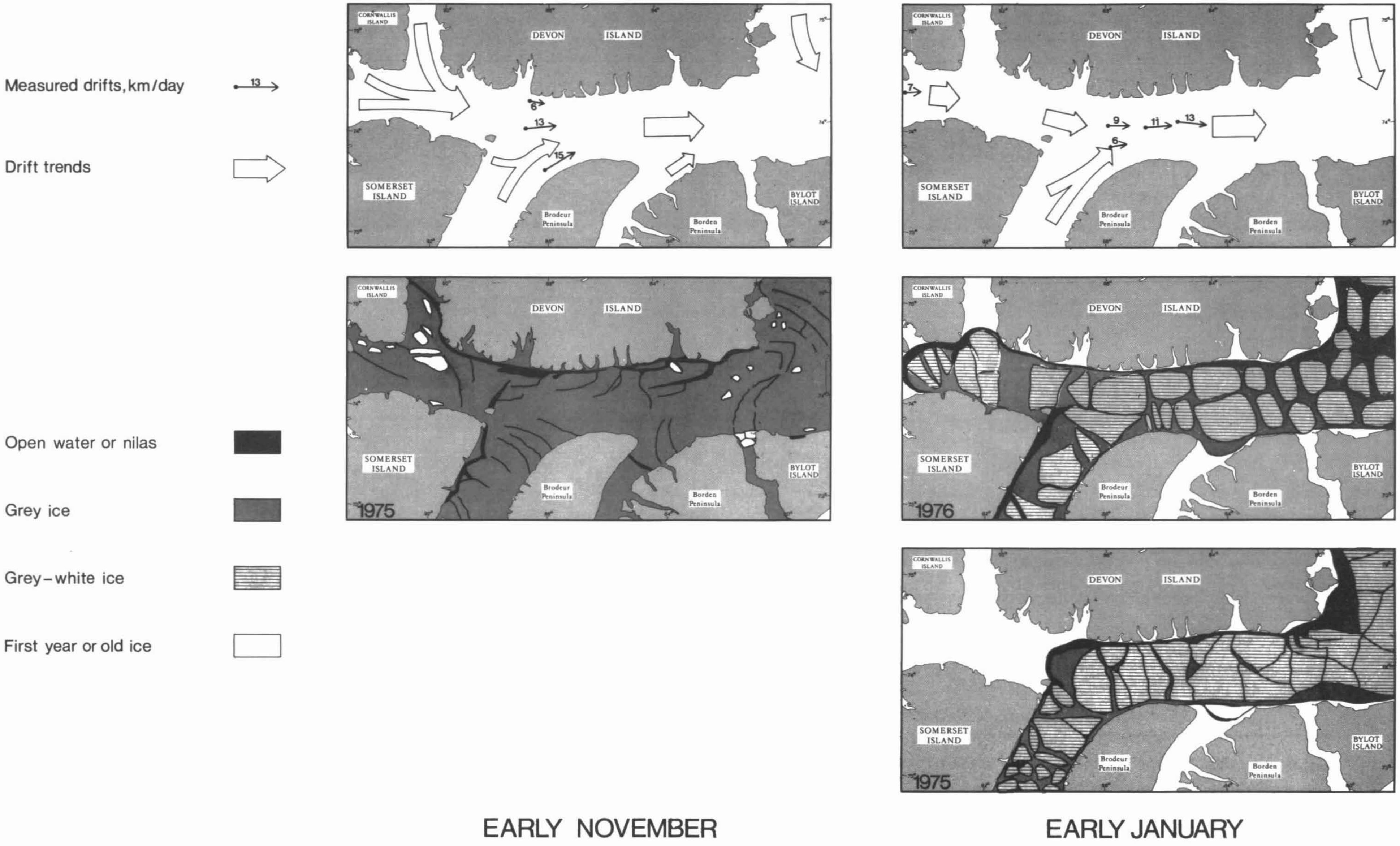


Figure 4.2 Ice freeze-up and breakup patterns, 1975 and 1976.

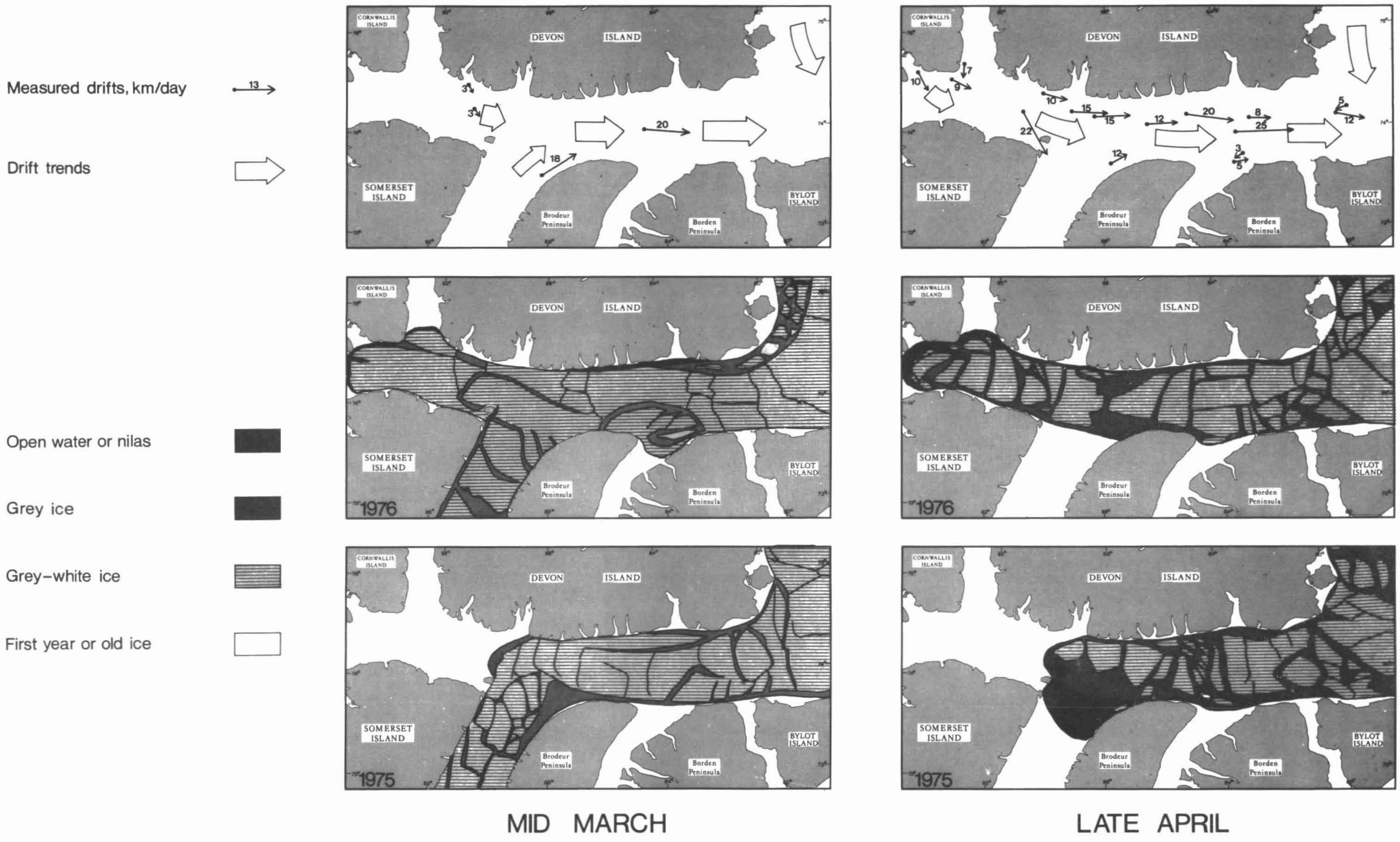


Figure 4.2 (cont'd) Ice freeze-up and breakup patterns, 1975 and 1976.

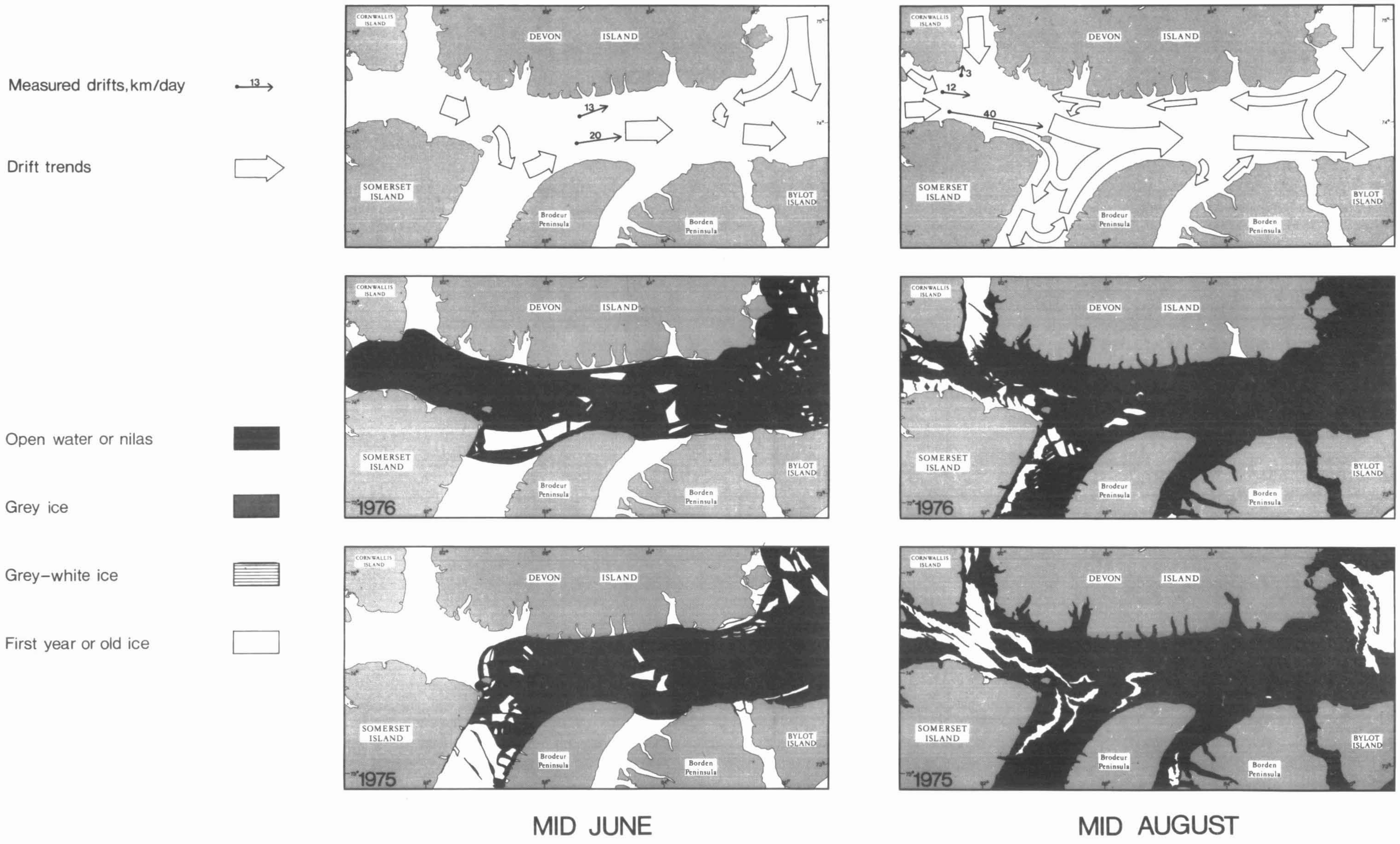


Figure 4.2 (con't) Ice freeze-up and breakup patterns, 1975 and 1976.

Before landfast ice forms in Barrow Strait and creates the fast ice-edge in western Lancaster Sound, ice from the west is continually drifting through the Sound. This drift is cut off by January, leaving predominantly second-year ice to continue eastward to mingle with newly forming first-year ice. Coriolis force tends to press ice against the southern shores of the Sound as it drifts toward Baffin Bay.

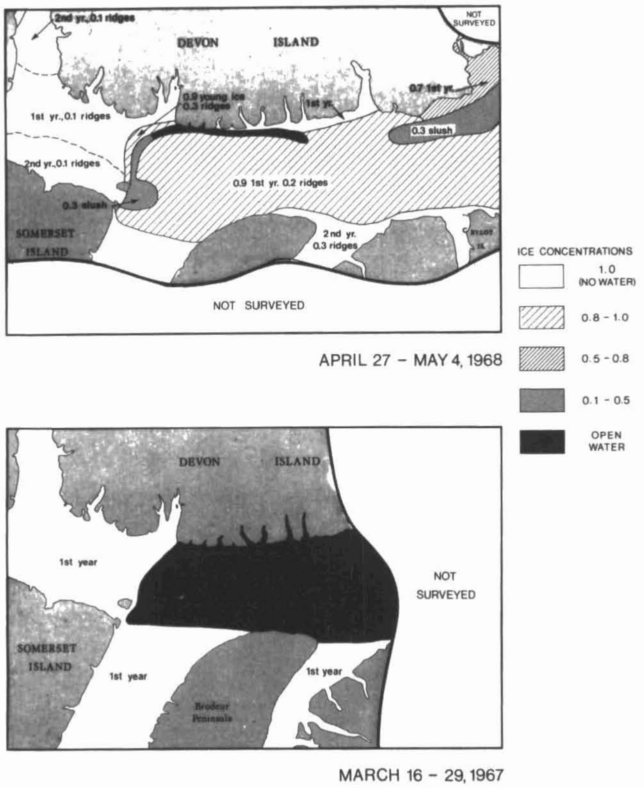


Figure 4.3 Springtime Ice Concentrations 1967 & 1968

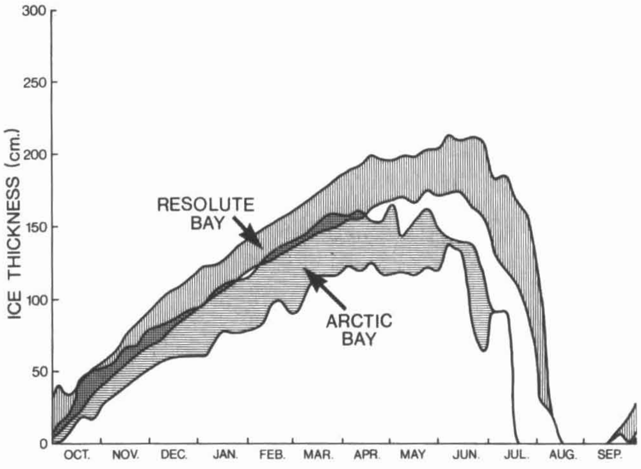


Figure 4.4 Ice thickness vs. time-of-year at Resolute & Arctic Bay.

In winter, the thickness of the eastward moving, growing ice, depends on three factors: (1) its drift speed eastward, (2) the number of degree-days of freezing since its inception, and (3) its accumulated snow-cover[4.8]. Figure 4.6 shows accumulated degree-days of air temperature below -1.8°C vs time of the year for Resolute; also shown[4.8] is a curve of ice thickness vs accumulated degree-days below -1.8°C. Using these curves and assumed ice drift speeds, estimates of the thickness of new ice can be made. For example, if the ice drift eastward averaged 10 km per day from the initiation of its growth on the 15th of March, off Prince Leopold Island, it would drift 260 km to north of Navy Board Inlet in 26 days, arriving on the 11th of April. The accumulated degree-days below -1.8°C between these dates is 660, causing the ice to grow a thickness of 51 cm.

During the melt in late spring, and early summer, the edges of the fast ice at the western end of Lancaster Sound and in Wellington Channel break off and drift eastward. This ice will diminish in thickness according to the accumulated degree-days of heating above -1.8°C. For example, ice can break-up in early July and have an initial thickness of 180 cm (Figure 4.4). This ice decreases in thickness by h cm where $h = 0.55\,\Sigma\theta$, and $\Sigma\theta$ are the accumulated degree-days in °C, above -1.8°C. For Resolute*, a representative $\Sigma\theta$ vs time of the year is plotted in Figure 4.7. Assuming an ice drift of 15 km per day eastward, the time taken from, say, the 5th day of July to reach Navy Board Inlet, 260 km to the east would be 17 days. From Figure 4.7, the accumulated degree-days above -1.8°C spanning this time is 114; hence $h = 0.55 \times 114 = 63$ cm. The original ice-thickness of 180 cm would have deminished by 63 cm to 117 cm.

* Derived from reference [4.9]

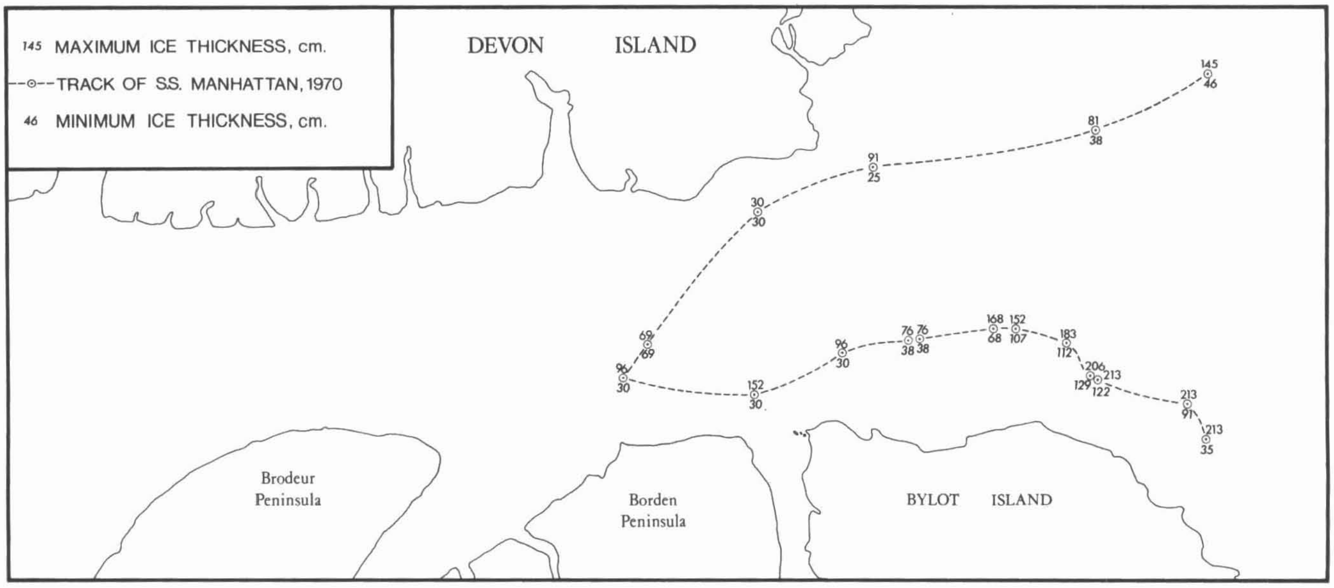


Figure 4.5 Measured ice thicknesses, May 3 to May 10, 1970.

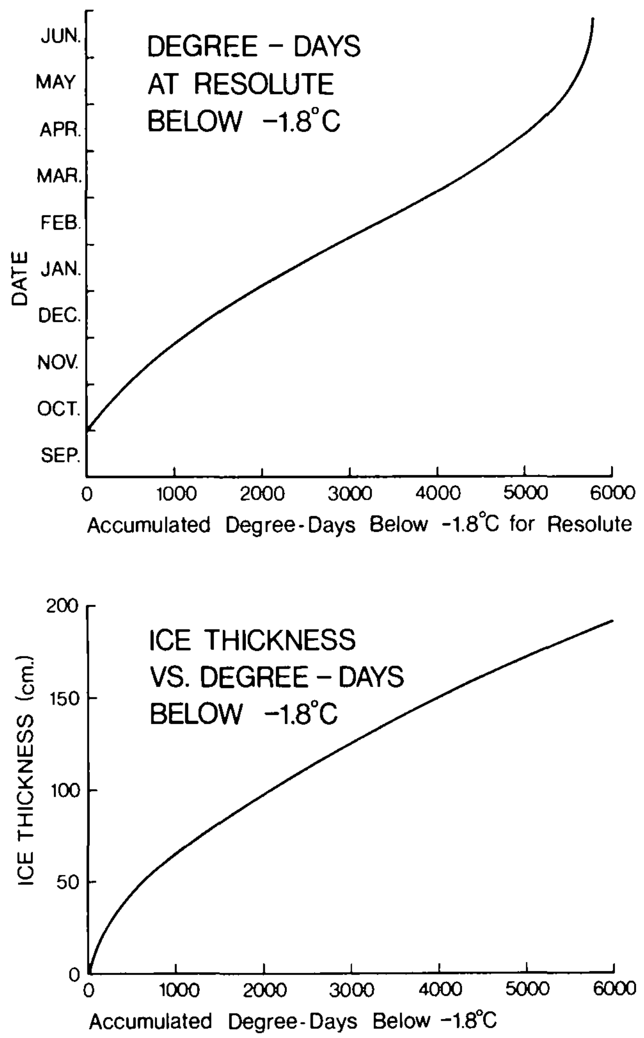


Figure 4.6

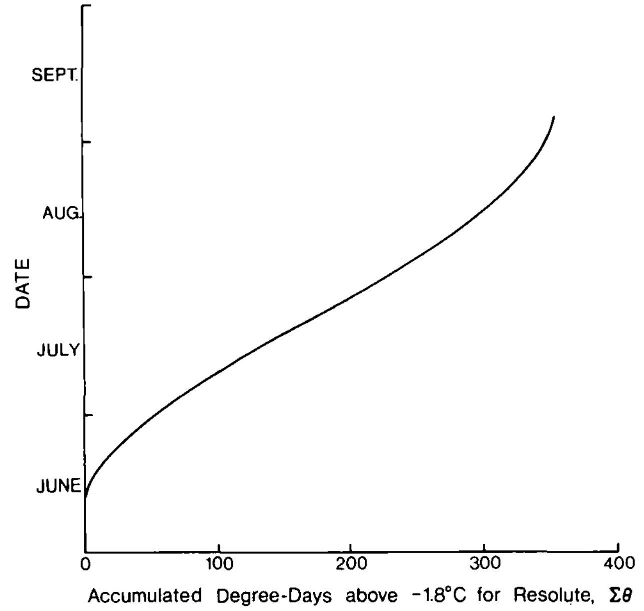


Figure 4.7

From Figure 4.7, the maximum value of $\Sigma\theta$ is 352 degree-days, hence the maximum ablation is h max = 0.55 x 352 = 194 cm. Consequently, all the first-year ice which does not drift out of Lancaster Sound will melt during the short summer. This will not be the case for polar floes entering Lancaster Sound from Wellington Channel or Barrow Strait. These are frequently more than 600 cm thick, even at the end of August[4.10].

Polar floes in summer could force a drillship off location, although, from western sources, they appear to be infrequent intruders at the eastern end of Lancaster Sound. At this end, intrusions of polar floes from Baffin Bay are likely in the latter part of September. East of longitude 82°W drillships need to be prepared for these intrusions[4.2].

4.1.1.4 Ice drift directions and speeds

Planning for offshore drilling requires a knowledge of ice drift directions and speeds. For drillships, the summer season is important; however, for oil spill countermeasures planning, year-round knowledge is required.

Few ice-drift measures can be made in summer, using satellite imagery, due to the summer overcast and the absence of ice-floes to track during clear weather. For selected times of the year, drift-vectors from low resolution NOAA satellite imagery[4.4] are collected in Figure 4.2. Drift trends are also shown but their directions can change in response to local weather disturbances. Some of these trends for August and September, are described in the Arctic Pilot[4.11]:

> "Baffin Bay receives its water in approximately equal quantities from the southeast (western Greenland water) and from the northwest, i.e. from Lancaster, Jones and Smith Sounds. While there is a large net efflux from each of these three Sounds, there are counter currents, westward along the northern sides of Lancaster and Jones Sounds, and northward along the east side of Smith Sound. That this in-going current along the north side of Lancaster Sound must penetrate in some volume at least as far west as the entrance to Prince Regent Inlet, is shown by the fairly common occurrence of large icebergs in that inlet. These bergs can only have come from the west or northwest coasts of Greenland, or possibly from the glaciers of Devon and Ellesmere Islands, and the only reasonable route by which they could have reached Prince Regent Inlet is via Lancaster Sound.
>
> In Prince Regent Inlet and the Gulf of Boothia, there is a southward movement along the west side and northward along the east side."

Compared to sea ice, icebergs float much deeper in the water making their drift-tracks different from those of sea ice. Nevertheless, evidence of a westward drift of sea ice on the northern side of Lancaster Sound was obtained during August, 1977 from the drift of a buoy tracked by the NIMBUS G. Satellite.* However, no buoys were positioned to verify a simultaneous eastward drift on the south side of the Sound.

Variations from ice drift trends (Figure 4.2) will be caused by winds and surface-eddies at junctions between channels. Shifting winds and eddies and the absence of re-identifiable floes, make the interpretation of drift trends by LANDSAT imagery difficult. Even without clouds, viewing is only possible in four daily passes in eighteen days. Figure 4.8 shows surface eddies[4.13] [4.14] outlined by filamentary ice-streams. The upper sequence is for June 8, 9, and 10, 1973. The centre sequence is for June 20, 21 and 22, 1974, at the eastern end of Lancaster Sound; and the lower sequence is for the 4th and 5th of August 1973, at the junction between Lancaster Sound and Prince Regent Inlet. In the lower sequence, ice moving northward along Brodeur Peninsula is swept westward upon entering the Sound, presumably under different winds. Most coast-lines exhibit high relief (Figure 4.9) so that winds tend to be

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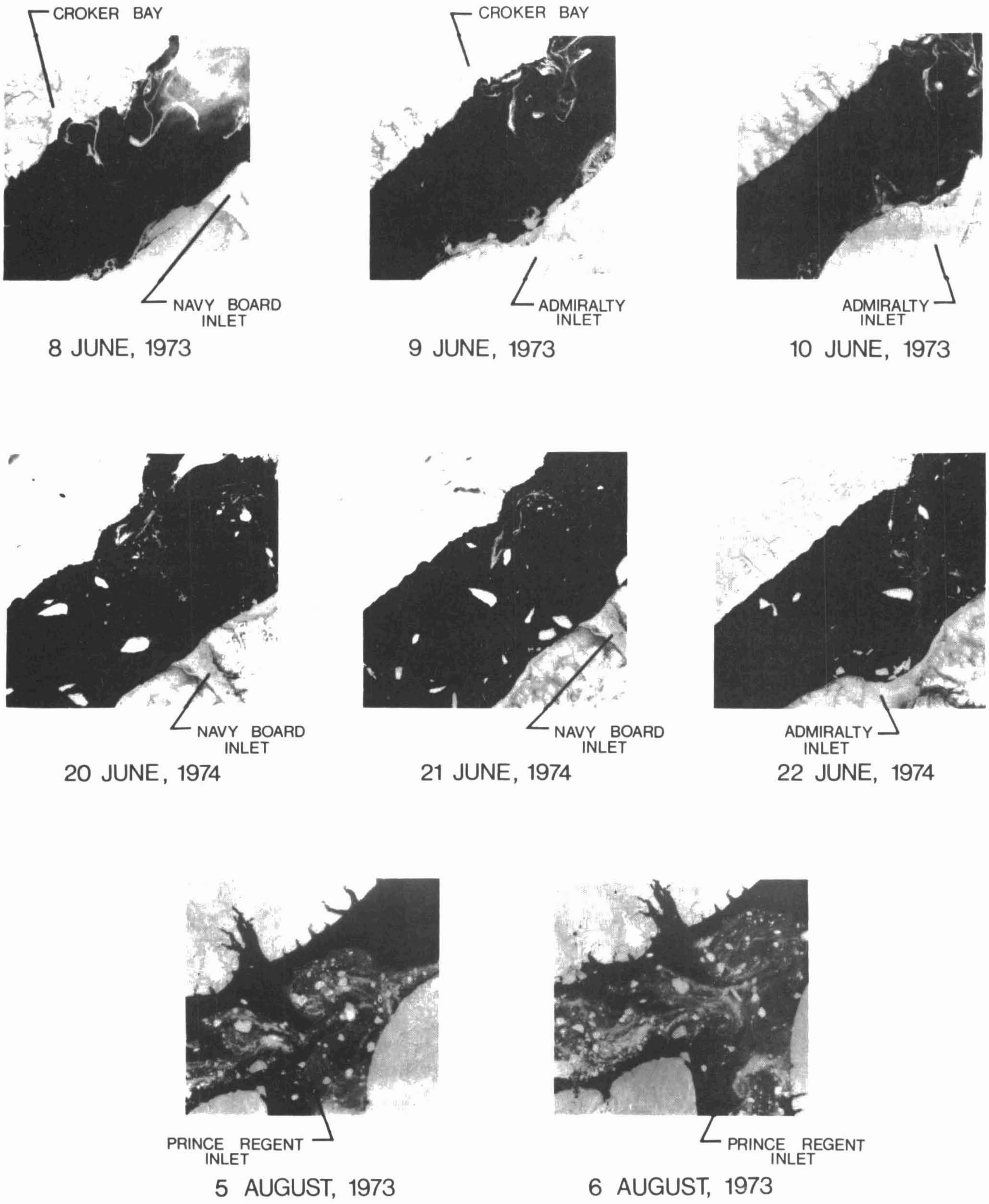
* Surface Drift-buoy Experiment, 1977, Institute of Ocean Sciences, Sidney, B.C.

SURFACE EDDIES OUTLINED BY ICE STREAMS



8 JUNE, 1973

9 JUNE, 1973

10 JUNE, 1973

20 JUNE, 1974

21 JUNE, 1974

22 JUNE, 1974

5 AUGUST, 1973

6 AUGUST, 1973

Figure 4.8

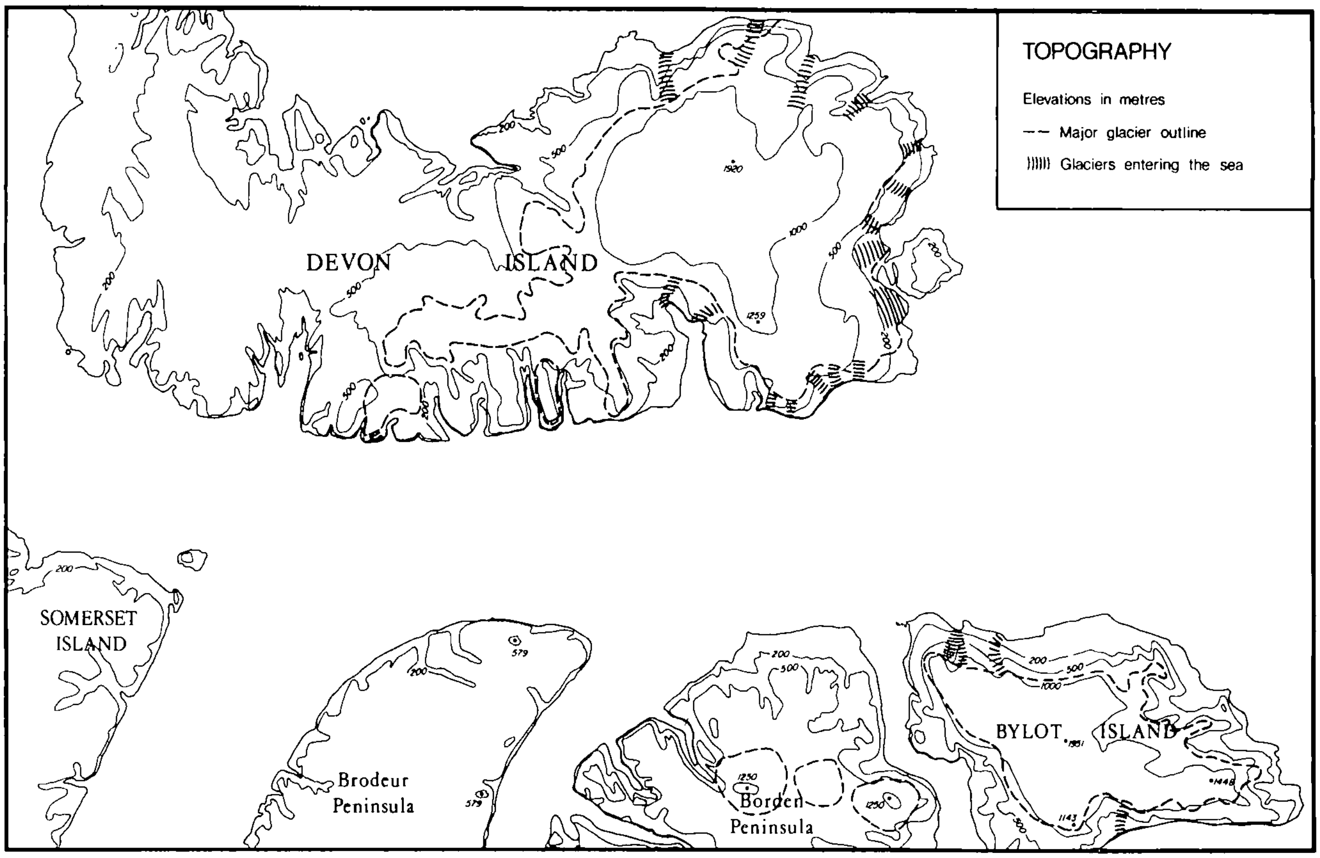


Figure 4.9 Land Topography, Lancaster Sound Region

oriented with channel directions[4.15]. Confluences of wind and surface currents complicate ice-drift prediction.

In summer, wind dependent ice drifts can be estimated from wind statistics derived from ships' observations between 1903 and 1973[4.14] (Figure 4.10). Most strong winds, those above 41 km/h, are from the east in both August and September. For intermediate speed winds, between 7 and 40 km/h, August winds differ from those in September, most oriented east or west in August but shifting, being from the north in September. In August, neither easterly or westerly winds predominate.

Unconfined sea-ice will drift at a speed of about two per cent of the wind speed and in a direction about 30° to the right of downwind—the rightward drift resulting from the Coriolis effect. Hence, winds from the west in August will move what ice there is to the south side of the Sound and winds from the east will move ice to the north side of the Sound. In September, due to increasing frequencies of northeast winds, more westward moving ice intrusions from Baffin Bay are expected in northeast Lancaster Sound.

Ice drift predictions could be aided by a weather prediction system that accounted for land topography[4.15], and incorporated local observations of weather; however, this would not be effective in the vicinity of major channel junctions. Monitoring upstream ice drift is important particularly at the exit to Baffin Bay. A land-based radar on the southeast coast of Devon Island could monitor sea-ice intrusions and iceberg movements as well.

4.1.1.5 Icebergs

Icebergs are numerous in eastern Lancaster Sound but no systematic observations of their size, speed of drift, drift tracks or of their frequency of occurrence have been made. It is clear, however, that drillship operations in eastern Lancaster Sound must be prepared to track, possibly divert, and avoid icebergs. The available information on icebergs is summarized in Figures 4.11, 4.12 and 4.13.

Atmospheric Environment Service's ice reconnaissance flights, between 1958 and 1976, recorded 1,400 iceberg sightings. Seventy per cent of these were in August and September. Iceberg recording was carefully done in early years, sporadically later, and recently more carefully with the advent of offshore exploration[4.11]. These are displayed in Figure 4.11, as the percentage of the 1,400 icebergs observed by area in Lancaster Sound. Heaviest concentrations were in the east.

Size estimates were made of icebergs in 1974 from the survey vessel, *Orion Arctic*[4.12] (Figure 4.12) during August and September, 1974. It was judged that an under-estimate of the true number of icebergs present was made, due to limited visibility.

In the region of proposed drilling by Norlands north of Navy Board Inlet, AES ice reconnaissances showed a yearly average of 17 icebergs during August and September in the "32%" area shown in Figure 4.11. In the same area, *Orion Arctic* saw about 65 in 1974. Assuming that 65 is a reasonable count, the average number of icebergs per 100 km^2 would be about one. It is not likely that the distribution would be uniform; icebergs tend to occur in groups or lines.

The probability of an iceberg encounter depends on its speed, direction, the number expected per unit area, and on an assumed danger distance between the iceberg and the drillship[4.12]. Assuming an iceberg drift speed of 1 km/h, a concentration of one iceberg per 100 km^2, a danger distance of 0.25 km and that all icebergs drift uniformly in the same direction, then one encounter would occur every eight days during August and September. Using the AES ice reconnaissance data and the same assumptions, encounters are predicted to occur once per month.

The seriousness of any encounter will depend on the size and momentum of the iceberg. Large icebergs in Lancaster Sound can have horizontal dimensions[4.12] of 200 m. Figure 4.13 shows the distribution of iceberg weights

Surface Winds from Ship Observations (1903-1973)

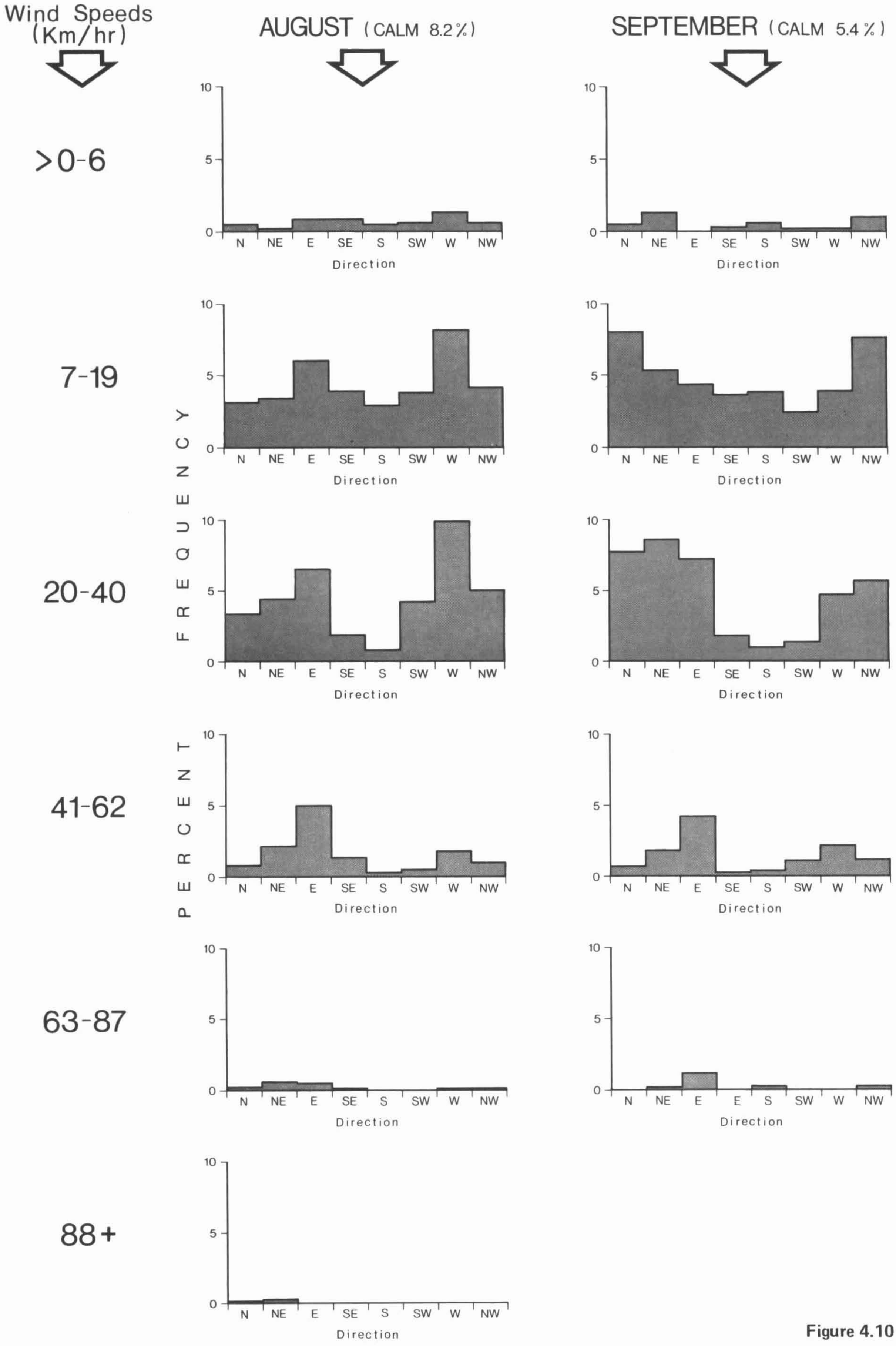


Figure 4.10

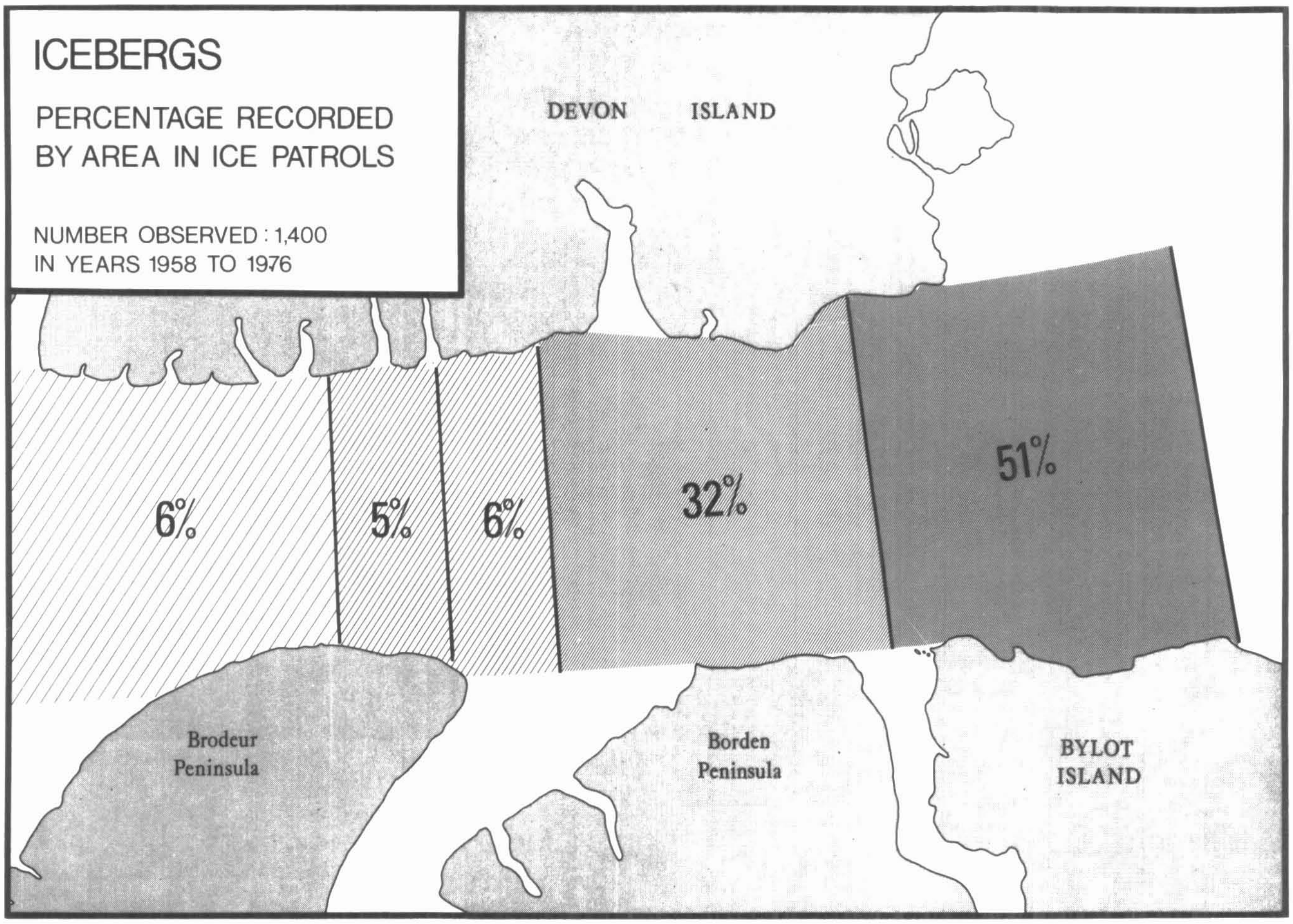


Figure 4.11

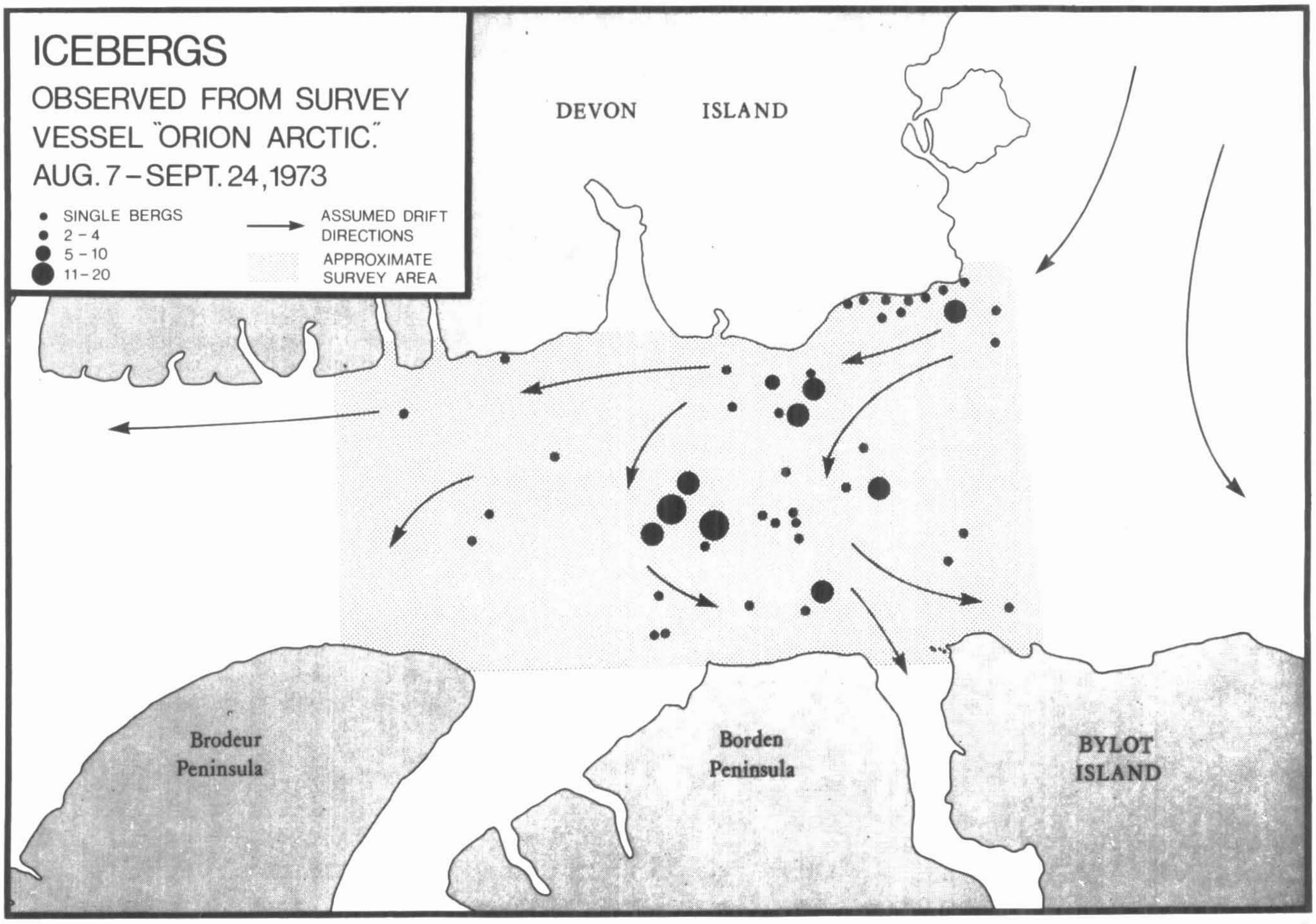
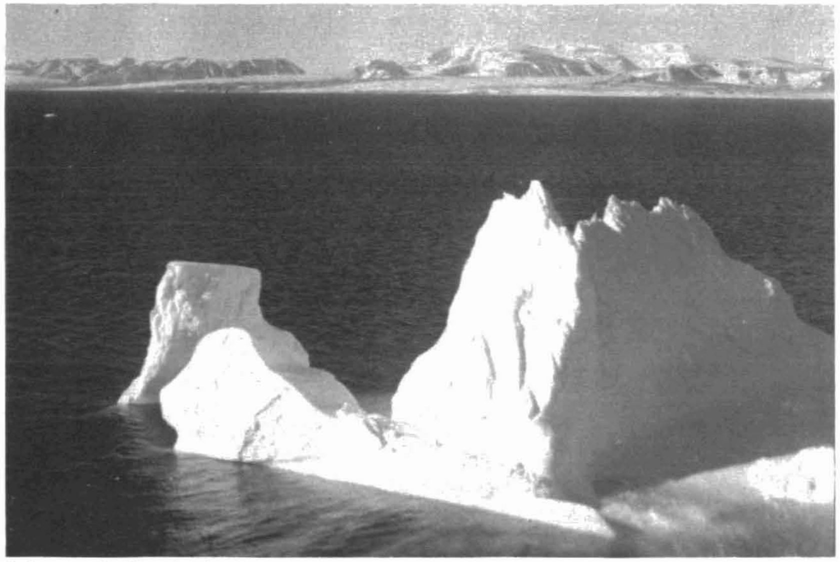
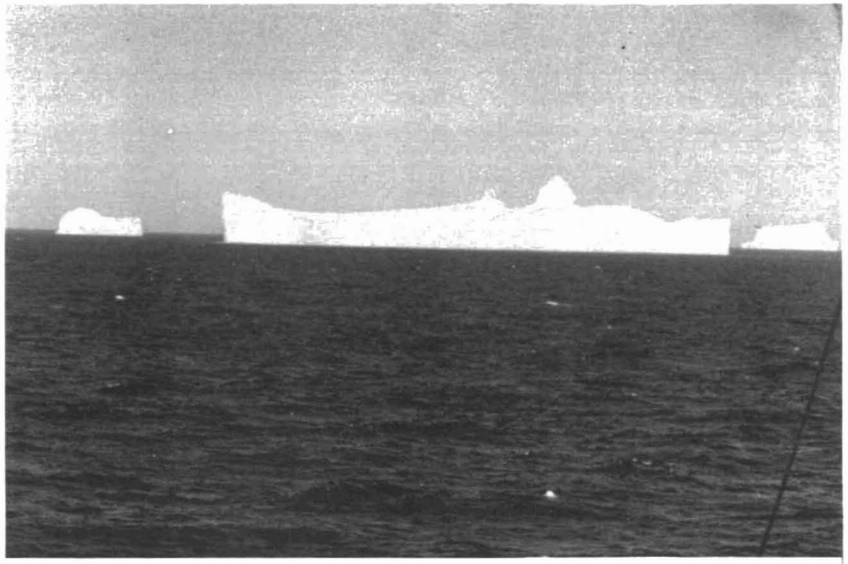


Figure 4.12



(photo: B. Smiley)



(photo: G. Wilton)

(photo: B. Smiley)

(photo: G. Wilton)

Icebergs in eastern Lancaster Sound

estimated during *Orion Arctic* surveys in 1974. Three were in the 2.5 to 5.1 million tonne class but most were in the 5,000 to 10,000 tonne class which could more easily be diverted from colliding with a drillship.

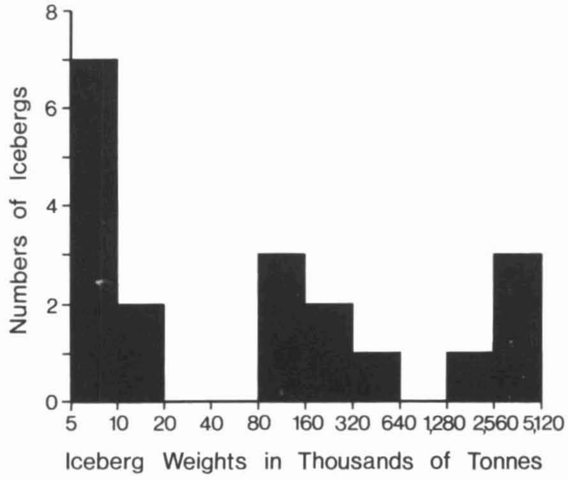


Figure 4.13

Icebergs originate from West Greenland glaciers and from the numerous small glaciers flowing from the Devon Island ice cap (Figure 4.9). Bergs seldom originate from the interior of the Arctic Archipelago. Ice Island fragments were found moving eastward into Lancaster Sound during the years 1963 to 1970. These broke off a large ice island which moved southward through Byam Martin Channel in 1963[4.1].

A tabular iceberg, with 20 m of freeboard has a draught of 100 m in seawater. Consequently, its motion depends on mean-square ocean currents averaged over its submerged cross-sectional area. These currents will not necessarily be the same as those at the surface which move sea ice and respond to surface winds.

Surface current distribution patterns for eastern Lancaster Sound, from calculations of dynamic topography by Muench[4.16], are shown in Figure 4.14. These patterns, and observed distributions of icebergs, tenuously support the circulation shown in Figure 4.12. This assumed circulation pattern is supported by recent time-series of current measurements, recorded from July 28 to September 30, 1977 in east-central Lancaster Sound (See 6b in Figure 4.26). Figure 4.15 shows a progressive vector diagram for currents measured at a depth of 39 m over the proposed drilling location, indicating the directions and speed variations in iceberg drift. Not much movement occurred for the first eighteen days from July 28 to August 16; then, southerly currents, averaging as fast as 35 km/day, were recorded.

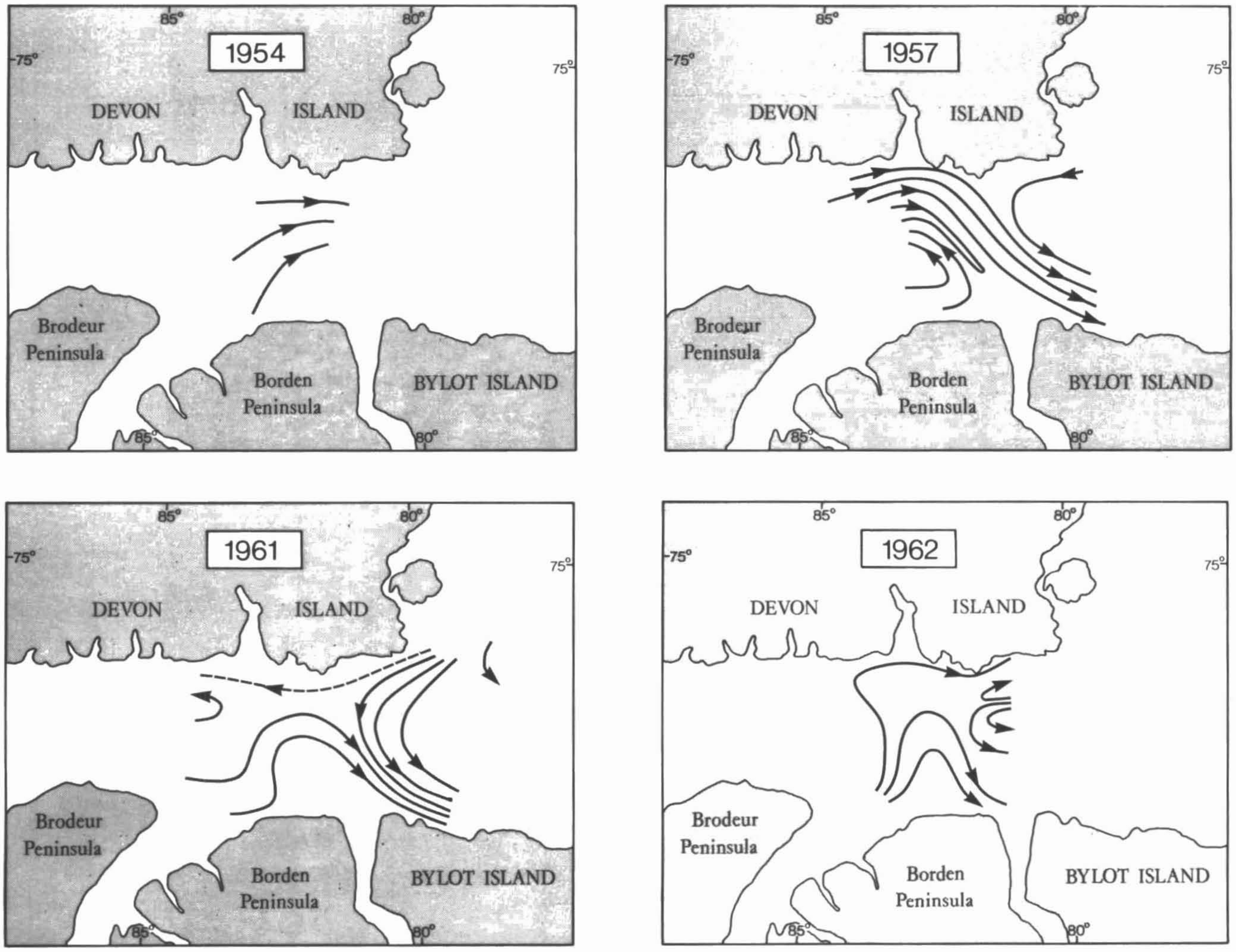


Figure 4.14 Surface current patterns calculated by Meunch[4.16] for July - August 1954; September 1957, September 1961 and September 1962.

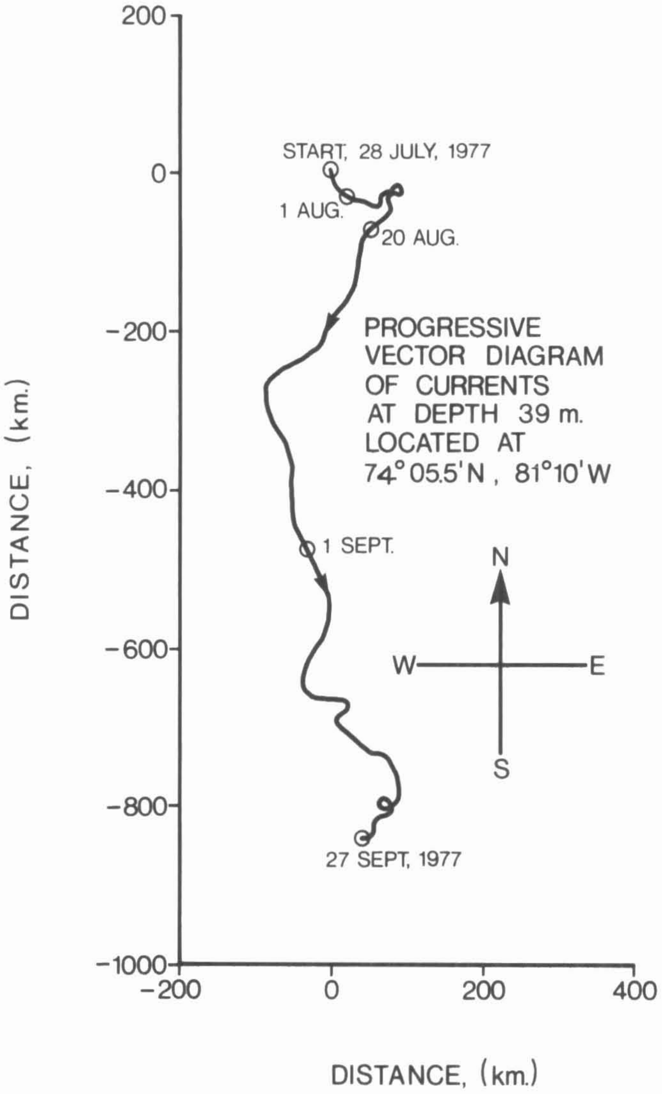


Figure 4.15

4.1.2 The Open water Climate

Hazards to drilling operations in open water, apart from ice and iceberg intrusions, include high winds, high seas, poor visibility and structural icing.

4.1.2.1 Wind climate

High winds occur without high seas when the fetch is shortened by nearby icefields, or land. Of interest are estimates of extreme winds and the expected return period of these winds, in years. Estimates of extreme winds, of an hour's duration, are shown in Figure 4.16 for Lancaster Sound, for the months of July, August, September and October[4.18] — the assumed drillship operating season. Also shown are similar estimates for June to October for the southern Beaufort Sea. Extreme hourly winds of less than 110 km/h are predicted to be more frequent in the southern Beaufort Sea. On the other hand, for return periods in excess of 20 years, higher extreme hourly winds are expected in Lancaster Sound. Cautionary notes are as follows:

- Analysis was based on 25 years of Resolute weather records - hence, reliance on longer return periods is dubious;
- predictions are not applicable near coasts or valleys which may channel winds; and
- predictions were based on atmospheric conditions applicable to open water only.

As in the Beaufort Sea, it was necessary to use historical wind records from a shore station to predict extreme winds — Cape Parry for the Beaufort Sea and Resolute Bay for Lancaster Sound. For Lancaster Sound, the discontinuity and scarcity of ships' records of winds precluded their use for estimates of strong winds. On the other hand, they do suggest that 30 to 50% of offshore winds, stronger than 63 km/h, will be from the east or northeast, as seen in the bar graphs of Figure 4.10.

Predicted extreme wind speeds, for other than hourly intervals, are plotted in Figure 4.17 for the months of July through October. Wind estimates would be improved if continuous weather observations had been available near the eastern end of Lancaster Sound. For comparison of hourly extreme winds predicted for Lancaster Sound with those at other offshore areas[4.18], see Figure 4.18. Extreme winds in Lancaster Sound are comparable to those observed in the southern Beaufort Sea and off the southern coast of California.

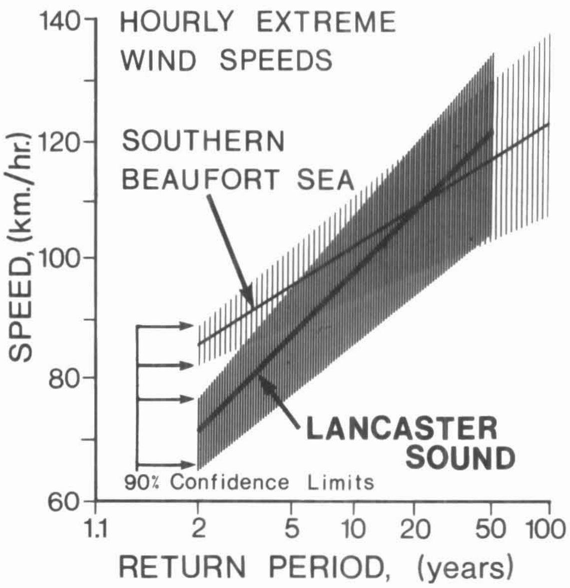


Figure 4.16

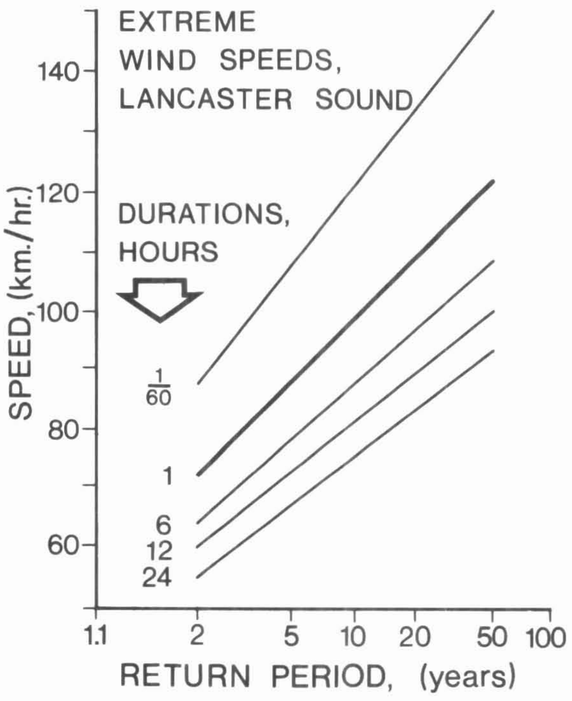


Figure 4.17

Comparisons of Estimated Weather				
Offshore Area	25-year return periods of extreme:			Visibility** % of time less than 3·7 km.
	1 hr. winds km./hr.	Significant Waves, m.	Accreted Ice, cm.	
Lancaster Sound*	109	5.8	13	12.2
Beaufort Sea*	113	6.5	28 39	18.3
Gulf of Alaska	169	15.5		
South Newfoundland	171	18.0		35.7
North Sea				11.0
West Baffin Bay				25.2
South coast California	113	11.6		5.5
Gulf of Mexico	156	13.8		0.4

*Open water season only

**Month of July except for the Beaufort Sea and Lancaster Sound which are for August

Figure 4.18

4.1.2.2 Wind Waves

Figure 4.18 further shows that significant wave heights in Lancaster Sound for a 25 year return period are predicted to be lower than in southern Beaufort Sea, where drillships have been operating since 1976. Wind waves are unlikely to threaten a drillship; but it is important to anticipate how often operations such as drilling, supply deliveries and oil spill countermeasures are likely to be shut down.

A "wave height" is measured from the trough to the peak of a wave. A "significant wave" is defined as the average height of the highest one-third of all the waves observed in a wave-train. The highest wave is estimated to be 1.8 times the significant wave height. Estimates of extreme waves occurring in the future are made by the hindcasting of significant waves. The Sverdrup-Munk-Bretschneider method is usually used for this purpose where meteorological data does not extend far into the past, such as in Lancaster Sound[4.18]. Significant wave heights vs return periods for central Lancaster Sound are plotted in Figure 4.19. In this figure, shading encompasses 95% confidence limits.

In using estimates shown in Figure 4.19, it is important to account for assumptions used in data manipulation. These are as follows: (1) Storm wind records at Resolute, in the years 1954 to 1975, were used, but only where ice charts revealed open water. These were adjusted to account for topography and atmospheric conditions over Lancaster Sound. Of these, storm winds coming from the sector 64°T to 105°T were used to represent easterly blows, and from the sector 250°T to 286°T to represent westerly blows. (2) Other wind directions were deemed to blow over fetches too short to permit waves to fully develop. (3) Storm winds were assumed to blow long enough for waves to fully develop from a calm sea. (4) Single, monthly, extreme storms in all years were selected for analysis on the bases of maximum fetches determined from ice charts. (5) Estimates apply to the generation of deep water waves in central Lancaster Sound, near longitude 84°W.

Highest seas are expected with winds from the east. Often, these occur when a fetch of up to 900 km extends across Baffin Bay, and when Baffin Bay pack ice does not block the eastern end of Lancaster Sound. Fetches for westerlies are usually shortened by ice moving south from Wellington Channel into Barrow Strait. Greatest fetches occur in late August and early September, at the time of most open water.

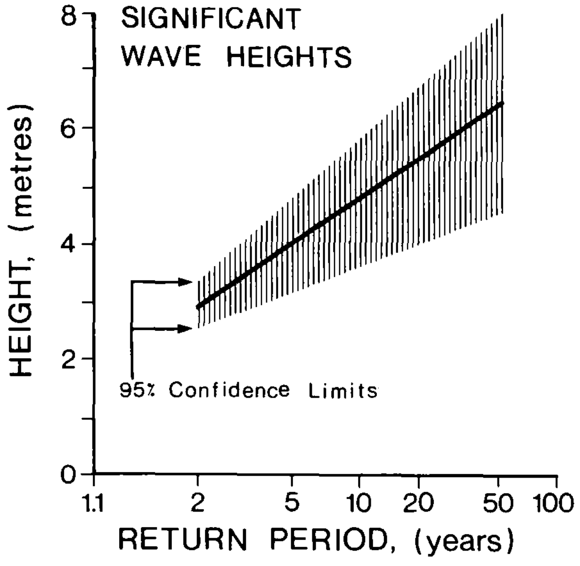


Figure 4.19

The percentage of time when significant wave-heights of various height ranges are to be expected is shown in Figure 4.20. This data is a hindcast from 500 ship reports, mostly in the years 1947 to 1973, inclusive[4.20]. These predictions are useful in providing estimates of expected shut-down times of various operations subject to termination by high sea states. It is seen that rougher seas have occurred more often in September than in August.

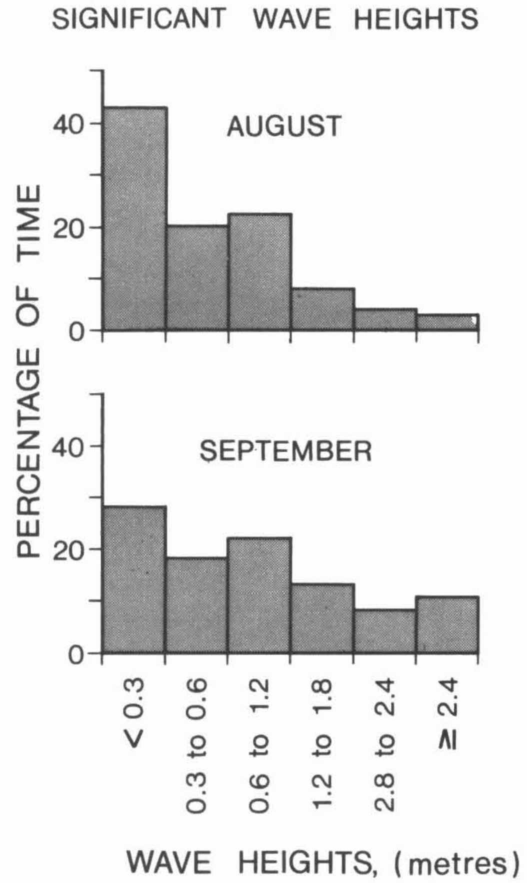


Figure 4.20

4.1.2.3 Structural Icing

Superstructure icing of fishing vessels has long been a menace during sub-zero temperatures. Rapid ice accumulation often results in capsizing when the increased topweight causes the craft to become unstable. For drillships in Lancaster Sound, the concern is whether or not significant structural icing is likely and, if it is, could a drillship with its tall and complex superstructure remain stable, or remove dangerous ice as it accumulates. The questions of stability and ice-removal techniques are a matter of drillship design; only the likelihood of icing is dealt with here.

Although icing can occur by fresh water accumulation from freezing rain and adhering snow, our concern is with salt water icing from freezing spray. High winds, high seas, low sea and air temperatures are required. The danger of freezing sea spray depends on the vessel's heading, how much it is plunging and on its ability to deflect spray from its superstructure. Frozen spray will accumulate above the water line; however, it is unlikely that much of it would accumulate on the upper reaches of the derrick on a drillship during storms of the intensities expected in Lancaster Sound.

Return periods[4.18] for extreme spray icing thicknesses are shown in Figure 4.21. The predicted return period for a sprayed on ice thickness of 13 cm is 25 years; this compares with an ice thickness of 28 to 39 cm predicted for the southern Beaufort Sea, for the same return period (Figure 4.18). Spray icing is predicted to be less serious in Lancaster Sound than in the southern Beaufort Sea[4.19]. Twenty-two storms were used in deriving Figure 4.21, each with air temperatures of -2°C or lower, and winds with adjusted speeds of 40 km/h or more. Data was selected from the years 1954 to 1975 and where open water existed over at least 75% of Lancaster Sound.

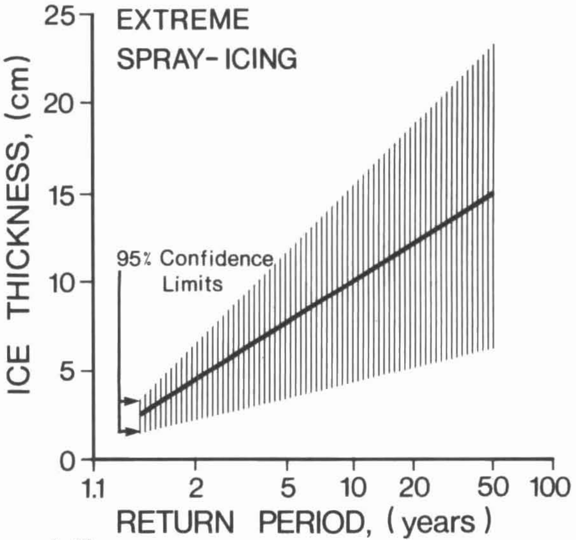


Figure 4.21

The extreme spray icing return periods predicted in Figure 4.21 say nothing about rates of ice accretion and durations of icing events. These relate to problems of ice removal and escape time to shelter. To solve this problem, a storm data set was selected for analysis having spray-ice accretion rates 0.3 cm/h or greater[4.18]. These fall into a "severe" spray icing category, so that predictions of total ice accretion will be slightly under-estimated. In 12 years of storms analyzed for September and October in Lancaster Sound, severe icing could occur on an average of 22 hours per year, varying from 6 to 67 hours in any one year. For example, from Figure 4.22, an ice accretion rate of 0.4 cm/h could occur a total of 70 hours in the 12 years, whereas a rate of 0.8 cm/h could occur for only four and one-half hours during the same period of time. High icing rates have short expected durations in Lancaster Sound.

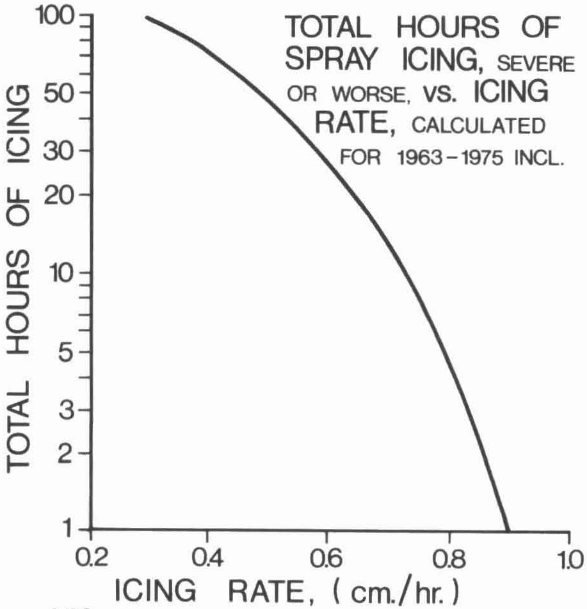
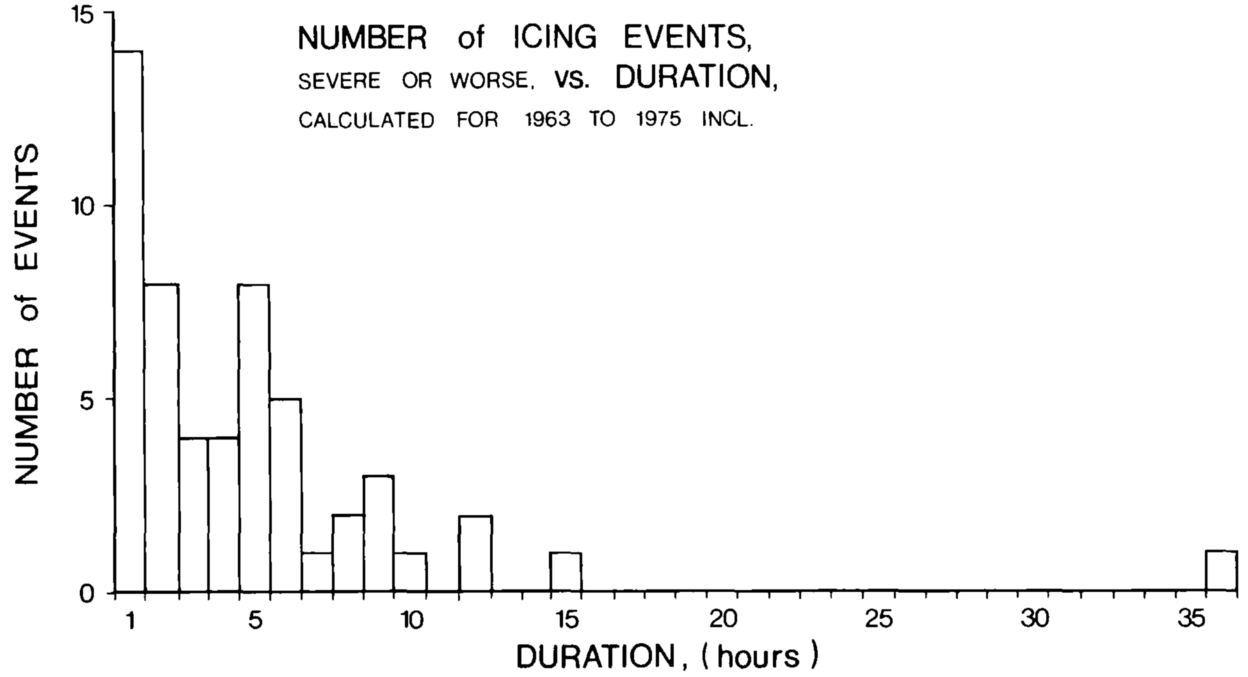


Figure 4.22

To estimate the total ice thickness accumulated per icing event, a conservative accretion rate of 0.45 cm/h is assumed. This is based on the total ice thickness which could have accumulated during the most severe storm in the 12 years. Figure 4.23 shows the distribution of durations, in hours, of all likely icing events in the years 1963 to 1975, inclusive. One 36 hour event occurred. Using the average icing rate of 0.45 cm/h, the accumulated ice thickness is 16 cm. This thickness corresponds to the upper 95% confidence limit for the 12 year return period shown in Figure 4.21. Other storms could have produced less accreted spray icing.

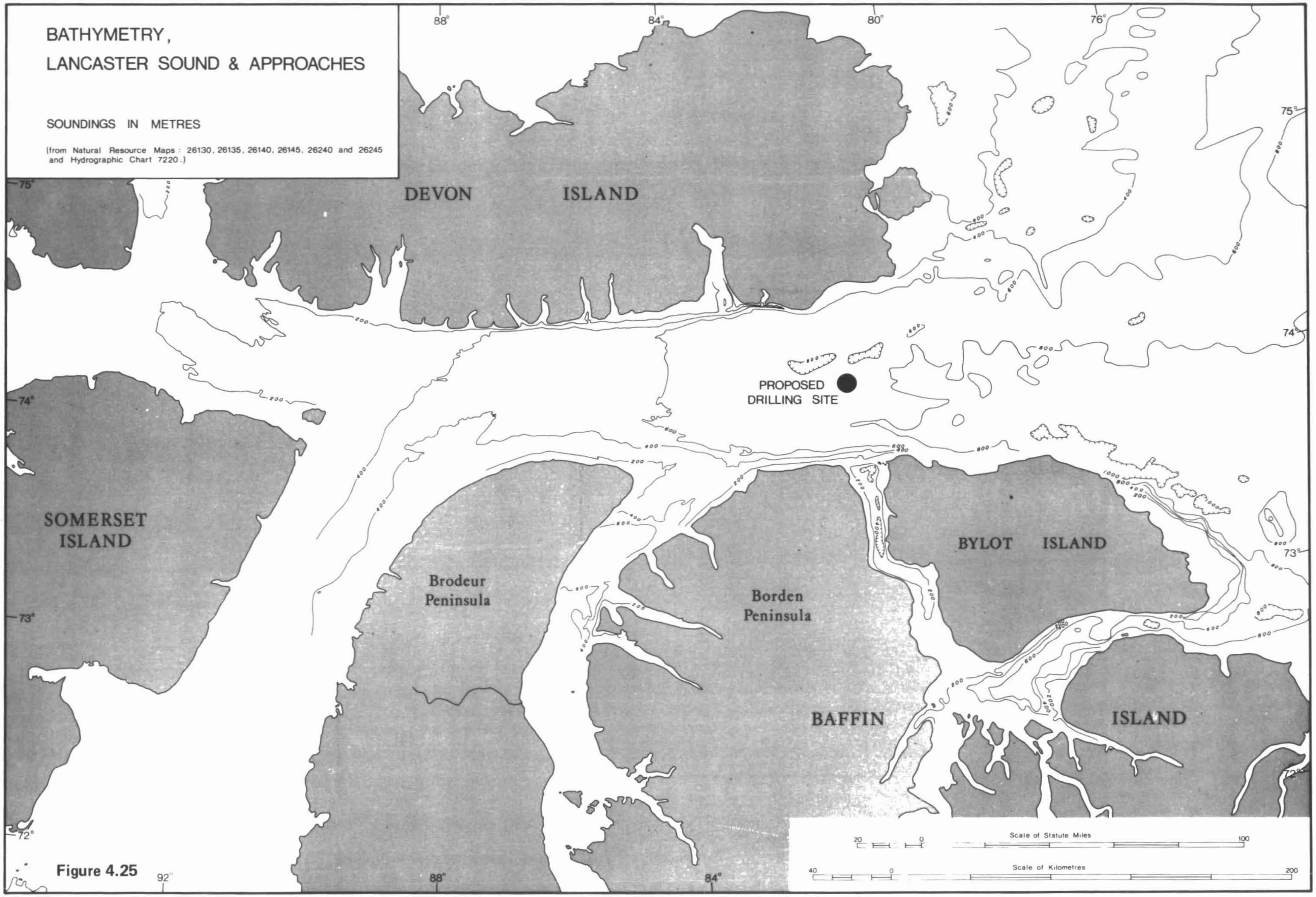
The proximity of protected inlets in eastern Lancaster Sound seems to ensure that dangerous spray icing accumulations could be avoided even if predictions of storms and conditions for spray ice generation were available.



DURATION OF STRUCTURAL ICING EVENTS : LANCASTER SOUND
(SEVERE ICING OR WORSE) 1963 - 1975

Date of Event		Duration	Date of Event		Duration	Date of Event		Duration
1963	Sept 22	4 hrs	1968	Sept 29	1 hr.	1973	Sept 15	2 hrs
	Sept 26	9 hrs		Sept 29	2 hrs		Sept 15	2 hrs
1964	Sept 26	4 hrs		Oct 13	8 hrs		Sept 15	1 hr.
	Sept 26	1 hr.	1969	Oct 13	3 hrs		Sept 15	7 hrs
	Oct 3	12 hrs		Oct 13	9 hrs		Sept 16	1 hr.
	Oct 4	6 hrs	1970	–	–		Sept 16	5 hrs
	Oct 4	6 hrs	1971	Sept 19	2 hrs		Sept 16	36 hrs
	Oct 4	8 hrs		Oct 9	5 hrs		Sept 19	6 hrs
	Oct 5	9 hrs		Oct 11	1 hr.		Oct 3	3 hrs
	Oct 5	10 hrs	1972	Sept 18	5 hrs		Oct 4	2 hrs
1965	Sept 18	1 hr.		Sept 20	1 hr.		Oct 4	2 hrs
	Sept 18	5 hrs		Sept 20	3 hrs	1974	Sept 29	1 hr.
1966	Oct 5	4 hrs		Sept 21	2 hrs		Sept 29	1 hr.
	Oct 7	1 hr.		Sept 21	4 hrs		Sept 29	1 hr.
	Oct 16	5 hrs		Sept 23	1 hr.		Sept 29	3 hrs
	Oct 17	2 hrs		Sept 24	1 hr.		Sept 29	5 hrs
1967	Sept 21	5 hrs					Sept 29	1 hr.
	Sept 21	5 hrs					Oct 10	6 hrs
	Sept 21	6 hrs					Oct 11	12 hrs
							Oct 11	15 hrs
						1975	–	–

Figure 4.23



BATHYMETRY,
LANCASTER SOUND & APPROACHES

SOUNDINGS IN METRES

(from Natural Resource Maps: 26130, 26135, 26140, 26145, 26240 and 26245 and Hydrographic Chart 7220.)

Figure 4.25

4.1.2.4 Visibility

Based on ships' logs during August and September, horizontal visibilities as a function of percentage of the time, are shown in Figure 4.24 for Lancaster Sound[4.18]. Insufficient data is available for other months, to generate statistics on wind speeds, directions or other weather parameters. From ships' observations in the Beaufort Sea, visibilities are expected to be lower than in Lancaster Sound in summer. Here, visibilities greater than 8 km occur for 73% of the time[4.19]. Operations which depend on good visibility will be easier in Lancaster Sound than in the southern Beaufort Sea.

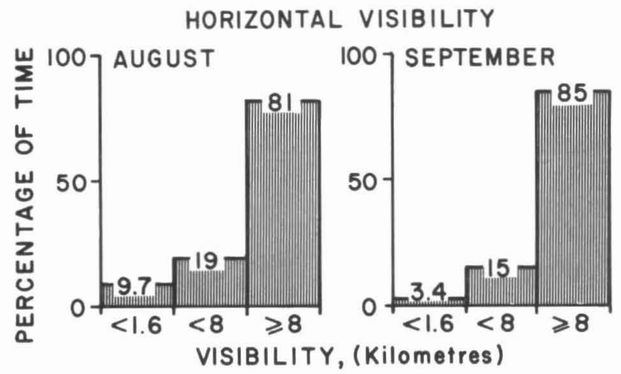


Figure 4.24

4.2 Water Column Problems

In the vicinity of proposed drilling, water depths are between 700 and 770 metres (Figure 4.25). It is essential to know the water currents for marine riser design, for assessing lateral forces on the well head and to anticipate station keeping problems for the drillship. Current measurements, which can provide engineering design data, are available for the summer of 1977*. These were obtained from three sets of current meters, moored from July 28 to September 30 at positions shown in Figure 4.26. Meters were deployed at average depths of 42,206 and 551 m. One other mooring, located on the north side of the Sound was not recovered.

It is important to appreciate the complex nature of currents in eastern Lancaster Sound and why it is essential to measure these at several depths, not only at a proposed drill-site but simultaneously at other sites, both across and along the Sound. These currents need to be known in the open water drilling season, and ideally in more than one drilling season.

Currents in Lancaster Sound, as elsewhere, are a combination of *barotropic currents* and *baroclinic currents. Barotropic currents* include tidal currents and currents resulting from atmospheric pressure differences from one

CURRENT METER LOCATIONS, LANCASTER SOUND REGION

	Date	Water Depth	Type	Source
1.	Sept. 23, 1973	740 m.	Profile to 670 m.	*Orion Arctic* [4.12]
2.	Aug. 16 - Sept. 13, 1974	11 m.	Moored at 10 m.	Can. Hydrog. Serv. [4.17]
3.	Sept. 22, 1973	440 m.	Profile to 400 m.	*Orion Arctic* [4.12]
4.	Sept. 22, 1973	545 m.	Profile to 440 m.	*Orion Arctic* [4.12]
5.	Apr. 22 - 28, 1973	155 m.	Moored at 153 m.	Herlinveaux et al[4.27]
5.	Apr. 22 - 28, 1973	155 m.	Profiles to 45 m.	Herlinveaux et al[4.27]
5.	Sept. 1 - 5, 1973	155 m.	Profiles to 50 m.	Herlinveaux et al[4.28]
6a.	Jul. 28 - Sept. 30, 1977.	741 m.	Moored at 51, 216 and 550 m.	Inst. Ocean Sci.
6b.	Jul. 28 - Sept. 30, 1977	772 m.	Moored at 39, 203 and 554 m.	Inst. Ocean Sci.
6c.	Jul. 28 - Sept. 30, 1977	724 m.	Moored at 35, 200 and 549 m.	Inst. Ocean Sci.

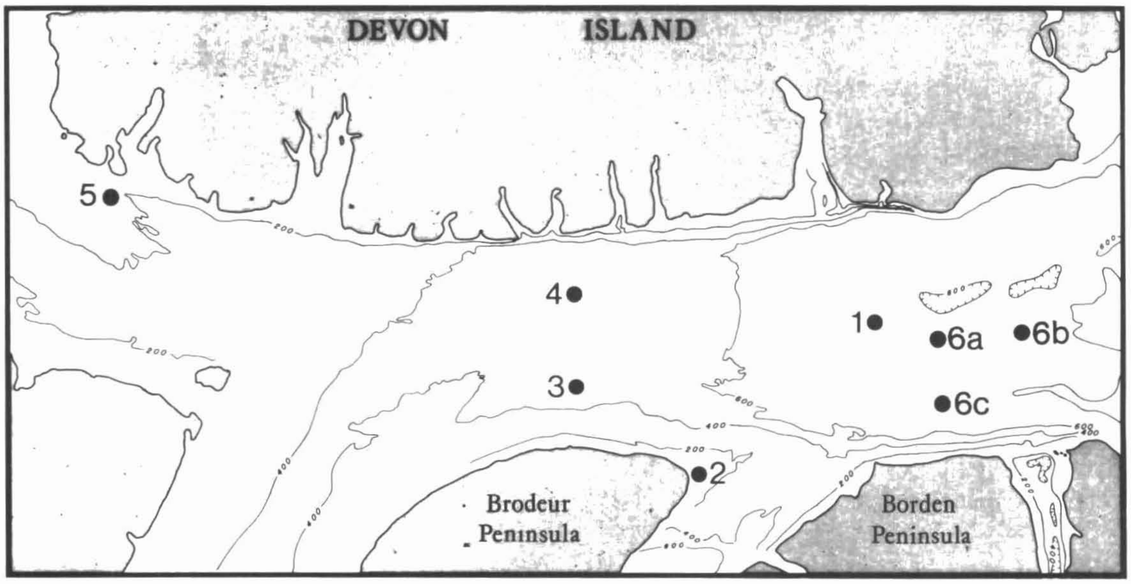


Figure 4.26

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* A joint program of Norlands Petroleum Ltd. and the Institute of Ocean Sciences, OAS, Pacific.

Table 4.2

Port	Latitude	Longitude	Elevation range, m		* Δt
			Mean	Large	minutes
Dundas Harbour	74°31′	82°26′	1.8	2.9	+ 99
Rigby Bay	74°33′	90°10′	1.7	2.8	+ 53
Radstock Bay	74°43′	91°05′	1.7	2.8	+ 46
Beechy Island	74°43′	91°54′	1.7	2.7	+ 19
Resolute	74°41′	94°54′	1.3	2.1	0
Cape Capel	75°04′	98°14′	1.0	1.6	– 47

* Δt is number of minutes that high tide occurs before that at Resolute.

region to another. These latter currents are related to sea-level changes and tend to be independent of depth. *Baroclinic currents* are those currents which intrinsically vary with depth. Examples are wind-driven surface currents and water flows resulting from internal readjustments in depths and thicknesses of water layers having different densities. Density variations with depth are determined from salinity and temperature profiles.

4.2.1 Barotropic Currents

4.2.1.1 Tidal Currents

A simple tidal model of Lancaster Sound, developed in reference 4.12, assumes that tides in Baffin Bay propogate shallow water waves westward into Lancaster Sound. The resulting wave system, accounting for reflections at major depth changes and channel junctions, was used to estimate tidal elevations and currents at points along Lancaster Sound with respect to known tidal elevations. The model assumes that the tidal currents are semi-diurnal and independent of depth; it does not account for the Coriolis effect. The model was used to estimate tidal currents at the eastern end of Lancaster Sound, near the longitude of proposed drilling - specifically, Dundas Harbour, at 82°26′W.

A listing of existing tidal elevations and their locations [4.22] in Lancaster Sound is shown in Table 4.2

The model indicated that the maximum east to west tidal current, at the longitude of Dundas Harbour, lags high tide by 108 minutes. Also, the maximum current, in cm/sec, equals 4.73 times the maximum elevation range over a given tidal cycle. Resolute tidal ranges were used to estimate Dundas Harbour tidal currents. For example, if over a given tidal cycle at Resolute, its range was 1.8 m, then at Dundas Harbour, the range (Table 4.2) would have been 38% greater or 2.5 m. The estimated amplitude of the tidal current would then be 4.73 x 2.5 cm/sec. The extreme tidal range at Dundas Harbour is 3.4m. For this range, the extreme tidal current, estimated from the model is 16 cm/sec.

Real tides in Lancaster Sound are mainly a mixture of diurnal and semi-diurnal components, the amplitude of the diurnal tide being about 1.5 times that of the semi-diurnal tide. From the model, it is not evident what the tidal currents would be when all components are in phase. The Coriolis effect in Lancaster Sound forces tidal currents to follow elliptical paths in the horizontal plane, making tidal currents a continuous and rotating phenomena. The model estimated only the average tidal currents in a vertical cross section of Lancaster Sound, of sufficient flow necessary to produce observed tidal ranges. The readjustment of water volumes can, however, occur non-uniformly with depth due to disturbances from an undulating sea bottom and layering of different density waters with depth.

Tidal currents near Cape Crauford[4.17], (No. 2, Figure 4.26) were at times as high as 40 cm/sec showing that results from the tidal model cannot be a substitute for currents measured in the field.

4.2.1.2 Currents from Atmospheric Pressure Gradients

Atmospheric pressure changes from one side of the Canadian Arctic Archipelago to the other produce currents dependent on the passage of weather systems. Water under a high pressure system depresses slightly as it flows toward the region of lower atmospheric pressure. Averages of sea-level atmospheric pressures over the years 1931 - 1960, for January and for July[4.23], are shown in Figure 4.27. During the average winter, there should be an eastward barotropic flow through Lancaster Sound. This is supported by the winter and spring ice drifts shown in Figure 4.2. By July, this averaged atmospheric pressure difference virtually disappears. From this, it is expected that the flow of water should slacken and reverse itself by summer. This may partly account for the westerly ice drifts along the south side of Devon Island in summer, which are not evident in winter. These pressure gradient induced flows could vary radically from year to year. Although this hypothesis needs testing by obtaining year-round current measurements, it raises uncertainties in the usefulness of a single summer's set of current measurements.

4.2.2 Baroclinic Currents

4.2.2.1 Wind driven Currents

Wind-driven currents and their accompanying waves take time to fully develop. Surface currents fully develop in about 2 hours. To depths of 25 metres, it is estimated that currents would fully develop in less than 6 hours[4.12]. For sustained winds and long fetches, surface currents in Lancaster Sound will move at about 3% of the wind speed. This speed decreases exponentially with depth and, in homogeneous water, about 4% of the surface speed is reached at a depth of about 40 m.

By mid-September, in eastern Lancaster Sound, a wind mixed layer of surface water extends down to 25 m, or less. Below this layer, there is a strong salinity gradient which will not permit wind driven currents to penetrate deeper. For fully developed seas, the current speed at a depth of 25 m will be about 15% of its surface speed. Also, wind-driven currents not only decrease their speed with depth but tend to change direction, clockwise with depth, due to the Coriolis effect. In Lancaster Sound, however, sustained easterly or westerly winds are likely to produce surface currents aligned with winds because of the confining effect of shorelines.

MEAN SEA-LEVEL ATMOSPHERIC PRESSURE (mb), 1931 - 1960

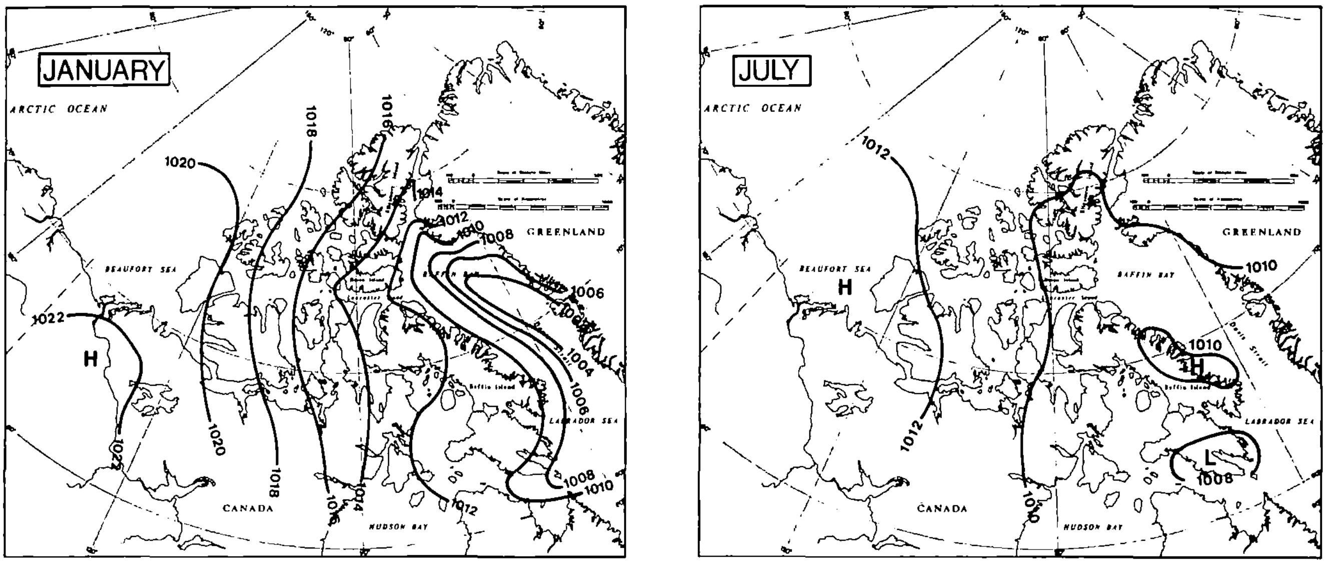

Figure 4.27

In estimating wind-driven current speeds, resulting from extreme winds, we assume that the currents throughout a 25 m thick water layer become aligned with the wind. Figure 4.17 shows return periods, in years, for winds of various durations. For surface currents, the duration would have to be 2 hours.

For currents to fully develop in the 25 m layer, the duration would have to be about 6 hours. This would produce an average current speed in the layer of about 50% of the surface current speed. With the surface current flowing at 3% of the wind speed, the average fully developed current in the layer will flow at about 1.5% of the wind speed. For example, from Figure 4.17, a 6 hour duration wind of 90 km/h could have a return period of 12 years. The surface current speed, at 3% of 90 km/h would flow at a speed of 2.7 km/h (=65 km/day or 75 cm/sec), while the average current speed in the 25 m layer, at 1.5% of 90 km/h, would reach a speed of 1.4 km/h (=33 km/day or 38 cm/sec). These currents would co-exist with wind waves of 5 m significant height (Figure 4.19).

4.2.2.2 Currents from Internal Readjustments.

Currents, resulting from internal readjustments in depths and thicknesses of water layers of different densities, are of special importance in Lancaster Sound. This is because the water in Lancaster Sound combines Arctic surface water flowing east from Barrow Strait and south from Wellington Channel, with westward moving Baffin Bay water. The sill-depths, of 130 m in Barrow Strait, and 146 m in Wellington Channel, only permit water with the surface characteristics of the Arctic Ocean to enter Lancaster Sound at its western end, while the Baffin Bay water, of higher density, originating from the West Greenland Current, intrudes under the Arctic surface water[4.14, 4.24]. Figure 4.28 shows an example of a resulting temperature and salinity distribution, in longitudinal section, from Barrow Strait on the left, to Lancaster Sound on the right. Corresponding variations occur in cross section as well. From the oceanographic cruise data reviewed in references 4.3 and 4.24, it is evident that the water masses intermingle

LONGITUDINAL VERTICAL SECTION,
TEMPERATURE AND SALINITY:
BARROW STRAIT AND LANCASTER SOUND. (COLLIN, 1962)

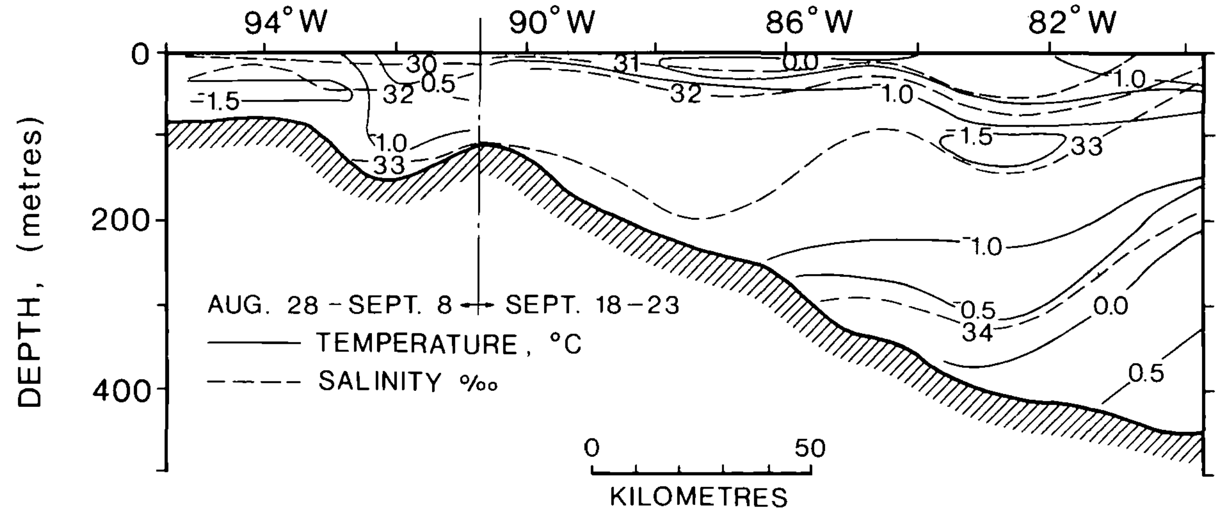

Figure 4.28

differently during each summer, and from one summer to the next. No comparable data is available in winter. From salinities and temperatures obtained in summer cruises, estimates of baroclinic currents have been made using dynamic topography calculation. Such calculations suffer from severe limitations: (a) they depend upon choosing a layer of zero motion (for convenience, often at the bottom); (b) they are subject to confusing changes-of-density with time and those which vary with distance; and (c) they take no account of the time it takes for currents to flow in response to measured densities. Hence, there is good reason to measure currents rather than relying on dynamic topography calculations. Nevertheless, such calculations have shed light on current variations with depth across Lancaster Sound. As an example, Figure 4.29 shows calculated current speeds in a cross section of Lancaster Sound, in September, at 82°W. The depth of assumed zero currents was 1,000 m[4.25]. Currents to the west along Devon Island and to the east along Borden Peninsula are evident. These features appear sporadically throughout the length of Lancaster Sound in summer in the calculations of most investigators[4.14].

Figure 4.14 depicts baroclinic, surface currents calculated by Meunch[4.16]. Their variability, at the eastern end of Lancaster Sound, gives some idea of what the variability in water movements in a vertical cross section is likely to be.

Calculations of the water volume per second[4.25, 4.26], averaged over the year, which flows eastward through Lancaster Sound, range between a low of 0.64×10^6 m^3/sec and a high of 1.5×10^6 m^3/sec. At longitude 82°W, the cross sectional area of the Sound is approximately 5.6×10^7 m^2. The average eastward current over this sectional area is, therefore, estimated to range between 1.1 cm/sec and 3.0 cm/sec.

Superimposed upon this theoretical picture of baroclinic currents are the barotropic flows described in 4.2.2.

Long duration current measurements in several locations and at different depths are required, in order to detect extreme currents and the depths over which these extremes might occur.

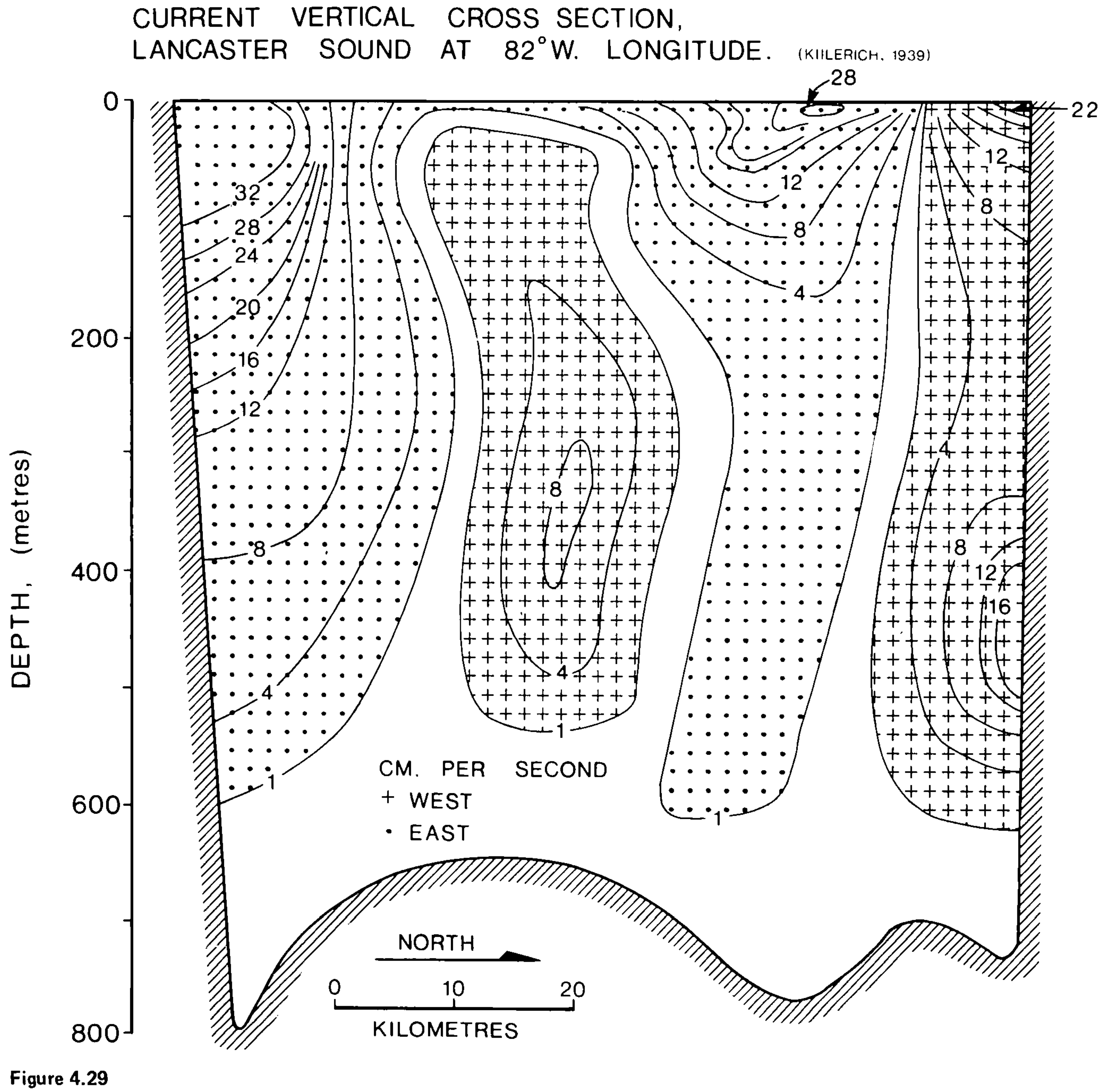

Figure 4.29

4.2.3 Maximum Current Profile

Although analysis of data from current-meter moorings deployed during the summer of 1977 is far from complete, magnitudes of currents vs time, during August and September, are available from two mooring positions; one near the proposed drilling site in 772 m of water and the other about 32 km further west, in 741 m of water. Meter depths and positions are shown in Figure 4.26 for moorings identified as 6a and 6b. Highest currents were recorded at mooring 6a, at 51 m depth. A maximum current of 110 cm/sec (2.2 kts), for a short period during September 10 was recorded. Sustained currents of over 82 cm/sec (1.6 kts), from August 9 to 11, were also recorded at this depth. Also at mooring 6a, but at a depth of 216 m, sustained currents of 50 cm/sec were recorded from August 13th to 15th.

Maximum currents, at corresponding depths, recorded at mooring 6b further east, were marginally less: at 39 m, 103 cm/sec, and at 203 m, 37 cm/sec. At both moorings, the deepest current meters, at 550 m at 6a, and at 554 m at 6b, recorded maximum currents of 18 cm/sec and 24 cm/sec, respectively. These were predominantly diurnal tidal currents.

Possible additional effects of storm winds are unlikely to influence surface currents much below a depth of 25 m. It is expedient to assume that surface currents due to storm winds are additive to those beneath. For this purpose, fully developed surface currents of 75 cm/sec, in a 25 m thick surface layer, are assumed to develop from 90 km/h storm winds. Adding this surface current speed to those maximum current amplitudes measured deeper, the estimated maximum current profiles, shown in Figure 4.30 are obtained. The maximum currents shown at the various depths did not necessarily flow in the same direction, nor occur at the same time.

Both maximum current profiles are not much different, except for near-bottom maximum currents. It is surmized that each profile is equally likely at either position. There remains the question of whether or not one summer's current records would safely define maximum current speeds suitable for marine riser design.

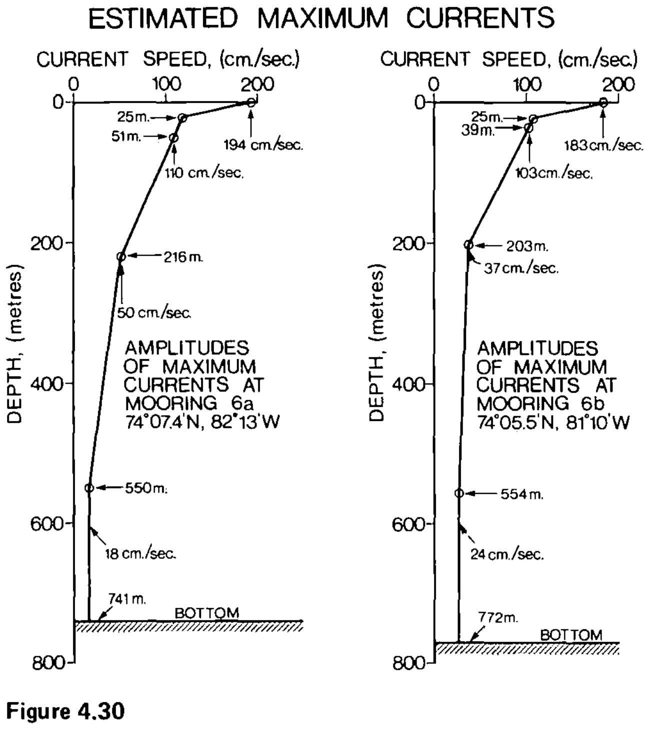

Figure 4.30

4.3 Sea-bottom Problems

Hazards to drilling associated with the sea-bottom and subsea-bottom include the possible existence of relict permafrost, gas hydrates, seismically-induced turbidity flows and iceberg scouring.

4.3.1 Sub-sea Permafrost

There is no direct evidence that sediments are ice-bonded in the deep waters of eastern Lancaster Sound. Preliminary refraction seismic results from the *Hudson* 1977 cruise in Lancaster Sound suggest that sediment seismic velocities, correspond to those of unbonded, coarse-grain sediments[4.29]. On the other hand, from 50 marine seismic refraction records off southeast Baffin Island, a cursory examination reveals seismic velocities in the range 2.2 to 2.6 km/sec, typical of hydrate or ice bonded sediments or older lithofied bedrock.

Sea bottom coring and high resolution marine seismic measurements could reveal whether or not hydrate or ice-bonded sediments exist near the proposed drilling site. The probability is likely low, based on the history of glaciation in Lancaster Sound. Bornhold[4.30] gives one version, of this history, paraphrased as follows:

> During glaciations, ice spread westward and southward from Devon Island. At the same time, ice spread northward from Somerset Island and Brodeur Peninsula in company with northward moving lobes of ice in Prince Regent and Admiralty inlets. Today a major moraine exists at the mouth of Admiralty Inlet. The Prince Regent ice lobe met the Devon Island ice southeast of Maxwell Bay where marginal ice deposits are presumed to have produced the east-west and northeast-southwest trending sediment deposits of today. The glacier tongues then extended eastward in Lancaster Sound.
>
> With rising temperatures, ice sheets receded back into Lancaster Sound, leaving an ice shelf grounded in the shallower Barrow Strait. The pebbly muds overlying the till in Lancaster Sound were likely created from dropped sediments. The ice shelf then receded westward as an enlarging embayment and, 9,000 to 10,000 years ago probably disintegrated, since the first marine beaches are of this age.
>
> When the ice blockage in Barrow Strait disappeared, Arctic Ocean water again flowed eastward, winnowing sediments in the west and depositing their fines in the deeper waters of eastern Lancaster Sound.

The likelihood of relict permafrost is determined by the unknown eastward limit of grounded ice during glaciation. Therefore drilling operations should anticipate possible relict permafrost in eastern Lancaster Sound.

4.3.2 Gas Hydrates

The generation of gas from organic materials in sediments is a normal occurrence. In 700 to 750 m water depths where drilling is planned in Lancaster Sound, some of this gas will be in a solid hydrate state. Hydrate bonding of sediments can form an impervious layer above sediments coexisting with gas.

Figure 4.31 shows the phase equilibrium diagram for gas hydrate, water, ice and either methane or natural gas[4.31]. The specific gravities of the various gases are referred to air. The hydrate of methane has a density of 0.91, while the natural gas hydrates have densities ranging to more than 0.95. Superimposed upon this diagram are straight lines showing natural temperature increases vs depth beneath the sea bottom for both recent eastern Arctic unconsolidated sediments, and eastern Arctic paleozoic bedrocks. It is assumed that the sea water temperature at a bottom depth of 750 m is 0.5°C and that the pressure on the gas increases hydrostatically with depth beneath the seabottom. Methane will be in hydrate form from the seabottom at 750 m to a minimum depth of 1060 m in unconsolidated sediments. For other gases and a more consolidated sea bed, hydrates would exist to depths in excess of 1,500 m. This means that an impervious layer of hydrate bonded sediments, ranging in thickness between 310 m and 850 m can exist from the sea floor, downwards. If relict permafrost also exists, then sub-seabottom temperatures will be lower, ensuring that gas hydrates exist to much greater depths.

Drilling operations must anticipate a gas-impervious layer of hydrate-bonded sediments, beneath which can exist free gas. A possible rapid breakdown of hydrates, through the production of warm formation fluids or by warming during drilling would need to be guarded against.

Figure 4.31 shows that, given time to reach phase equilibrium, gas in the water column exists in hydrate form below 250 m depth, and possibly shallower, depending on the gas. This characteristic of gases complicates the modelling of an oilwell blowout.

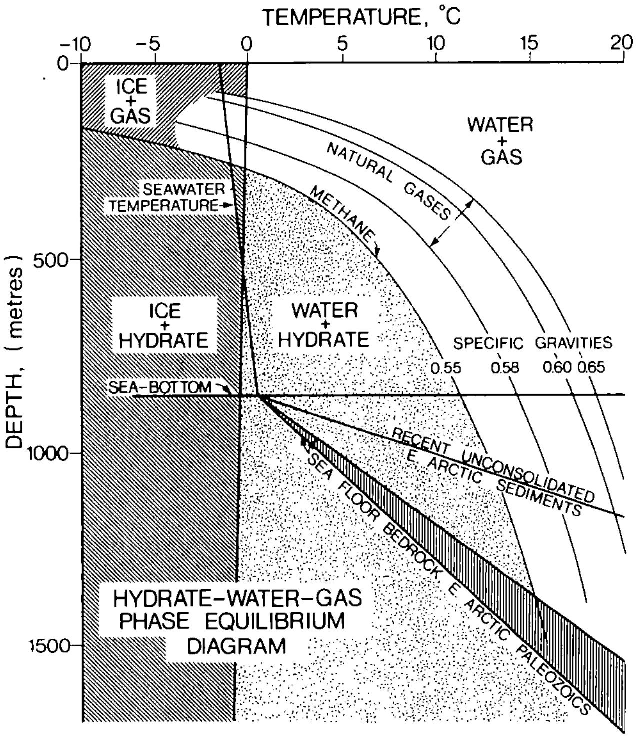

Figure 4.31

4.3.3 Seismicity and Turbidity Flows

Earthquake epicentres and their magnitudes for Lancaster Sound are shown in Figure 4.32. Most were recorded during the years 1962 to 1974, following the development of the northern seismograph network[4.32]. In the vicinity of an earthquake; magnitude 3 is usually felt, magnitude 5 results in minor damage and magnitude 7 is at the lower limit of major earthquakes.

Two earthquakes of magnitude less than 5 have occurred close to the proposed drilling site north of Navy Board Inlet. Further information on the depths of their epicentres, the likely ground motions and accelerations which occurred, and the likelihood of similar or greater magnitude events is available from the Division of Seismology and Geothermal Studies, Department of Energy, Mines and Resources. The design of the seabottom well and well-head should take account of anticipated ground motions and accelerations with respect to a selected design earthquake.

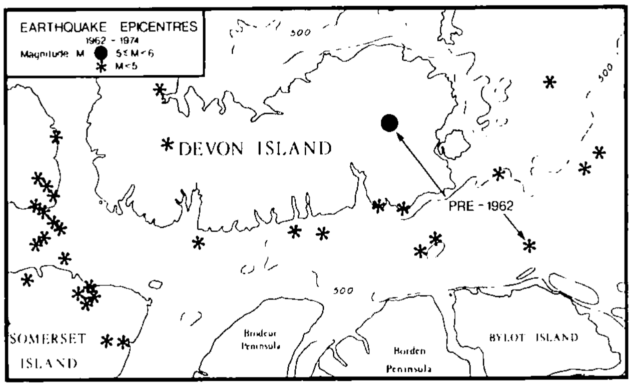

Figure 4.32

Slumping and associated sediment turbidity flows are an indirect threat to sea-bottom installations, even though evidence of them does not exist to date in eastern Lancaster Sound. However, seismically induced slumping may occur along the steep, fault bounded north side of the Sound[4.30]. Turbidity flows, precipitated by earthquake induced slumps, could bury well head equipment and shear off exposed electrical, hydraulic and acoustical control equipment.

4.3.4 Iceberg Scouring

No systematic observations of bottom scouring or ploughing by icebergs have been made in eastern Lancaster Sound. Side-scan sonar surveys off Maxwell and Radstock Bays[4.30] in western Lancaster Sound revealed iceberg scouring in water depths to 140 m. The age of these scours is not known. Icebergs ground in 120 m depths along the south coast of Devon Island between Cape Sherard and Dundas Harbour (Figure 4.12). A berg aground in 451 m deep was observed east of Carey Island in North Baffin Bay[4.31]. Its estimated weight was 10 million tonnes. Icebergs with estimated weights over 5 million tonnes are found in eastern Lancaster Sound (Figure 4.13). At this time, there have been too few observations of iceberg sizes from which probabilities of an iceberg keel hitting a wellhead can be calculated. The probability is likely low in the 700 to 750 m depths where drilling is proposed; however there is doubt that the probability is zero.

The draught of an iceberg depends on its shape and size. Ratios of draught to freeboard, derived from direct measurements by the International Ice Patrol[4.34] are 5:1 for table top bergs; 4:1 for a rounded berg; 3:1 for a pyramidal berg; 2:1 for a columnar berg and 1:1 for a winged berg. Classifications according to shapes for given sizes are not available in Lancaster Sound. The proposed drilling site is on the "main line" of iceberg tracks in eastern Lancaster Sound. In view of the above mentioned uncertainties, it would be reassuring to see side-scan sonar records and cores for aging purposes from the sea bottom in the vicinity of the proposed drilling.

4.4 Summary: Hazards and Constraints to Drilling

- The median drillship operating season, at 81°W, near the proposed exploratory drilling site, is about 109 days. This compares with a median of 105 days, minimum, over most of the Beaufort Sea Shelf.
- Ice free seasons can be much shorter than 109 days in adjoining bays and inlets which may be suitable for supply bases and overwintering.
- Prediction of ice and iceberg drift, will be inadequate if based on meteorlogical observations alone. Direct upstream monitoring of ice and iceberg drifts will be necessary because of unpredictable water currents.

- Icebergs constitute the major hazard to drillships in eastern Lancaster Sound. Their areal and size distributions are poorly known, as is the variability in these factors from summer to summer. From available data, encounters can be expected once every 8 days.
- Expected winds and extreme wind waves are unlikely to be hazardous to drillships in Lancaster Sound. Sufficient data exists for estimating percentages of the time that various drilling and supply operations would have to cease. High winds and high waves occur marginally less often in Lancaster Sound than in the southern Beaufort Sea.
- The spray-icing hazard is slightly lower in Lancaster Sound than in the southern Beaufort Sea, not only because of fewer possible extreme icing events but because of short distances to protected anchorages away from wave-spray.
- Visibility is better in Lancaster Sound than in the southern Beaufort Sea – better than 8 km for 73% of the time.
- Maximum current profiles, suitable for marine riser design, are available for the summer of 1977. There is uncertainty that one summer's data would be adequate for the next; hence, it would be expedient to apply safety factors to account for this uncertainty.
- There is a slight possibility that sub-sea permafrost exists in the sea bottom of eastern Lancaster Sound. Drilling programs should take account of the possibility.
- Gas hydrates, which may form a gas impervious layer in the sediments, must be anticipated in drilling. Breakdown of hydrate bonded sediments would need to be guarded against.
- Earthquakes of magnitude less than 5 are common in eastern Lancaster Sound. While these may not be a direct threat to seabottom installations or drilling systems, there is a possibility that seabottom turbidity flows could be generated. These could bury well head equipment, and shear off exposed control apparatus.
- Iceberg bottom scouring is remotely possible in the over-750 m water depths where drilling is proposed. In anticipation of emergency disconnections of the marine riser, when time for cementing-in the well is not available, it would be reassuring to have data indicating the prevalence of sea-bottom scouring, if any, at these depths.

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5. FATE OF CRUDE OIL FROM A SEABOTTOM OILWELL BLOWOUT

If an oilwell blowout occured in the deep water of eastern Lancaster Sound, would the oil threaten its local wildlife? The purpose of this section is to trace pathways of oil from the seabottom and to predict the fate of oil season by season. With this knowledge, the vulnerability of wildlife in Lancaster Sound can be crudely predicted.

Threats to wildlife not only depend on expected oil pathways, but on the volumes of oil which would escape each day, initial composition and the length of time the well remains uncontrolled, if not bridged naturally. For the scenario of an oilwell blowout in the southern Beaufort Sea[5.1], it was assumed that a well would have an initial flow of 400 m^3 per day (2,500 bbl/day), reducing to 239 m^3 per day (1,500 bbl/day) after one month. Accompanying this oil would be 34,500 m^3 of gas at the sea surface each day.

In eastern Lancaster Sound, where excessive pressures typical of the Mackenzie Delta and Beaufort Sea are not expected, the geological formations are sufficiently delineated to permit estimates of potential flow rates, in percentage possibilities, to be made[5.2]. Very roughly, these estimates are:

- A 50% probability of a flow of 160 m^3/day (1000 bbls/day), and
- a 10% probability of a blowout flow rate of 950 m^3/day (6000 bbls/day).

For the purposes of this report, the high flow rate is assumed, and remains constant unless the well bridges itself, or flow is stopped by a relief well. It is also assumed that the volume of natural gas which emerges *at the sea-bottom,* in 770 m of water, will be three times the oil volume per day, or 2,850 m^3 per day. This 2850 m^3estimate assumes saturation of the gas in the oil[5.3] at formation depth of 3,000 m and is the volume of gas, per day, which comes out of the solution as the warm oil rises in the well bore.

Regarding the physical and chemical characteristics of the expected oil, it is assumed to be identical to Norman Wells crude oil, for which an extensive body of information is available[5.4].

5.1 From the Sea Floor to the Surface

Vital information needed in scenario development concerns the state of gas as it rises through the cold water from the oilwell blowout. Will some or all of it be in solid, hydrate form? Experimental work in response to this question will not be completed by the Frozen Sea Research Group at the Institute of Ocean Sciences until mid-1978; and until then, calculations and educated guesses must suffice.

5.1.1 Near the Sea Floor

An oilwell blowout is assumed to inject into the bottom of the water column at 770 m depth, a mixture of 950 m^3/day of Norman Wells-type crude oil and 2,850 m^3/day of natural gas, from a 15 cm diameter pipe. The resultant exit flow speed could average 62 cm/sec for this mixture of oil and gas. Exit temperatures could be 75°C, assuming the oil bearing stratum was 3,000 m below the sea floor, under consolidated Paleozoic bedrock (Figure 4.31).

NORCOR[5.4] has shown that oil, freely emerging from an underwater orifice without gas, breaks up into droplets, in a slowly rising conical-shaped plume, with a half angle of about 25° to 30°. Droplet sizes range from 2 to 10 mm in diameter. The rising plume entrains considerable volumes of water; hence the upward mobility of droplets is not necessarily governed by their buoyancy and drag in a static water column. Measured upward velocities average 27 cm/sec. (Norcor's observations were confined within 2.5 m of the orifice.) If conical spreading had continued upward, it is likely that the droplets would have slowed as vertical motion in the water column diminished.

In contrast to these results, Topham[5.5] reports that gas and oil, ejected from an orifice 2.2 cm in diameter into the sea water at an exit speed of 190 cm/sec, produces oil fragmentation into tiny droplets, all less than 0.3 cm in diameter. Higher exit speeds shift the droplet size distribution to even smaller sizes. For the deep water Lancaster Sound blowout, with an exit speed of 62 cm/sec, it is certain that the droplet size distribution would favour somewhat larger droplets — but smaller than observed by NORCOR with no gas. With this in mind, an assumed droplet size distribution for the Lancaster Sound blowout is shown in Figure 5.1. This was scaled up by an arbitrary factor of 2 from the distribution for orifice exit speeds of 190 cm/sec. Figure 5.2, derived from Figure 5.1, shows a plot of relative oil volumes, which rise in the water column, vs droplet size. Superimposed is a plot of the terminal velocity in ascent of oil droplets vs droplet size. These plots are used for modelling the volumetric dispersion of the oil droplets as they rise through the water column.

Once free from the sea floor orifice, the gas forms a rising shower of bubbles, generally less than 0.3 cm in diameter. These rapidly cool in the 0.5°C water. Immediately above the orifice, the gas propels the oil upward with the water; however, as the bubble stream diverges, and with the assumed small gas flow of 0.034 m^3/sec, the bubbles and oil droplets will likely begin to ascend independently at all depths 50 m above the sea floor orifice. The ever-present horizontal tidal currents ensure this separation. With no hydrate formation, the gas expands only 7% in volume upon reaching 50 m above the bottom. The terminal velocity of the gas bubbles[5.7] averages about 24 cm/sec, roughly independent of bubble size for bubble diameters over 0.2 cm.

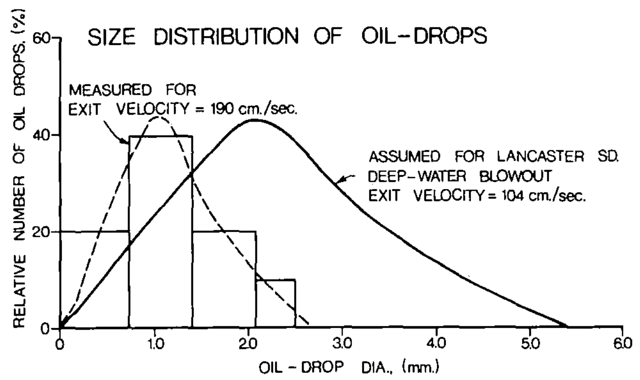

Figure 5.1

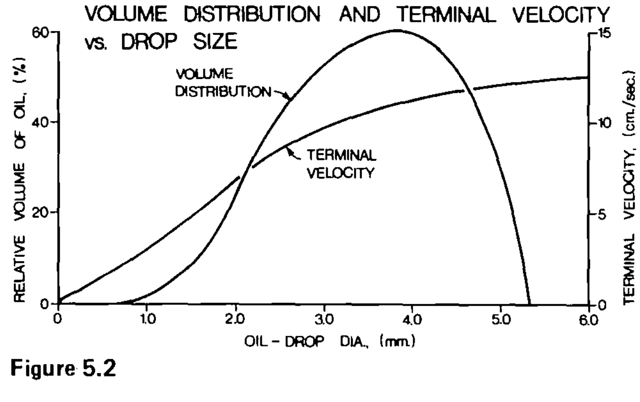

Figure 5.2

5.1.2 Gas, Hydrate, Oil and Water Interactions

According to the hydrate-water-gas phase diagram in Figure 4.31, free gas and that which comes out of solution in rising oil droplets, forms hydrates. Hydrates are 10% gas and 90% water, by weight. The gas does not form hydrates instantaneously, so that the rising bubbles of gas would initially form a bubble plume[5.5]. In addition any gas coming out of solution in rising oil could form a crust of hydrate on oil droplets.

Ethane, and simulated natural gas, experimentally bubbled from a depth of 650 m in water at 7°C forms hydrates[5.8]. This depth and temperature falls just within the phase diagram for hydrate formation (Figure 4.31). In contrast, bottom water temperatures at 770 m depth in Lancaster Sound are much colder, about 0.5°C. Also if the gas is even slightly sour (containing H_2S) the range of temperatures and pressures over which hydrates form increases[5.9]. Thus a large fraction of the gas is expected to form hydrates during some part of its journey to the sea surface.

To further develop our scenario, it is necessary to estimate the percentage of gas likely to form hydrates. Gas bubbles become coated with hydrate as they rise,[5.8] possibly inhibiting the flow of heat from the gas to sea water. Assuming 2 cm diameter bubbles, at least 50% of the gas could be in hydrate form prior to ascending to the limiting pressure for its formation[5.10], likely at depths 250 m or less. The shedding of hydrates could enhance its formation rate; however, diffusion of gas through a hydrate shell could occur. In this event, hydrate growth would be slowed. For this report, 50% is accepted as the percentage of the gas volume which forms hydrates. This is equivalent to 9 kg/sec of hydrates, or 70 tonnes per day. Another 166 tonnes per day, can form by water uniting with the gas which comes out of solution from the rising oil droplets. The gas could, however, become super-saturated and subsequently expand within an oil droplet. This expansion could shatter the droplet and provide energy to form emulsions. This speculation has no experimental basis; nevertheless, calculations indicate that the possibility exists[5.11]. The effect would be an enhancement of dispersion of oil in the water by shifting the droplet size distribution to a lower order. For the present purposes, this is assumed not to occur.

Another interaction of rising oil droplets with sea water occurs. Water-soluble toxic components of the oil can migrate from the oil droplet to the sea water. An estimate of the concentration of these soluble components in the water column is now made.

An oil droplet, of Norman Wells crude oil, is assumed to consist of two pseudo-components: a soluble component of about 5% of the drop's mass and a remaining insoluble component. The rate of solution of the soluble fractions decreases exponentially, with the exponent varying directly with time, and inversly as the square of the droplet diameter[5.12]. This means that water soluble fractions in small droplets vanish more quickly than from large droplets.

Figure 5.3 shows a plot of the time taken for oil droplets of various sizes to rise through 770 m of water. Superimposed is a family of curves showing the percentage of the water soluble fractions which leave from droplets of various sizes after immersion in water for a given number of hours. For example, 3% of the water soluble components will have left an oil droplet of 1.9 mm diameter by the time it reaches the sea surface. Generally the percentage dissolution is small for the droplet sizes expected (Figure 5.2).

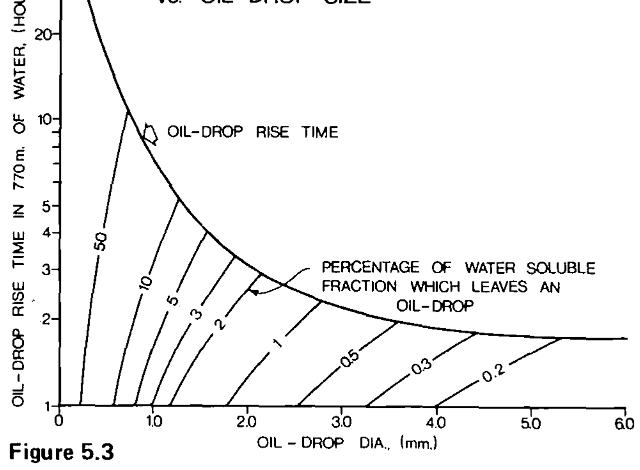

Figure 5.3

The transit time for an oil droplet to travel from the sea-bottom to the sea surface is roughly inversely proportional to its diameter, so that the water soluble volume of oil, which escapes, is almost independent of each droplet's volume. Accordingly, about 0.1% of the total oil from the blowout would be dissolved in the water before reaching the surface - or about 0.95 m^3 per day. On the other hand, if the rising oil droplets become fragmented by gas coming out of solution, more oil will be dissolved in the water.

Rising oil droplets are spread by currents in the water column, most rising to form a "patch" on the sea surface of 3,200 m average diameter. Therefore. the oil droplets will lose their 0.95 m^3 of soluble oils per day in a volume of sea water equal to that of an inverted cone 770 m high, with a base of 3,200 m in diameter. The average concentration of the soluble fractions in this volume from one day's flow of oil would be 0.46 x 10^{-9} parts of oil to 1 part sea water, or about 0.40 ng/l. If all the soluble fractions dissolve in this volume (5% instead of 0.1%), the average concentration increases to 20 ng/l, However the average concentraion will be less since the water in this hypothetical cone is exchanged more than once per day. By comparison, naturally-occurring, polycyclic, aromatic hydro-carbon concentrations measured in the southern Beaufort Sea[5.13], varied between 13 and 45 ng/l. It is concluded that the toxicity from oil dissolved during the time droplets rise from the sea bottom is negligible.

5.1.3 Oil, Gas and Hydrate Trajectories in the Water Column

Figure 5.4 shows a model of a deep water blowout assuming a constant current of 20 cm/sec, independent of depth. The gas bubbles rise at 23 cm/sec, 50% of which transform to hydrates. The envelopes of the gas bubbles and oil droplets separate after rising 50 m above the blowout orifice. Then the oil droplets drift upward, governed by their terminal velocities (Figure 5.2).

In central Lancaster Sound, tidal currents tend to be independent of depth and follow elliptical paths in plan view. Superimposed on tidal currents are residual currents.* These currents will disperse rising oil drops and produce a moving "patch" of oil at the sea surface which will accumulate oil at the rate of 950 m^3/day, or about 40 m^3 of oil per hour. This patch of oil is analogous to paint hitting a ceiling from a moving spray gun. The horizontal dimensions and location of this patch of "just surfaced oil" will vary with time. For example, with semi-diurnal tides of 20 cm/sec peak amplitude, the patch would follow an elliptical circuit at the sea surface, be about 400 m wide and, after one day, would have made two circuits. During the day, the average oil slick thickness would be about 0.34 mm. In reality, the oil patch will follow a more tortuous path.

The volume of gas, about 50%, which does not form hydrates surfaces independent of the oil. The hydrates, of density between 0.91 and 0.96 gm/cm^3, are not likely to be perceived when they are eventually transformed, and surface as scattered as gas bubbles. This is important to remember when considering interactions of oil and gas with sea ice; the gas will not fracture ice floes where oil surfaces, nor will it displace oil from underice domes and pockets.

5.2 Spread of Oil at the Sea Surface

Depending on the season, oil surfacing from a blowout will encounter varying concentrations of sea ice or open water. The sea ice can be motionless or drifting at speeds averaging 20 km/day (23 cm/sec) eastward (Figure 4.2, mid-March). Likewise ice-free waters in summer can be calm historically for between 5 to 8% of the time in August and September (Figure 4.10).

Except for the first year of drilling, there is no preferred time in the summer's drilling season when a blowout might occur. An incomplete well can be completed early in the following summer, for example. Although same season relief well drilling may be possible in the future for wells drilled at the start of the season, it will be assumed that, for a well which blows in the second half of the summer's drilling season, its flow will continue unabated until the following year's mid-drilling season. Consequently, its flow is assumed to occur during all seasons and continue for up to 12 months.

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* currents remaining after tidal currents are removed.

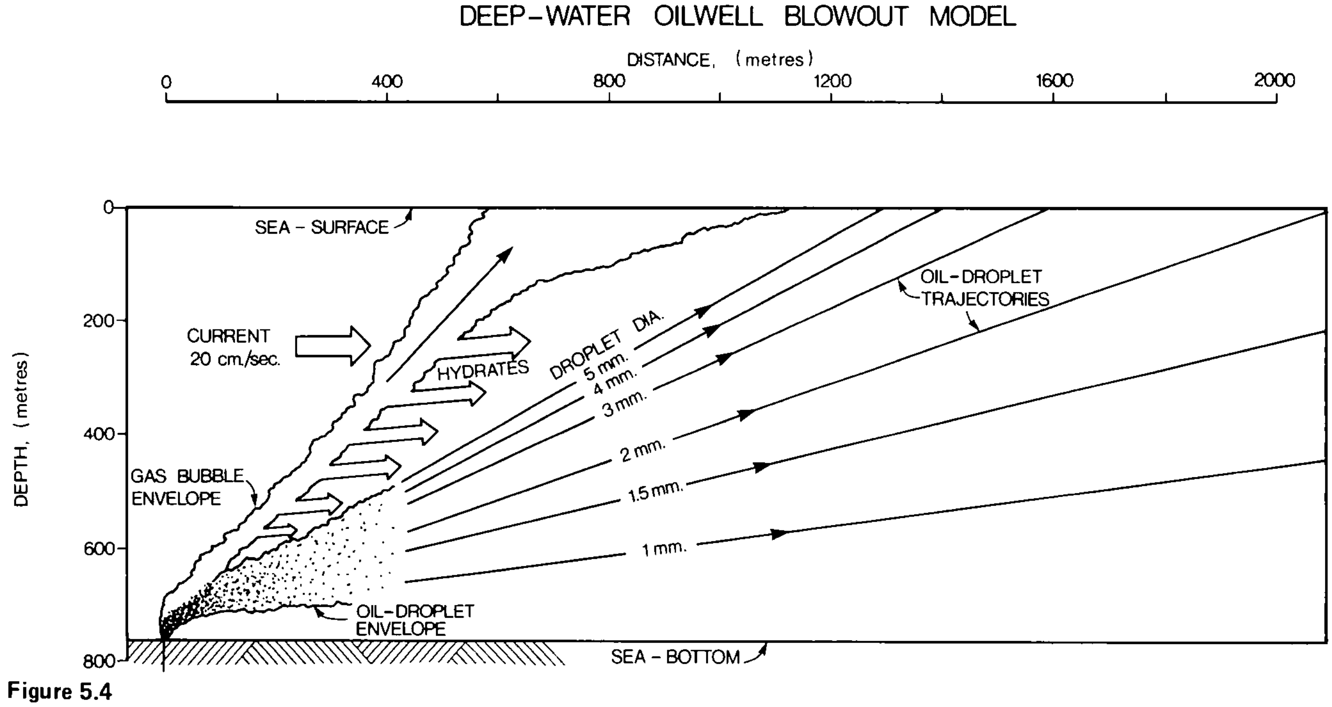

Figure 5.4

5.2.1 Effects of Seasonal Changes

During the open water season, oil is driven downwind at 3% of the wind speed (in cm/sec, the wind speed in km/h x 0.83). Therefore, winds at speeds above 40 km/h, will in large part determine the oil trajectory from the blowout site. For lower wind speeds, surface currents assume more importance. Such is the case in August and September, when winds above 50 km/h historically occur for only 15% of the time[4.14]. Unfortunately, surface currents are known only to a limited extent and exhibit complex surface flow patterns for brief intervals in the summer (Figure 4.14).

Another unknown is the seasonal changeover between summer and winter current regimes, (section 4.2.1.2.). The more random surface currents in summer seem to be replaced by a more vigorous west-to-east flow by autumn, particularly along the south side of Lancaster Sound. Direct evidence of this vigorous flow was obtained from the odyssey of a NIMBUS satellite-positioned drift buoy in 1977*. This buoy meandered throughout mid-Lancaster Sound in early September, but, by early October, has shot eastward across the mouths of Admiralty Inlet and Navy Board Inlet, at a speed of 50 km/day, into Baffin Bay. Such rapid surface currents could afford some protection to these inlets and the south shores of Lancaster Sound by diverting oil slicks to Baffin Bay.

By Early October, ice forms in Lancaster Sound, and remains close to 10/10ths concentration in east-central Lancaster Sound until clearing occurs by mid-June (Figure 4.2). However, adjoining inlets and bays and most shores of Lancaster Sound are protected by a barrier of landfast ice until July when open water conditions prevail again.

During the fall, winter and spring, the ice generally moves eastward. This movement is not uniform, and for days at a time, the ice remains motionless. At such times, oil could collect in considerable volumes under the ice, to be eventually transported into Baffin Bay.

5.2.2 August and September

5.2.2.1 Wind Drift of Oil

Aside from icebergs and occassional ice intrusions, August and September are considered to be open water months. Figure 5.5 shows (a) percentage of time (in August and in September) that all winds blow in a given direction, (b) their average speed, (c) the number of days in the month in which they occur and (d) how many kilometres in a given direction that an oil slick, driven at 3% of the average wind speed, would travel in that month. Using these distances, Figure 5.6 shows how far a wind driven oil slick might move *in the absence of surface currents.* The geographical limits of slick movements are outlined after one month, and two months, assuming a blowout starting on the 1st of August; and one month later, starting on the first of September. Wind-driven oil moves relatively small distances since summer winds are weak. For example the strongest *average* wind speeds from the east at 30 km/h blew for less than six days in August or September.

5.2.2.2 Currents and Oil Movement

Figure 5.7 is a sketch of oil slick movement and the likely daily progress resulting from surface currents, but *in the absence of winds.* As discussed in Section 4, surface current patterns and speeds are assumed composites based on:

(1) ice drift patterns described in reference 4.4;

(2) break up patterns deduced from a more recent examination of satellite imagery;

(3) descriptions of ice and water movements from the Arctic Pilot[4.11]; and

(4) clues provided by measurements described in subsection 4.2.

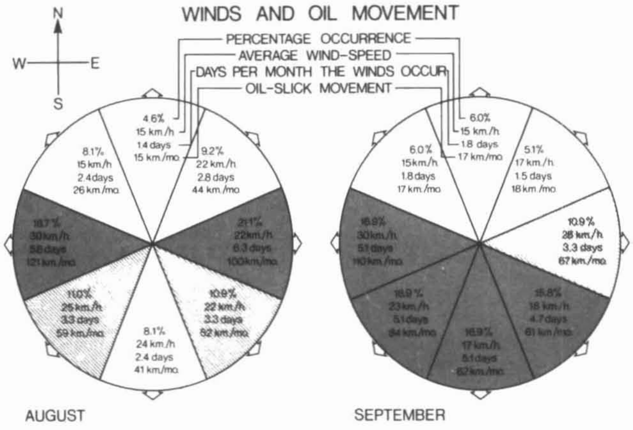

Figure 5.5

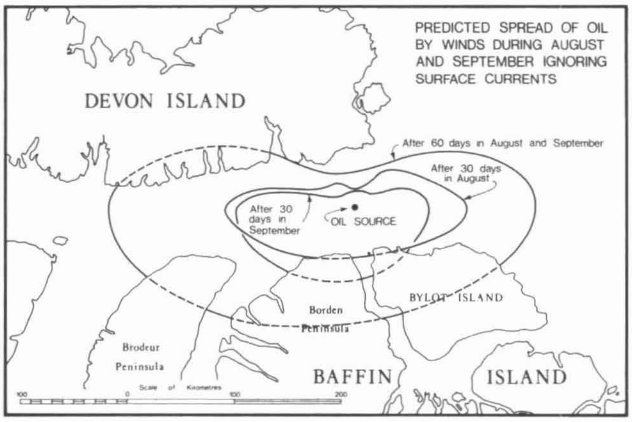

Figure 5.6

Surface currents will have the greater influence on oil movements in eastern Lancaster Sound because winds are generally light, and strong winds blow for a short time. It is evident that the major targets for the oil will be Bylot Island and Navy Board Inlet and, to a lesser extent, Borden Peninsula.

5.2.2.3 Oil Drift Due to Currents and Winds

Strong winds can significantly distort the spreading pattern of oil established by surface currents. From available wind statistics[4.14] strong winds seldom blow for as long as a day; consequently, the distortion will be temporary. By using geometric-mean wind speeds to represent the wind speeds in the data groups shown in Figure 4.10, and assuming that the high winds occur in once-a-month storms, the distortion by winds from all directions can be obtained. The summation of these wind distortions on the oil spread due to currents alone defines the *probable* area which could be influenced by oil. This is shown in Figure 5.8. A larger *possible* area could be contaminated by oil driven by occasional long-duration storm winds which occur in some years.

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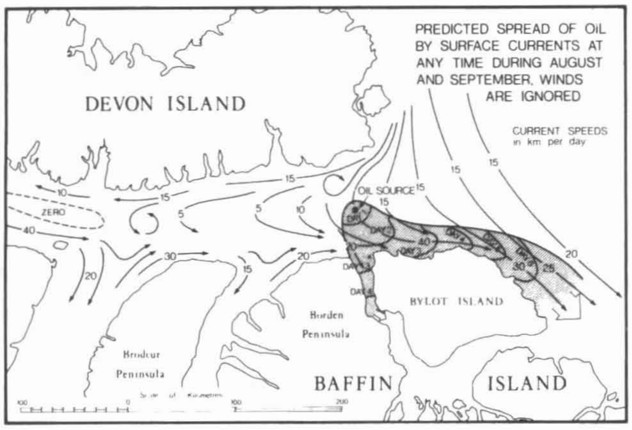
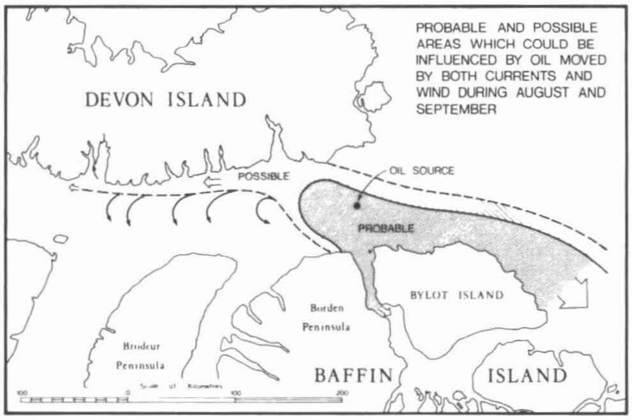
* An Experimental Program of the Institute of Ocean Sciences, Patricia Bay, Sidney, B.C.



PREDICTED SPREAD OF OIL BY SURFACE CURRENTS AT ANY TIME DURING AUGUST AND SEPTEMBER. WINDS ARE IGNORED

Figure 5.7



PROBABLE AND POSSIBLE AREAS WHICH COULD BE INFLUENCED BY OIL MOVED BY BOTH CURRENTS AND WIND DURING AUGUST AND SEPTEMBER

Figure 5.8

5.2.2.4 Dispersion and Evaporation

Having established areas likely to be contaminated by oil in summer, it is now important to estimate how much oil might enter Navy Board Inlet, how much might impinge on the shores of Bylot Island and what volumes might be evaporated and dispersed into the water en route.

The oil droplets surfacing from a deep water oilwell blowout are assumed to form a slick averaging 0.12 mm in thickness, for one day's oil accumulation of 950 m^3. The size of this slick into which oil droplets randomly surface is assumed to be 3,200 m in diameter. In calm water, or even under rough seas, the droplets must rise and coalesce into slicks at the surface. Then, depending on the vigour of breaking waves, some oil from slicks will be thrust downward, to a depth on the order of the wave height, and fragmented into very small particles[5.14], ranging in size between 1 and 30u ($1u = 1 \times 10^{-3}$ mm). The vertical distribution of these oil particles has the theoretical form[5.15]: $f(z) = v \exp(-vz)$, where z is the depth and v is a function of the terminal velocity of an oil particle (due to its bouyancy) and the surface wind speed. This equation means that, in high seas, most of the oil will travel below the surface. For droplets this small, all the most water soluble fractions of the oil, about 5%, will quickly dissolve in the wind mixed water layer. The remaining soluble 55% will dissolve more slowly. The insoluble 40% will be unlikely to surface, having a density close to that of water.

Oil remaining on the surface may form a water-in-oil emulsion, containing as much as 83% water[5.16]. The stability of such emulsions depends on the type of crude oil, however for the Norman Wells-type crude oil assumed in this report, emulsions are unstable and oil slicks will re-establish themselves once seas subside.

Evaporation will be somewhat enhanced by high seas and the horizontal spreading of oilslicks. For example, in the Ekofisk spill, 21% of the oil evaporated in the first 7.5 hour, and emulsification apparently did not affect evaporation[5.16].

Oil floating on the sea surface or dispersed in the wind-mixed layer will spread horizontally. For a continuously running blowout, the lateral spreading of slicks will be largely a function of variable winds and variable surface currents. Additional lateral spreading, resulting from surface tension and viscous drag forces, is likely to be insignificant. Uncertainties in lateral spreading due to surface currents alone are accounted for in the assumed spread of oil shown in Figure 5.7. Spreading due to both winds and currents, is accounted for in the "probable" area shown in Figure 5.8.

The volume of oil dispersed into the wind-mixed layer depends on wind waves and how long winds blow. For sustained winds and risen seas, all the oil eventually will be dispersed. However, in Lancaster Sound, winds are variable and, in summer, strong winds have short durations (Figure 4.10). Figure 5.5 shows that average wind-speeds, from all directions, range between 15 and 30 kilometres hour; the average for all directions is 23 km/h for August and September. This wind speed is used to estimate quantities of oil dispersed by resulting wind-waves. Driven by winds of this speed, seas are classified as "medium" and have numerous white-caps. Calculations of dispersion loss[5.12] from slicks in medium seas indicate approximate oil volume losses of 15% in one day, 25% in two days, 31% in three days, increasing by a factor of 1.1 for each additional day. Figure 5.7 is a useful guide to determine the number of days for oil ro reach various destinations along Bylot Island, and vicinity. In two to six days, dispersion losses range from 25% to more than 45%, on average, during August and September.

Evaporation of a Norman Wells type crude oil is relatively independent of sea state; about 40% will evaporate within the first 24 hours as well as 50% within the first 100 hours[5.12]. Beyond this time interval, evaporation losses are insignificant on the time scale shown for slick movement in Figure 5.7. Even after oil reaches a shoreline, 45% of the volume persists after several days' travel downstream. Another 5% of the highly water-soluble fractions are dissolved in the surface waters directly from thin slicks. This quantity added to evaporation losses of 55% and dispersion losses determines the volume of oil remaining in drifting slicks.

5.2.2.5 Concentration of Dispersed Oil in Surface Waters

An estimate of concentration of dispersed oil in the surface waters is based on the following assumption: oil from a blowout surfaces in a 3.2 km-diameter patch; a steady wind at 23 km/h disperses the oil and, together with currents, causes the oil to drift at a speed of 20 km/day; and the surface water-layer is 25 m thick.

Initially, about 19% of the oil is dispersed each day into the 25 m thick surface layer. Allowing for 50% evaporation loss over the first few days, of the 950 m^3/day of oil from the blow-out, 47.5 m^3 is dispersed. The average concentration of oil in a layer 25 m thick, 20 km long and 3.2 km wide is one part in 3×10^{-8}. Horizontal dispersion[5.17] ensures that concentrations will diminish still further.

5.2.2.6 Oil Destinations and Volume Estimates

There are large uncertainties in: likely oil-drift trajectories winds near shore, the type of oil from the blowout and resulting seasonal averages of dispersion losses. Table 5.1 shows the summertime loss by evaporation, solution and dispersion at various expected destinations. Evaporation and solution losses were lumped as "source" losses before dispersion losses were applied. The percentage of oil from the blowout which reaches various destinations is shown in Figure 5.9 for August and September.

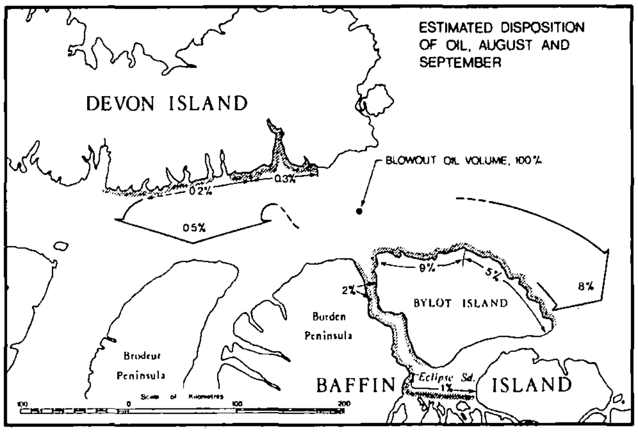


Figure 5.9

TABLE 5.1 Estimates of Oil Destinations and Volumes for August and September.

Near-Source volumes & losses	%	m^3/day
Blowout volume per day	100	950
Evaporation loss	55	523
Loss of water-soluble fractions after evaporation	5	21
Effective Source Volume/day	43	409

Destination A	N. end of Navy Board Inlet		N. coast of Bylot Island		E. coast of Bylot Island		S. E. Devon Island		Baffin Bay	
	%	m^3/day	%	m^3/day	%	m^3/day	%	m^3/day	%	m^3/day
Part of Effective Source volume to Destination 'A'	15	61	30	123	20	82	5	20	30	123
Dispersion losses	30	18	30	37	40	33	30	6.0	>40	>49
Volume of Blowout Oil at Destination 'A'	4.4	43	8.8	86	5.0	49	1.5	14	<7.6	<74

Destination B	Both shores of Navy Bd. Inlet		South shores of Eclipse Sound	
	%	m^3/day	%	m^3/day
Part of Destination 'A' volume to Destination 'B'	50	21	50	21
Dispersion losses	10	2	50	11
Volume of Blowout Oil at Destination 'B'	2.0	19	1.1	10

Destination 'C'	Croker Bay region		S. Coast Devon Island		Central Lancaster Sd.	
	%	m^3/day	%	m^3/day	%	m^3/day
Part of Destination 'A' volume to Destination 'C'	25	4	25	4	50	7
Dispersion losses	30	1	40	1	>40	3
Volume of blowout oil at Destination 'C'	0.26	2	0.23	2	<0.45	<4

5.2.2.7 Major Unknowns

The scenario for August and September depends critically on assumed surface currents in eastern Lancaster Sound, but these have been based on tenuous evidence. Should they be significantly incorrect, other coasts further west could suffer more extensive pollution, with correspondingly less on the coasts of Bylot Island. The destiny of oil which would enter Navy Board Inlet is uncertain; all of it could be immobilized on coasts while en route south but this is unlikely. How much and by what route oil would enter Eclipse Sound is unknown. How much oil would go ashore on Bylot Island depends on along-shore and near-offshore surface currents. These, too, remain unknown.

5.2.3 October and November

Areas which could be contaminated by oil drifting during the months of October and November are shown in Figure 5.10.

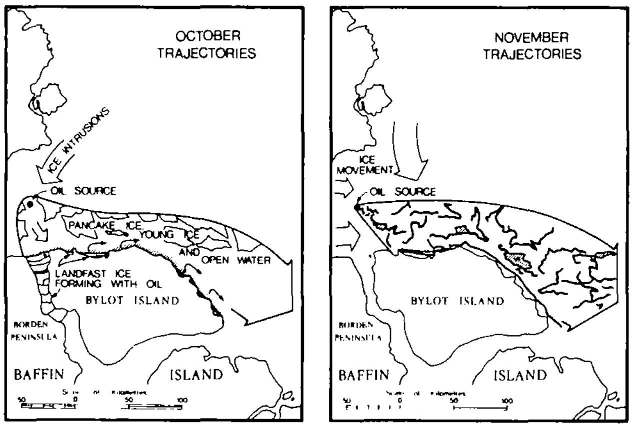


Figure 5.10

5.2.3.1 Effects of Ice Drift and Ice Growth

By early October, as air temperatures drop, freeze-up begins in Lancaster Sound, (Figure 4.4). An easterly flow of young ice is established into Baffin Bay by November (Figure 4.2). Strong easterly surface curretns appear off the south shores of Lancaster Sound in mid-October (Section 5.1.4.1). These could inhibit oil from entering Navy Board Inlet even before landfast ice forms. Baffin Bay ice increasingly intrudes from the northeast but is quickly swept out eastward, after drifting south across the blowout site. Since open water persists longest north of Bylot Island, oil swept into these waters could be incorporated in growing landfast ice, which eventually bridges headlands. The trend, during these months is a progressive herding of oil from the blowout by increasing concentrations of ice, eastward, into the stream of drifting ice in Baffin Bay. Direct effects of wind on oil would diminish, and oil can only contaminate exposed headlands, and landfast ice as it grows. Oil rising from the blowout surfaces under moving ice, or in open water where it is soon mixed with newly forming ice. By these processes, the ice gradually immobilizes the oil, except in new and extending leads.

In October, the oil is somewhat more mobile than in November. Some of it could be immobilized in bands across Navy Board Inlet, as the ice progressively becomes landfast toward its northern end.

In the extensive open water north of Bylot Island, oil moves shoreward, and some is captured by new ice in bays. Some is carried off by currents down the east coast of the island, and into Baffin Bay. By November, very little oil is likely to impinge on Bylot Island — almost all of it being herded between and under sea ice into Baffin Bay.

5.2.3.2 Consequences of Oil Drift During Freeze Up

From freeze up to spring melt, oil is locked into the ice. By July, this ice melts and loosens. In Navy Board Inlet, ice will probably move down to Eclipse Sound, with its October oil-load. Depending on winds, the shore ice off Bylot Island melts in place, or moves off with its oil-load. The coasts are once again exposed to shoreward drifting oil.

Based on Table 5.1, we guess that 4.4% of the 950 m^3/day of oil becomes locked into the growing ice in Navy Board Inlet between the 1st and 15th of October. This 15 days accumulation of oil is estimated to have a volume of 627 m^3 (550 tonnes). This oil eventually sweeps into Eclipse Sound when ice moves south in early August.

It is more difficult to estimate volumes of oil locked into landfast ice along the north and east coasts of Bylot Island. Oil could be mixed in at the surface if the ice grows in place; or be concentrated in bands as the fast ice extends and stiffens itself seaward. However, the volume of this oil is predictably less than that which would have already contaminated the shores during the summer's open water. Once landfast ice is in place, further direct contamination of the shores is prevented. In the next year, puddling on the ice normally starts in early June, but with dark oil mixed in its surface, this will begin much earlier — possibly mid-May. Oil then spreads in melt water and flows ashore or out to sea.

5.2.4 December to the End of April

5.2.4.1 Effects of Ice Drift

Heavy ice concentrations occur in Lancaster Sound from early December through to late April, except in the occasional years when ice clears as early as mid-March (Figure 4.3). Figure 5.11 shows the probable oil trajectory from a continuously running blowout during the 5 month period, based on ice drifts and concentrations shown in Figure 4.2.

From a deep water blowout, most of the time the oil and gas will surface separately so that nearly all oil droplets will settle under ice of various thicknesses, a small fraction forming slicks in transient leads and polynyas. During these months, nearly all the oil will be confined under ice floes, these having more than enough domes and pockets to

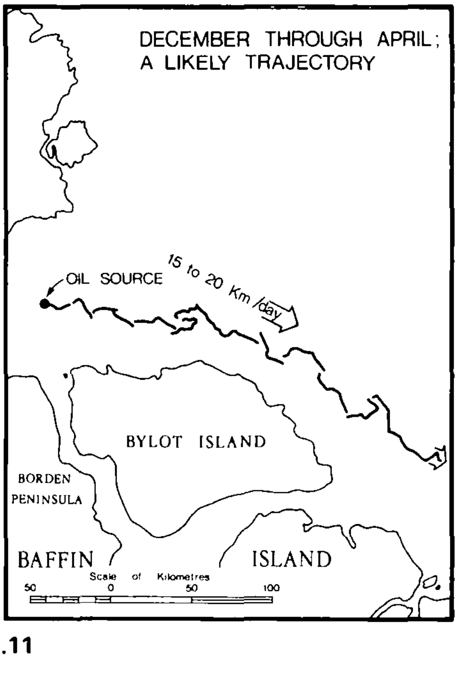


Figure 5.11

contain the widely spread oil. A day's oil accumulation averages less than 0.12 mm thick; meanwhile, the ice drifts eastward at average speeds of 13 km/day, or more. The under ice roughness of sea ice averages 20% of its thickness. Assuming 1 m thick ice, it can remain over the blowout for, at least, 16 days before its capacity to confine all the oil within a patch-size of 3,200 m diameter is exceeded. Therefore, motionless ice – expected for no more than a few days at a time – would not contribute to the spread of oil.

During the cold of winter, oil under growing ice is soon incorporated into it as the ice grows from beneath. No evaporation and dissolution occurs. Oil would move out of Lancaster Sound, almost entirely encapsulated, into the stream of ice drifting southward in Baffin Bay. The estimated net drift per day eastward, and then southeast, is 20 km, comprised of a meandering path, perhaps 30 km long. Oil would be in a swath 4 km wide and equivalent in volume to a ribbon of oil, 1 cm thick and 3.2 m wide. By late April, oil migrates up through brine channels in the ice to its surface[5.4]. This applies to oil in or under the ice, and everywhere along its path. The dark hued oil will hasten ice melting and, by late May, most will be free to drain from melt ponds into adjoining leads and polynyas.

5.2.5 May, June and July

5.2.5.1 Effects of Landfast Ice

By May, ice ceases growing and open water does not freeze to any significant extent. During May, or later in June, ice clears out of Lancaster Sound east of the fast ice edge (Figure 4.2). Open water prevails apart from occasional ice intrusions from the breakup of land fast ice in Prince Regent Inlet and Admiralty Inlet. The areas contaminated by oil from the blowout will be essentially the same as those in August and September, (Figures 5.8 and 5.9), except that landfast ice prevents oil from entering Navy Board Inlet as well as the bays along north Bylot and south Devon Islands. The oil will concentrate at landfast ice edges and drift with alongshore currents, eastward, during May and most of June. The exception is, that southerly currents entering Navy Board Inlet will concentrate oil against the ice edge at its northern end. This accumulation could be extensive up to 3,140 m^3 of oil (about 4.4% of 950 m^3/day of oil for 75 days), prior to breakup in late July.

5.2.5.2 Disposition of Oil

Figure 5.12 shows the estimated disposition of oil during these months. Wind data is not available but is assumed to be similar to that during August and September.

The 50% lower estimates in Figure 5.12, compared to Figure 5.9, of oil remaining in place seaward of the landfast ice, reflect the likelihood that half the oil would be swept eastward as the ice progressively breaks away from the shore, the rest remaining to intrude inshore, mostly in June and July.

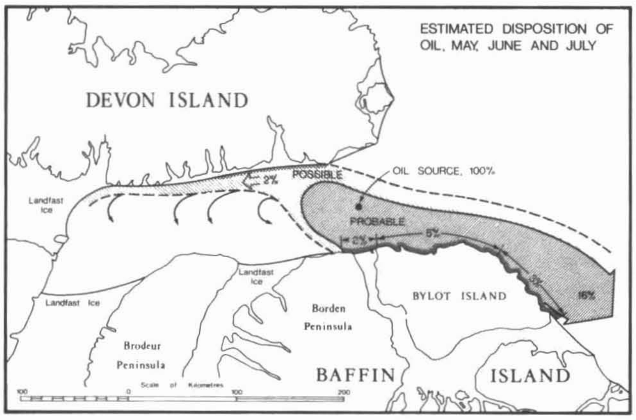


Figure 5.12

5.2.5.3 Major Unknowns

Except for ice drifts obtained from infrequent satellite imagery, surface currents are unknown in May, June, and July. Wind observations are non-existent. The southward surface currents which would trap oil against landfast ice at the north end of Navy Board Inlet, need confirmation. Better knowledge of land-fast ice breakup along Bylot Island shores, would aid the prediction of oil deposition in Baffin Bay.

5.3 Summary:

Fate of Oil from a Seabottom Oilwell Blowout

For a continuously running 950 m^3/day (6,.000 bbl/day) blowout, at a depth of 770 m, virtually all of the oil will rise in droplets ranging in diameter between 1 and 5 mm. Most of the oil will surface separately from the gas. The oil droplets are likely to be distributed in thin slicks, in a patch of about 3,200 m in diameter. The average slick thickness for a day's oil accumulation, is assumed to be 0.12 mm with a maximum of 0.5 mm. Depending on season, the oil patch will surface in calm or rough seas, or under various concentrations of still or moving sea ice.

5.3.1 Summer

Prevailing surface currents will largely determine the drift of oil since winds are generally light and storms brief. Dispersion of oil by wind-waves into surface waters will occur for brief periods, but long enough to disperse from 30 to 40% of the oil into the surface water layer. An additional 5% of the water-soluble oil would be lost directly from the thin slicks. About 55% will be lost due to evaporation after a few days. Major destinations for oil are Navy Board Inlet, and the north and east coasts of Bylot Island. Figure 5.9 shows estimates of percentages of the original 950 m^3/day expected at all destinations.

5.3.2 Fall

During October and November, sea ice increasingly confines the oil to ice drift paths. Open water will exist, at times, to permit oil to accumulate in growing coastal landfast ice, and in northward extending ice in Navy Board Inlet. This oil would become preserved for release in early summer.

5.3.3 Winter

From December through April, most oil would float up under moving sea ice to form an under-ice swath of thinly distributed oil as much 4 km wide, averaging, in thickness, less than 10u (10^{-3} cm) for ice drifting at 20 km/day. Most oil would become encapsulated by growing ice after surfacing in under-ice depressions. By late April, most will then emerge on the surface of the sea ice everywhere along its trajectory into Baffin Bay (Figure 5.11). At this time, its light ends will evaporate, and the remaining oil will be free to flow off with melt water in late May.

5.3.4 Spring

Massive clearing of ice from Lancaster Sound occurs in May, leaving landfast ice bridging headlands and inlets. Except for the landfast ice protecting shores, expected oil destinations will be similar to those in summer (Figure 5.12). As much as 1,700 m^3 of oil could accumulate against the fast ice at the north end of Navy Board Inlet, and some would drift south at break up in late July to Eclipse Sound.

5.3.5 A Year's Oil Pollution

For a blowout lasting a year, most of the year's oil will drift into Baffin Bay. About 6% of the 950 m^3/day, averaged over a year will pollute the southeast margin of Lancaster Sound. This 6% is equal to 21,000 m^3 of oil (18,000 tonnes, or 132,000 bbls).

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6. COUNTERMEASURES TO OIL FROM A BLOWOUT

Unless stopped, the blowout is assumed to flow at 950 m^3/day through all seasons. Questions are: What can be done to stop the blowout? Before it is stopped, can the oil be removed from the sea? If it cannot be removed, can it be prevented from invading critical regions and habitat? If invasion occurs, can polluted regions and habitat be repaired? Countermeasures are those actions taken by man to assist nature in cleansing itself of pollution. The possibilities for effective action are examined in the context of oil pollution from the assumed blowout in eastern Lancaster Sound.

6.1 Stopping the Blowout

Oil from the blowout was assumed to originate from a depth of 3,000 m below the sea floor. Normal drilling this deep would take 60 days[6.1], not accounting for additional time which may be required for drilling in deep water. Successful relief-well drilling, to kill a blowout, requires longer — an estimated 80 to 100 days. If the oil source is only 1,500 m below the sea floor, initial drilling time could be 33 days. Relief well drilling time, to the same depth could take 45 to 65 days, allowing for one or two re-drills of the lower section to intersect the original hole.

The median operating season is less than 113 days at the proposed drilling site (Section 4.1.1.1.), and ends about October 15 when there is new ice 15 cm thick, or less. It is evident that a 3,000 m below-sea-floor target horizon is unattainable with same season relief well in a median length season. On the other hand, targets 1,500 to 2,000 m below sea floor, with a same season relief well would likely be attainable. Weather forcasts in an actual operating season could expand or shrink the number of operating days.

If a same season relief well capability is not mandatory, then an end-of-season blowout would not be stopped by relief well drilling until the next season.

6.2 Countermeasures at the Blowout Site

Even with a same season relief well, the blowout could flow for 45 to 65 days, from the latter part of August to the 15th of October, assuming a 1,500 to 2,000 m well depth below sea bottom. There is no existing technology to collect oil near or at the sea bottom[6.2]. The oil would surface in a random pattern to form slicks, spread over an area of 3,200 m or more in diameter. Gas which did not form hydrates also surfaces randomly but confined to a smaller surface area of perhaps 2,000 m in diameter.

6.2.1 Summer: August and September

Figure 6.1 shows a typical oil slick facing clean-up operations in open water. A 22 km/h wind is assumed to blow for 6 hours in a direction 45° to a steady 10 km/h surface current. The wind commences blowing 10 hours after time "zero". The resulting 24 hour trajectory is formed from oil drifting away from a moving patch of rising oil droplets. Semi-diurnal tides move the patch around two circuits in 24 hours. The average slick thickness, in the narrowest part of the trajectory, ignoring evaporation losses, is 0.025 mm, or 25 micrometres; hence the oil will be thin on the surface, even over the blowout site.

Oil containment booms would have to span a horizontal distance of 4 km, or more, to collect most of the oil. Offshore booms and mechanical clean-up units are ineffective for sea states greater than 3 (waves 1 metre high); also more of the oil is dispersed into the surface waters by waves downstream from the blowout site. Chemical dispersants, applied in risen seas at the blowout site, could ensure that some of the oil lost to mechanical containment is dispersed. Assuming that (1) a 4 km offshore boom is deployed, (2) a recovery capacity of 950 m³/day of oil exists and (3) low toxicity chemical dispersants are applied during risen seas, then Table 6.1 can be used as a guide to the efficiency of primary clean-up[6.1], in August and September. The efficiencies take into account wave height statistics (Figure 4.20), and the likelihood of iceberg interruptions twice every day.

Collisions between icebergs and booms could be minimized if booms and associated equipment are employed as independent sections within the required 4 km width. Assuming this, the reduction of efficiency due to iceberg interference could be less than that listed in Table 6.1.

The percentage of clean-up effectiveness in August (obtained by summing the products of Columns 6 and 7 in Table 6.1) is 55.9%. Similarly, in September, the effectiveness is 50.1%. Hence, not much more than 50% of the oil could be cleaned-up and chemically dispersed near the blowout site in a typical Lancaster Sound summer, using the best technology available.

It is estimated that, if chemical dispersants are not used, the clean-up effectiveness would reduce to 45% in August and 35% in September.

It is fairly certain that the thin slicks from the blowout could not be burned in place.

6.2.2 Fall: October and November

In the fall, oil slicks from the blowout become increasingly entangled in newly-forming ice and unavailable to containment by booms. Dispersants are ineffective when

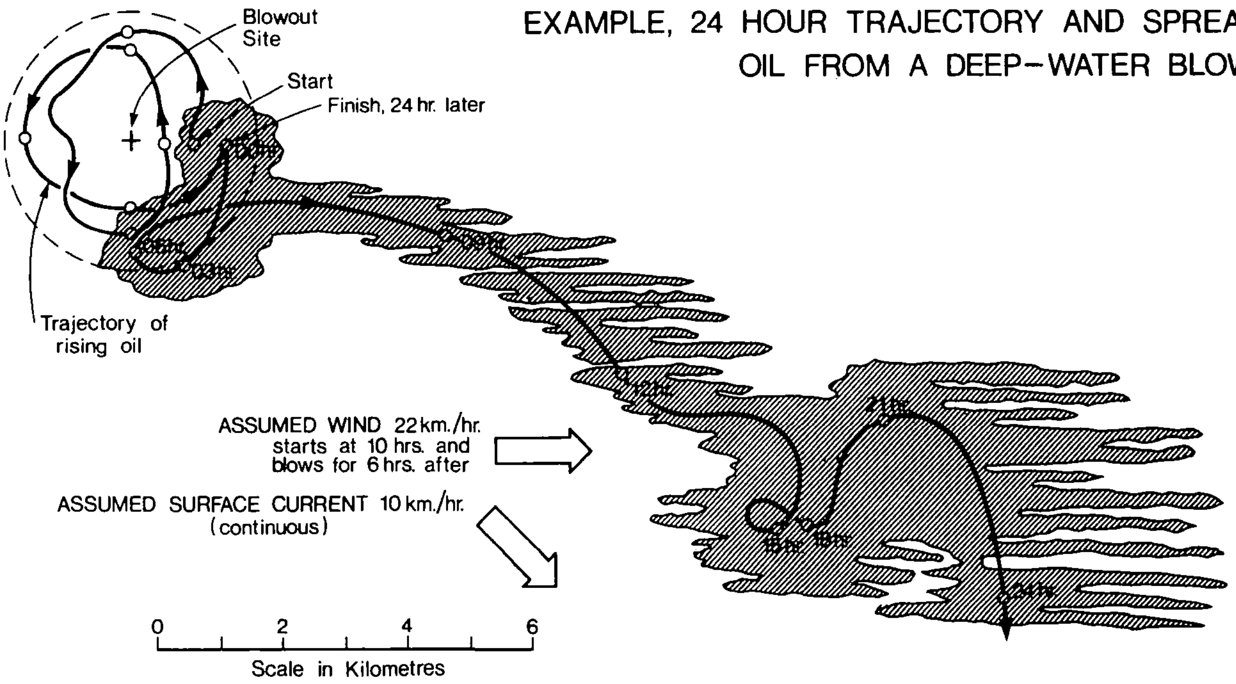
EXAMPLE, 24 HOUR TRAJECTORY AND SPREAD OF OIL FROM A DEEP-WATER BLOWOUT

Figure 6.1

Table 6.1 **Effectiveness of Blowout Site Clean-up — August & September.**

Sea State (1)	Beaufort Scale (2)	Wave Heights (m) (3)	Clean-up Effectiveness (%)			Percentage of Time	
			(4)	(5)	(6)	(7)	(8)
			From ref. 6.1	Effect of Icebergs	Geometric mean of (5)	August	September
Calm	0	< 0.3	80-100	60-75	67.1	43	29
Low	1-3	0.3-1.2	60-80	45-60	52.0	42	40
Medium	4-5	1.2-2.4	40-60	30-45	35.7	13	21
High	6-7	> 2.4	20-40	15-30	21.2	2	10
			Net % Effectiveness :			55.9	50.1

mixing energy from wind waves does not exist; oil would mix with a slurry of ice crystals and pancake ice, inhibiting mechanical mixing by ships' propellers. Open water at the blowout site becomes an increasingly transient feature. New ice, punctuated with icebergs, renders ineffective conventional countermeasures. Oil concentrations are too small to ignite — most being in thin slicks and thinly spread under new ice. Clean-up effectiveness in October and November is close to zero at the blowout site.

6.2.3 Winter: December to the end of April

In winter, no clean-up technology exists to remove oil from under moving sea ice in the small areal concentrations expected (Section 5.2.4). Countermeasure operations can merely mark the ice over the blowout site with homing beacons, at intervals during the winter. Ice containing oil can be examined in the springtime.

6.2.4 Spring: May, June and July

Although clearing of ice from Lancaster Sound can occur in May, access to the blowout site, and elsewhere, depends on where ships, booms and oil-removal and disposal equipment over-winter. Protected harbours, bound by landfast ice, do not break up until late June. Site selection for overwintering ice-breaking vessels and countermeasures equipment should take advantage of shortest possible routes to open water, and earliest possible times for breaking out. This also applies to a drillship which might be engaged in relief well drilling.

Once vessels have broken through the landfast ice in spring, countermeasures effectiveness at the blowout site is comparable to that in summer, except for more frequent ice intrusions from the west. Assuming break-out occurs in mid-June, countermeasures effectiveness at the blowout site is estimated as follows: May, 0%; June, 10%; and July, 40%. If no dispersants are used, these are likely reduced to: May, 0%; June 8%; and July, 32%.

6.2.5 Summary of Countermeasures Effectiveness at the Blowout Site

Estimates in percent effectiveness are summarized for a typical year, as follows:

	August	Sept.	Oct. to May	June	July
Mechanical and Dispersants	56	50	0	10	40
Mechanical alone	45	35	0	8	32

The high effectiveness in the summer months depends critically on the assumed deployment of 4 km of boom, in mobile sections, to allow for frequent ice and iceberg intrusions.

6.3 Coast Protection and Clean up Possibilities

6.3.1 Coast Protection

The shores of eastern Lancaster Sound are exposed to the sea for 4 months of the year, between mid-June and about mid-October, and for less time further west. An ice foot and landfast ice grows out from shore by mid-October; this breaks up or melts in place during the latter half of June. Oil is trapped in this ice as it grows and then released in early summer. Throughout late fall, winter and spring, no oil can drift ashore.

The application of special protection against incoming oil, such as the use of booms or dispersants, raises the question of what is the purpose of the protection. Apart from special wildlife habitat, it is important to protect the lowest energy shores, i.e., the ones least subject to wave action, ice push and alongshore sediment transport. In general, these are within fjords and inlets, and behind barrier beaches. There are few very low energy shores capable of being protected by booms as short as 2.5 km in the region likely to be subjected to oil pollution (Figure 5.9). A major data gap is the examination of locations, if any, suitable for protection.

6.3.2 Estimates of Oil Pollution on Coastlines

Unlike oil from a single large spill, oil from a blowout flows continuously, in variable trajectories, spreading extensively before shores are reached. The possibility of intercepting a significant fraction of the oil is remote, either with offshore mechanical equipment or with chemical dispersants. With this assumption, estimates of oil volumes distributed along ice-free shores can be made. It is also necessary to postulate when the blowout occurs, when it is stopped, and other conditions as follows:

- The oilwell blows on October 1, and is stopped on September 1 of the following year. It flows at a rate of 950 m^3 per day.
- The mechanical clean up capabilities, summarized in sub-section 6.2.5, apply to the blowout site.
- The offshore evaporation, solution and dispersion losses apply, as described in section 5.

Table 6.2 shows that the heaviest shoreline pollution occurs along the north coast of Bylot Island - the equivalent of a ribbon of oil 1 cm thick and 8.0 metres wide. The sum of all the oil on shores from the assumed eleven month blowout is about 5% of the oil volume from the blowout.

The estimates of oil volumes entering Navy Board Inlet depend critically on ocean currents at its northern end (Section 5.2.1).

The disposition of oil on the shores of Eclipse Sound is uncertain. The E-W expanse of its southern shores subject to direct onslaught of southerly-moving oil is about 90 km (however, some oil could be dispersed in Milne Inlet, further south). A large fraction of the oil moves into Eclipse Sound, via Navy Board Inlet, with the ice during break up. A description of how this might occur is found in the Arctic Pilot[6.3] which states: "Eclipse Sound ice breaks up rapidly *in situ* beginning mid-July. This break-up is followed by a later movement of ice southward from Navy Board Inlet, which tends to remain in the west end of Eclipse Sound. Winds and strong currents* drive the melting ice back and forth in western Eclipse Sound, and in and out of Milne Inlet to the south until it all melts." It is likely that oil will coat the shores of western Eclipse Sound and adjoining inlets, as it is progressively freed from melting ice.

6.3.3 The Coasts[6.5]

The persistence of oil on shores depends on the energy available to rework them. Biodegradation, weathering and leaching are hastened within the active zone of shores by tides and waves. Because of the short open-water season and short fetches, most Arctic Island shores exist in a low energy wave environment. The shores of eastern Lancaster Sound, however, are in close proximity to Baffin Bay, where wave fetches and the open water season are longer.

6.3.3.1 Coastal Morphology

The northern coast of Lancaster Sound, formed by Devon Island, is a smooth curve broken by fjords, and bays flanked by coastal cliffs rising to 600 m. The cliffs are

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* An extensive review of the oceanography of Eclipse Sound is given by Barber[6.4].

Table 6.2 Estimates of Oil Pollution Along Shores

Period	Oil escaping clean-up at blowout site †		Oil at various destinations, m^3 ††							
	m^3/day	m^3	Bylot Island North Coast	Bylot Island East Coast	Devon Island Croker Bay Region	Devon Island South Coast	Navy Board Inlet			Eclipse Sound S. Shores
							Trapped in Landfast Ice *	Accumulated at N. ice-edge *	East and West Shores	
1-15 Oct.	950	14,250	1,283 (9%)	713 (5%)	43 (0.3%)	29 (0.2%)	627 (4.4%)			
1-31 May	950	29,450	2,784 (5%)	1,670 (3%)	(0%)	(0%)		2,876 (4.4%)		
1-30 June	874	26,220								
1-15 July	646	9,690	3,262 (9%)	1,812 (5%)	108 (0.3%)	72 (0.2%)				
15-31 July	646	10,336							531 (2%)	266 (1%)
1-31 Aug.	523	16,213					Oil Released from Ice at Break-up: 3,503			
Oil moves south at break-up 50% heads for East and West shores → less 30% dispersion loss →									1,226	
50% travels to South shores of Eclipse Sound → less 50% dispersion loss →										876
SUMS OF VOLUMES ON COASTS, (m^3)			7,329	4,195	151	101			1,757	1,142
Estimated length of coast (km)			90	130	130	130			250	90
1 cm-thick oil-ribbon width (m)			8.1	3.2	0.1	0.07			0.7	1.3

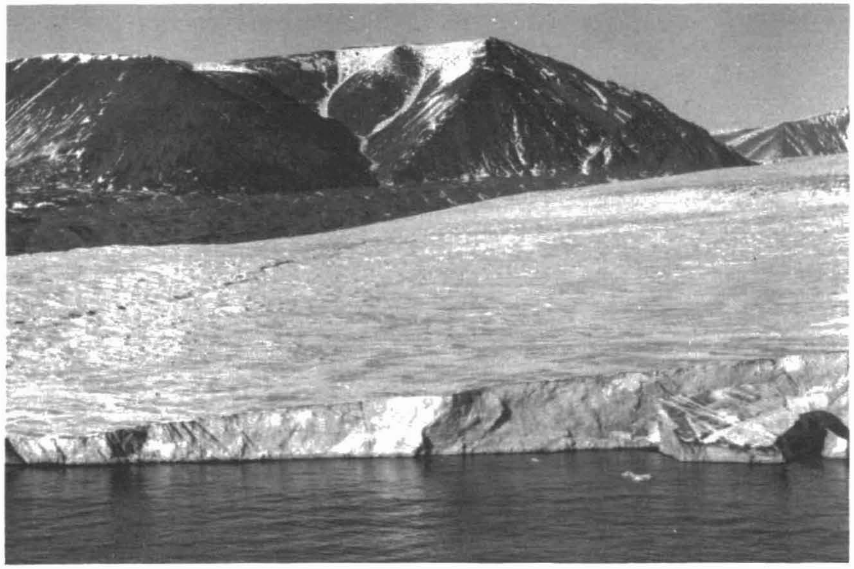
* see sub-section 5.2.3

† see sub-section 6.2.5

†† destinations are shown in Figure 5.9

East of Cunningham Glacier, south Devon Island (photo: B. Smiley)

East of Cunningham Glacier, south Devon Island (photo: B. Smiley)



Cunningham Glacier, south Devon Island (photo: B. Smiley)

Cape Sherard, southeast Devon Island (photo: B. Smiley)

West shore of Croker Bay (photo: B. Smiley)

Croker Bay lowlands (photo: B. Smiley)

East shore of Croker Bay (photo: B. Smiley)

East of Cape Warrender, south Devon Island (photo: B. Smiley) fronted by talus deposits or narrow gravel beaches. At the foot of gentler coastal slopes, there are terraces of raised, gravel beaches. Croker Bay gravel beaches extend as far as 4 km inland, bordering a low coastal plain. Bay-head deltas occur in fjords where glaciers have receded. Tide water glaciers occur, mainly in Croker Bay and to the east (Figure 4.9).

Bylot and Baffin islands form the south shores. Precipitous cliffs, rising to 490 m occur along Brodeur Peninsula, but Borden Peninsula has a lower coast with large deltas and raised beach terraces. Bylot Island's northwest corner is low; however, the rest of its north coast rises sharply to 600 m, and to 1,200 m in places.

Rates of erosion and littoral sediment transport are low, due to coarse sediments and the short summer's wave action. Beach sediments are pebble-to cobble-size along Borden Peninsula, while rocky shores are common along northern Bylot Island.

No succinct description exists of the shores of Navy Board Inlet and western Eclipse Sound; however, a brief review of available photographs indicates the prevalence of shores inaccessible to air-craft – most having pebble and cobble beaches.

6.3.3.2 Coastal Processes

Beaches are not reworked by waves until the landfast ice disappears. The ice foot, a form of landfast ice inshore of tide cracks, builds across beaches within the tidal range. It erodes quickly in spring when confronted with waves. In Lancaster Sound, the melting of landfast ice progresses from east to west, commencing in mid-June. The bays and fjords of southern Devon Island shed their ice with favourable north winds during July. At the end of summer, landfast ice reforms, beginning in September in the bays of western Lancaster Sound, and later, in the east.

Oil can reach the shores only in the short three or four months of summer. This is also the only time that waves can rework the beaches – when offshore storm winds occur. As a result, the extent of beach change varies greatly from one year to the next.

When offshore winds blow, oil could accompany ice floe fragments grounding in shallows. Depending on concentrations of this ice, it severely hampers shoreline oilspill countermeasures (see photographs). Brash ice, accompanying ice floes, is often thrust up beach slopes during onshore storms, and buried by sediments on the upper foreshore or backshore. On melting, these leave beach pits which would be repositories for oil. Oil pushed up slope, beyond normal wave action during storms, weathers and degrades very slowly.

The beaches of Lancaster Sound have a foundation of permafrost which annually thaws less than one metre in depth. In spring, thawing proceeds from backshore, to foreshore, as landfast ice melts and permits waves to wash the beach. In fall, the backshore freezes first, then the lower foreshore. The mobile permafrost prevents oil penetrating more than a metre in summer; however, an oil blackened beach may cause deeper melting. Ground water seepage over the permafrost also spreads oil beneath the beach foreshore, and eventually into the sea. Any oil incorporated into the frozen layer in the fall would be released in the following year.

Oil deposited across a beach can be redeposited and buried when alongshore currents and accompanying glancing wind waves redistribute sediments. Oil is subject to greatest weathering by waves reworking the polluted beaches at mean tide. However this process is inhibited if oil and sediments pave the shores.

Sea ice often damps waves approaching beaches; it can raft onshore to plough beach sediments, causing ice-push ridges. Oiled sediments, pushed to backshores, weather slowly; modest ice-pushes can re-expose oil to weathering on foreshores.

6.3.4 Shoreline Clean up Possibilities

Estimates of oil volumes reaching shorelines (Table 6.2) invoke the image of beaches voraciously sponging up all the oil drifting toward them. Realistically, oil weathers and is remobilized on high energy shores. Some drifts back to sea and some into low energy back-waters and sediment sinks. The extent to which oil drifts seaward again is unknown. Undoubtedly, oil will contaminate quiet bays, lagoons and inlets which serve as important bird and mammal habitats. Such locations should receive high priority in clean-up countermeasures. Detailed inventories of such critical habitats and strategies for appropriate countermeasures are major data gaps.

In general, the morphology of the region severely restricts coastal access, except by sea. In a few locations, access by light aircraft is possible. The effectiveness of beach clean-up operations is likely negligible.

6.4 Slick Tracking

Shoreline countermeasures are enhanced by using oil slick tracking devices, especially when deployed frequently at the blowout site. In eastern Lancaster Sound, it is possible that optimum tracking could be accomplished using floating radar-transponders and a shore-based radar. Although these are useful, horizontal dispersion of the oil would not be accounted for. Airborne remote sensing is a necessary supplement to slick tracking to establish slick dimensions at right angles to a trajectory and depict its fragmentation.

6.5 Summary: Countermeasures to Oil from a Blowout

- Same season relief well drilling, for a median duration open water season of 109 days, will be possible only for relatively shallow wells.
- At the blowout site, countermeasures would be most effective if it is possible to:
  - deploy 4 km of offshore containment boom, comprised of several independent booms, to allow for disruptions by icebergs and ice;
  - remove and dispose of up to 950 m^3 of oil per day;
  - disperse oil that escapes removal.
- At the blowout site, countermeasures effectiveness is expected to increase by the use of dispersants. The maximum effectiveness, by months, is estimated as follows:

  56% in August, 50% in September, 0% in October to May, 10% in June and 40% in July.
- In the open water season, airborne remote sensing is needed to determine the extent of horizontal spreading and fragmentation of oil slicks as an aid to devising strategies for shoreline protection.
- Coasts are exposed to oil pollution for about 4 months.
- The northern coast of Bylot Island will be the most heavily polluted. About 5% of the total volume of oil from the blowout, averaged over 11 months, could reach the coast – assuming optimal countermeasures at the blowout site.
- A major data gap is the absence of an inventory of countermeasure designs needed to protect critical wildlife habitats along coasts.
- Beach clean up efforts are expected to be a logistical nightmare but, if attempted, will be most beneficial within or near critical wildlife habitat associated with very low energy shores.

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7. MARINE PLANTS AND ANIMALS OF LANCASTER SOUND

7.1 Plant Communities

We include a general description of plant communities in Lancaster Sound and other Arctic regions for two reasons. First comparisons of standing crops, biomass and other measures of primary productivity demonstrate that relatively high plant growth is sustained in Lancaster Sound which, in turn, supports a large biomass of zooplankton. For whatever the reasons (nutrient enrichment, current upwellings, extended open water season and so on), Lancaster Sound promotes phytoplankton growth up to ten fold greater than other arctic regions. This food base, in turn, supports fishes, marine birds and mammals, and ultimately man — the Arctic's summit predator. Secondly, the annual primary production is not restricted to offshore waters, and the summer season. For example, in a coastal bay near Resolute, it is estimated that one third of the total plant production is benthic seaweeds; the remainder is planktonic. Offshore, over deeper water, the under-ice algae is roughly equivalent to shallow water benthos in production.[7.1] These three major communities are at risk, locally, in the event of an oil spill.

Few marine plant ecologists express much concern about the effects of oil on total phytoplankton populations; under-ice algae or coastal seaweeds are unlikely threatened with extinction by oil pollution. However, local depletion can occur near the spill source or where the oil eventually concentrates. This is a real concern in the arctic when large numbers of animals depend upon plants which are only briefly available or accessible. This probably occurs at landfast ice and floe edges in spring, for early seabird and marine mammal migrants.

7.1.1 Under-Ice (Epontic) Algae

A feature of arctic (and antarctic) plant communities is the seasonal two month "bloom" of algae on the underbelly of sea ice. This diatom-dominated community blooms briefly, commencing in late April and peaking in mid-June.[7.2] This occurs just prior to and during spring breakup and snow melt in most arctic regions. A month later, only remnants of this plant community persist in the plankton. The diatoms are, of necessity, "shade tolerant", that is they can grow and flourish under low light intensities. For example, under the ice and snow of McMurdo Sound in the Antarctic, ice flora is capable of about 20% of its full photosynthetic potential when the mean light intensity is only 10 foot candles.[7.3]

This "shade" community is comprised mainly of pennate (spindle or rod shaped) diatoms which find the microhabitat of the under-ice crystals suitable for colonization. Diatoms genera often collected from ice cores are *Nitzshia, Thalassiosira, Fragilariopsis, Achnanthes, Navicula and Pleurosigma* [7.4 to 7.8]. Together, the algaes' chloroplasts colour the bottom 30 cm thickness of the ice a brown yellow. Algae growth is usually most concentrated in the lowest 3 to 4 cm. In Austin Channel and Barrow Strait, the epontic standing crop has been measured at 789 x 10^5 cells per litre of melted sea-ice water.[7.9] Compare this value to the high planktonic standing crop of 22.8 x 10^5 cells per litre in the open water of Lancaster Sound. In terms of arctic marine plant biomass, the "shade" flora contributes from 3 to 23 mg/m^2 of chlorophyll - a (a standard measure of plant growth); the higher values were measured in early May from Resolute Bay and Barrow Strait.[7.1] Volumetrically, this biomass is greater than that measured during rich coastal algae blooms in temperate oceans.

There is virtually no information on the ice flora of Lancaster Sound and adjacent inlets. The above generalizations, based on studies of nearby Jones Sound and Barrow Strait, serve to highlight the significance of this plant community to the total primary production of Arctic waters. Only by inference is Lancaster Sound judged as typical.

The relationship between ice flora and the spring phytoplankton developing under ice infested waters, is disputed among biologists. Some claim that the release of the ice diatoms during ice melt actually "seeds" or triggers the phytoplankton bloom.[7.10] Others[7.11] argue that differences in the composition of the two plant communities, and the time-lag between the blooms, negate this hypothesis.

The ice community of diatoms, dinoflagellates, flagellates, ciliates, heliozoans, nematodes, polychaete larvae, copepodes, amphipods, and fishes is of major ecological significance. Ice algae is food for large grazing amphipods [7.12], which, in turn, are easy prey for Arctic Cod *(Boreogadus saida),* the most common fish in Canadian Arctic waters.

7.1.2 Benthic Seaweeds

In Lancaster Sound and most Arctic Canada regions, the distribution and abundance of benthic seaweed communities is not known. However, some aspects of the general ecology of benthic flora[7.13] are summarized below:

1. High Arctic seaweeds comprise relatively few species, about 150 from west Greenland, Baffin, Devon and Ellesmere islands, compared with 571 in Canadian Maritime waters and 400 species in New England waters.
2. One half of the seaweeds are brown algae (Phaeophycea).
3. Less than 1% of Arctic marine flora are endemic. Most are northern extensions of North Atlantic marine flora.
4. Annual species comprise about one third of the seaweeds (45-49 annuals to 109-113 perennials). Most annuals are brown algaes (31 species).
5. Most annuals are found in the upper sublittoral zone, and on the shore, partly because of warmer water temperatures during the peak of the Arctic growing season.
6. Many annual algaes tend to perenniate in the Arctic. Several shore "annuals" overwinter as frozen unicells, filaments or cell aggregates in the littoral ice cover.
7. Arctic seaweeds grow to greater depths than in southern waters. Most grow below 10 metres and a large number of species grow below 30 metres.

Some evidence suggests that benthic algae is more plentiful in eastern Parry Channel (Lancaster Sound) than in waters to the west.[7.14] Dense beds of macrophytes (kelps) are common but restricted to locales of shallow water and boulder-cobble substrates. Although benthic seaweeds may not contribute significantly to total primary production, they do enhance and diversify the region's local ecology by offering food and shelter to marine invertebrates and fishes. We must assume that such benthic seaweed communities exist along the Sound's irregular coastlines, especially where the shore is rocky and moderately-exposed to wind and waves.

Arctic seaweeds grow in characteristic bands or zones, as dictated by waves, currents, salinity, light and so on. The nature of seaweed communities changes dramatically between high tide levels and 100 metre depths. The following description emphasizes such trends, with special reference to a typical rocky, moderately-exposed shore environment in arctic marine waters.[7.13]

Shoreline and sub-tidal communities are at risk in the event of oil pollution. The north coast of Bylot Island and shores of Navy Board Inlet are destinies of floating oil slicks from an offshore blowout in eastern Lancaster Sound. The extent of seaweed communities at these locales is unknown.

7.1.2.1 Intertidal Algae

The High Arctic, having less than 50 species of littoral (intertidal) flora, is impoverished relative to Canadian Maritime waters of almost 3 times this diversity. The ice cover and abrasion of intertidal ice contributes to this unimpressive littoral growth. Few of the conspicuous thalloid perennial seaweeds of North Atlantic shores can survive this abuse. The few that do (such as *Fucus distichus)* are dwarfed and grow in the protection of rock crevices and sheltered depressions. The upper shore community is distinct and predictable. The *Blidingia-Calothrix* zone covers the upper few centimetres of shore, just below high tide (Figure 7.1). The two species, after which the zone is named, give the substrate a green-black colour. Annual species appear here in mid-July, and peak in growth in August and early September. These are not restricted to protected rocks and crevices and briefly populate most exposed surfaces at their peak of development.

Crust algae, as a group, straddle the littoral and sublittoral (below tide level) habitats, and are the most primitive of the Arctic algal community. The crusts are perennial plants which form a "skin" over the rocks and shells, even on the *Fucus* kelp holdfasts. This ubiquitous trait makes them important primary producers for grazing benthic animals. Of the 23 species found in Arctic waters, 4 to 5 are calcareous crusts.

MARINE SEAWEEDS OF AN ARCTIC ROCKY COASTLINE

(from Wilce, 1973)

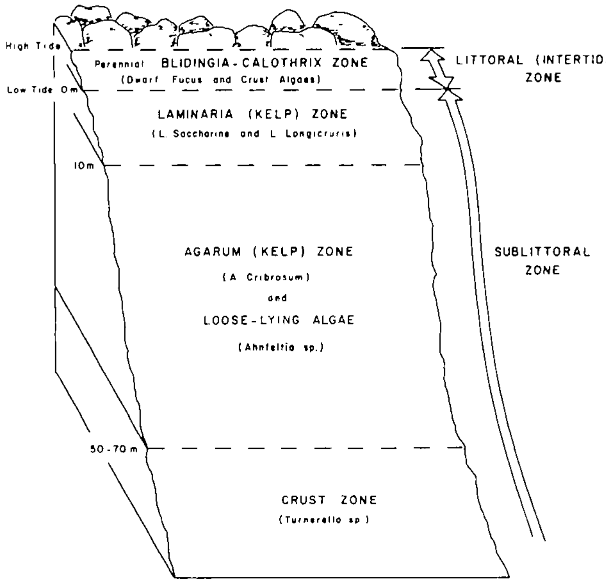


Figure 7.1

7.1.2.2 Sublittoral seaweeds

The sublittoral flora is more luxuriant and more diverse than its counterpart on shore. About 126 Arctic species are known but are still not as numerous as North Atlantic species to the south. In contrast to littoral community, perennial seaweeds dominate annuals. Arctic sublittoral vegetation appears as a broken and unpredictable belt of vegetation – possibly a function of unstable substrate. For example, a fully developed sublittoral community can grow beside a nearly or completely uncolonized rock at the same depth, and exist under seemingly the same conditions. The size and species diversity of seaweed patches varies considerably, making post-oil spill impact assessment and monitoring an impossible task – even assuming precise baseline studies are made of Arctic seashores.

Extending about one metre below low water is the sublittoral *Barren Zone.* The uniform barrenness of this zone makes it a characteristic feature of rocky coasts throughout the Arctic archipelago. In the words of Wilce (1973),[7.13] "I have searched scrapings from the crevices of this inhospitable zone without finding evidence of even microscopic algae of animal life." Continuous ice scouring and salinity fluctuations are the major life inhibiting factors. In Canadian Maritime regions, the first metre of the sublittoral zone is often the most populated.

The uppermost vegetated zone in the Arctic sublittoral is called the *Laminaria Zone.* Two kelps *(Laminaria saccharine, Agarum cribrosum)* appear abruptly at about 2 metres below low tide level. These are dwarfish with stout robust holdfasts, short stipes, and short firm blades – all good adaptations to wave surges. Another *Laminaria* species, *L. longicruris,* predominates down to waters 10 metres deep, the lower limit of the zone. The more or less rigid hollow stipes of this species forms a "jungle" 3 to 5 metres high, from which 7 to 9 metre blades drift overhead, each about 1 metre broad. In North Atlantic waters, the *Laminaria Zone* provides the bulk of seaweed biomass. In contrast, the Arctic zone is discontinuous and patchy and even locally absent, possibly from causes such as: a scarcity of nutrients, low resistance of the substrate rocks to erosion and weathering, unfavourable forms of rocks, low illumination and low salinity water.[7.13]

Like a hardwood forest, the *Laminaria Zone* comprises distinct storeys. These are a kelp canopy (mentioned above), bushy-leafy under-storey and, on the bottom, a crustose basal stratum. The bushy under-storey is typified by 30 to 37 species of perennial seaweeds. The diversity, and biomass as well, is about half of that expected in non-arctic regions. Nonetheless, in the Arctic, this is the vegetation zone approximating the colourful, luxuriant and ecologically complex sublittoral vegetation of the Canadian Maritimes, where less severe conditions permit plants to reach normal sizes. The crust algae grow at the "feet" of this perennial community, covering exposed substrate and the kelps themselves. The brown crust species outnumber the red crusts but the red crusts actually cover more of the seabottom. Where the kelp canopy and bushy under-storey are thinnest, the crusts are most intensively colonized. Conspicuous crust algaes are the generas *Ulothrix, Pseudolithoderma, Ralfsia* (the browns), *Lithothamnion, Leptophytum, Cruoria* and *Hildenbrandia* (the reds).[7.13]

The *Agarum Zone* (named after the dominant kelp *A. cribrosum)* extends downward, from about 10 metres to 50-70 metres, depending on locale. This zone is relatively stable ecologically, except for changes due to seasonal light fluctuations. Temperature is nearly constant, and salinity changes are minor. Ice scouring is minimal, leaving large areas of rock untouched by ice and suitable for perennial seaweed colonization. The community structure of 48 species is similar to the *Laminaria Zone* but vegetation is far less abundant. The under-storey seaweeds are more prevalent than kelp. A feature of the arctic *Agarum Zone* is *loose-lying algae,* most often encountered along moderately exposed coasts, deep bays and fjords. These populations of one or mixed species grow unattached to the sea bottom but are, nevertheless, permanent residents. They simply require shelter where water movement is minimal; the type of substrate is not critical. These beds of unattached plants can be extensive, up to 50 m square and 1 m thick. Where water movements are variable, loose lying algae grows sparsely among the attached kelp beds.[7.13]

The *Crust Zone* is the region of Arctic sea bottom below 50-70 metres, where only the hardiest crust algae and upright species can survive. Although these water depths provide the most uniform, stable, physical environment, low illumination severely limits plant growth. Only the crustose basal stratum is present; included, are members of the under-storey, growing to heights of 1 cm or less.

7.1.3 Planktonic Algae

The abundance and distribution of phytoplankton in Lancaster Sound were measured by Sekerak et al (1976b)[7.4] from late July to mid-September, 1976. Although their findings show great variability, both geographically and seasonally, several trends and generalizations are possible concerning the Sound's phytoplankton ecology. The following description relies heavily on their findings.

Beginning in late spring or early summer, the spring "shade" flora is replaced by an open water flora primarily composed of diatom algaes[7.15 to 7.19].

The maximum summer bloom, as shown by chlorophyll concentrations, occurs in early July, at least in Jones Sound when the sea is still ice infested[7.20]. The behaviour of the phytoplankton community in Lancaster Sound is probably similar. Three-quarters of the 125 recorded species are diatoms; the remainder are chrysophytes (14%), microflagellates (9%), and dinoflagellates (2%), with negligible numbers of chlorophytes. This composition is typically arctic. Figure 7.2 shows that diatoms dominate throughout the summer, and at all depths. Other trends occur: diatoms are proportionately most abundant at depths of 25 m, or so, possibly because of their intolerance to low salinity surface waters. In contrast, brown algaes (predominantly *Dinobryon balticum,* an euryhaline species) are most numberous in the Sound's uppermost 10 metres[7.4].

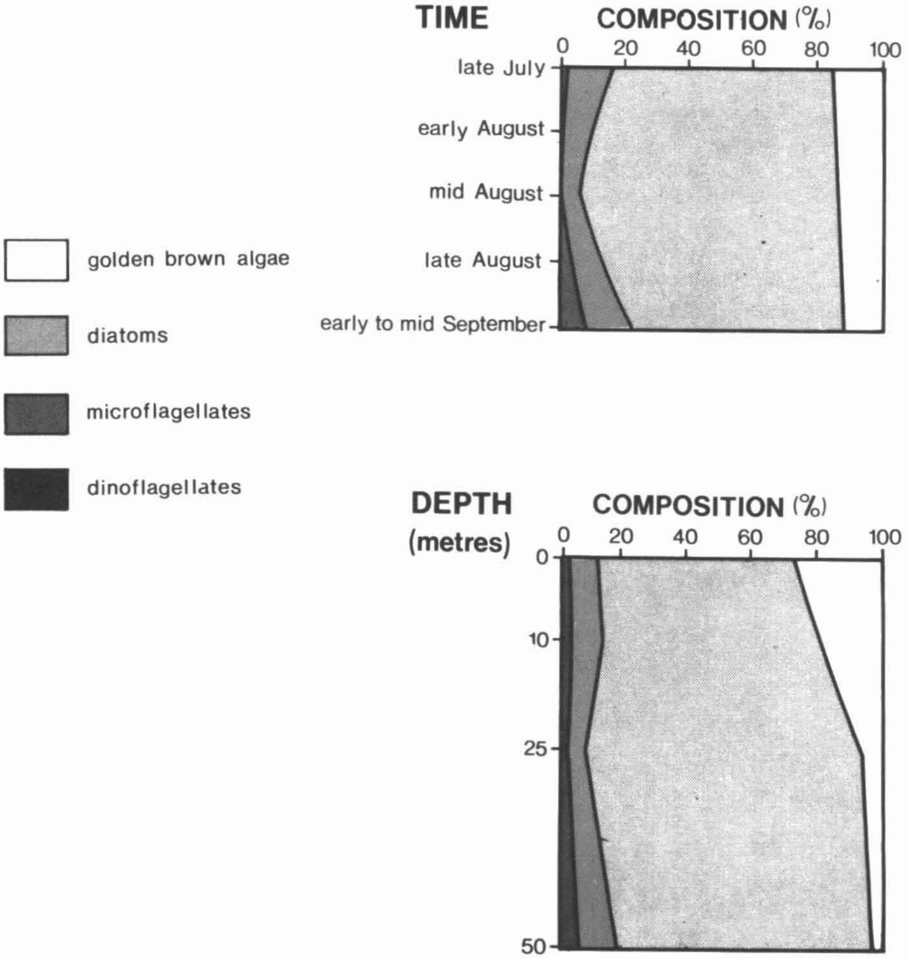


Figure 7.2 Composition of the Phytoplankton Community in Lancaster Sound varied with time and depth. (from Sekerak et al, 1976b).

The phytoplankton standing crop, expressed as total cell counts per litre of seawater, is very high in the upper 25 metres of Lancaster Sound (Table 7.2 and Figure 7.3). At the surface, the average cell count of 22.8 x 10^5 cells/litre is greater by one order of magnitude than in most other High Arctic regions (Table 7.1). Variable temperatures and salinities in the top 5 metres tend to discourage plant growth, to some degree. Below 50 m depths, low illumination prohibits significant plant development[7.2].

The standing crop generally declines through late July to September (Table 7.3 and Figure 7.4), primarily due to the gradual disappearance of a single diatom species *Chaetoceros socialis.* The standing crop also generally decreases from east to west through Lancaster Sound. In 1976, the phytoplankton standing crop measured at eastern mid-Lancaster Sound and Cape Warrender was highest compared to those at stations further west when averaged for all periods and depths[7.4]. Nutrient enrichment from nearby glaciers and ocean mixing are possible reasons for the enhanced plant growth.

As previously mentioned, the Sound's water supports about 125 species of phytoplankton. This compares closely to the diversity of Foxe Basin (121 species) but contrasts with "richer" areas such as Hudson and James bays (235 and 202 species, respectively) or sparser regions, such as the Beaufort Sea (87 species)[7.2, 7.18, 7.19].

The diatom *Chaetocerus socialis* accounts for over 50% of the standing crop. A massive bloom occurs in late July and early August; concentrations of over 100 x 10^5 cells/litre are common in the surface waters. Despite the plant's small size, it is a large contributor to phytoplankton biomass. Other important diatoms are two *Thalassiosira spp.;* although not as numerous as *C. socialis,* they are much larger in size and contribute significantly to total plant biomass[7.4].

A common method used to estimate plant biomass is the measurement of plant pigments, in particular, chlorophyll-a concentrations. This technique has limitations, rendering chlorophyll-a figures most useful for comparing the "richness" of different seas. In Lancaster Sound, the surface

Table 7.1 Comparison of Phytoplankton Standing Crop (expressed as average total cell counts) in surface waters of Lancaster Sound, and other Arctic waters (modified from Sekerak et al, 1976b)[7.4]

Location	Mean Cell Count (# of cells x 10^5/l)	Reference
Lancaster Sound (eastern)	22.8	Sekerak et al, 1976b[7.4]
Igloolik (N. Foxe Basin)	4.1	Bursa, 1961a[7.21]
Suglik (Ungava Peninsula)	2.0	Bursa, 1971b[7.16]
Point Barrow, Alaska	4.2	Bursa, 1963[7.22]
Faroe Isles	3.9	Steeman-Nielsen, 1935[7.23]
Cape Farewell, Greenland	3.9	Steeman-Nielsen, 1935[7.23]
Iceland (south coast)	9.1	Steeman-Nielsen, 1935[7.23]
Creswell Bay (Somerset I.)	3.5	Sekerak et al, 1976a[7.24]
Cunningham Inlet (Somerset I.)	7.9	Thompson et al, 1975[7.9]
Assistance Bay (Cornwallis I)	10.0	Sekerak et al, 1976a[7.24]
Frobisher Bay (SE Devon I)	13.7	Bursa, 1961a[7.21]

Table 7.2 Phytoplankton Standing Crop (expressed as average total cell counts) varied with *depth* in Lancaster Sound, July 22 to September 13, 1976 (from Sekerak et al, 1976b)[7.4].

Depth (m)	Mean Cell Count (No. of cells x 10^5 per litre)	Range (No. of cells x 10^5/litre)
0	22.8	10.3 - 38.7
10	26.8	8.3 - 51.2
25	24.8	14.1 - 37.8
50	5.8	3.0 - 10.8

Table 7.3 Phytoplankton Standing Crop (expressed as average total cell counts), varied with *time,* in Lancaster Sound, 1976 (from Sekerak et al, 1976b)[7.4].

Period	Mean Cell Count (No. of cells x 10^5 per litre)	Range (No. of cells x 10^5/litre)
July 22-28	30.6	6.5 - 94.0
Aug. 3-8	29.4	10.4 - 74.3
Aug. 16-22	14.7	7.5 - 28.3
Aug. 27 - Sept. 1	16.4	2.9 - 30.8
Sept. 7-13	10.8	1.9 - 33.9

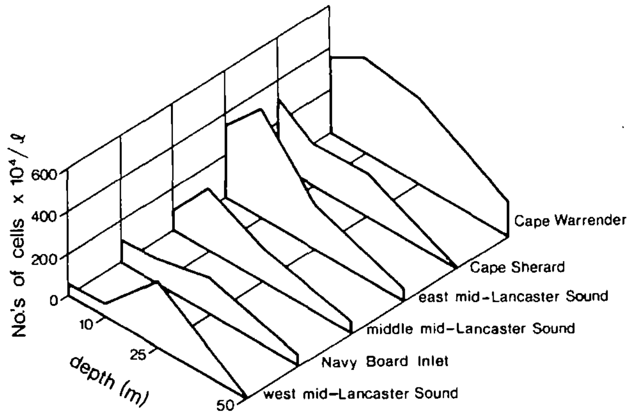


Figure 7.3 Phytoplankton Standing Crop (expressed as total cell counts) varied with *depth and location* in Lancaster Sound, July 22 to September 13, 1976 (from Sekerak et al, 1976b)[7.4].

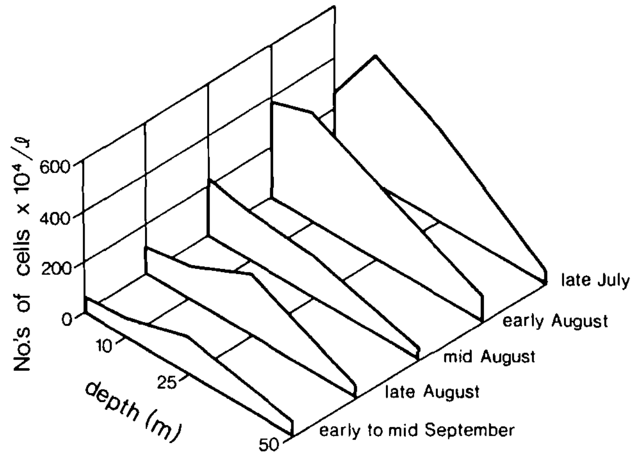


Figure 7.4 Phytoplankton Standing Crop (expressed as total cell counts) varied with *time and depth* in Lancaster Sound, 1976. (from Sekerak et al, 1976b)[7.4].

waters exhibit average chlorophyll-a concentrations of 1.23 mg/m^3; but range as high as 5.61 mg/m^3 [7.4]. Figure 7.5 shows a close relationship between the phytoplankton standing crop and biomass estimates (using plant pigment concentration). Because of small sample size and their variability, these data simply suggest that Lancaster Sound is relatively productive. The above cited biomass estimates were measured several weeks after the predicted peak of phytoplankton growth. The reader should keep this in mind when comparing other biomass estimates in Table 7.4.

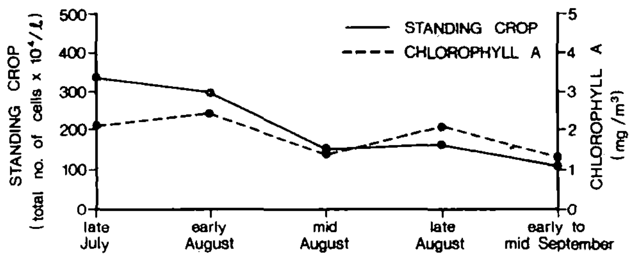


Figure 7.5 (from Sekerak et al, 1976b)[7.4].

Table 7.4 Comparison of Phytoplankton Biomass (expressed as plant pigment concentrations) in surface waters of Lancaster Sound and other Arctic regions (Modified from Sekerak et al, 1976)[7.4]

Location	Chlorophyll-a concentration (mg/m^3)	Reference
Lancaster Sound	0.14 - 5.16 (x = 1.23)	Sekerak et al, 1976b[7.4]
Prudhoe Bay, Alaska	0.10	Horner et al, 1974[7.6]
Western Bering Sea	0.62	Motoda & Minoda 1974[7.25]
Bristol Bay, Alaska	2.49	Motoda & Minoda 1974[7.25]
Antarctic (Atlantic)	0.01 - 118.35	El-Sayed, 1971[7.26]
Antarctic (Pacific)	0.01 - 5.80	El-Sayed, 1971[7.26]
High Arctic Ocean	1.00 - 2.20	English, 1967[7.27]
Frobisher Bay (SE Baffin I)	0.17 - 0.35	Grainger, 1971[7.28]
Wellington Channel	0.04 - 9.51	Bain et al, 1977[7.5]
Resolute Passage	0.13 - 0.34	Bain et al, 1977[7.5]
Allen Bay (Cornwallis I)	0.00 - 5.45	Apollonio, 1956[7.29]

7.2 Animal Communities

7.2.1 Zoobenthos

Zoobenthos are those marine invertebrates that live in and on the sea-bottom, whether permanently or temporarily. Some zoobenthos, called infauna, are burrowing and digging forms that inhabit the upper surface-layers of mud and sand; clams and polychaete worms are examples of these. Others are categorized as epifauna and include bottom-dwelling, slow-moving crawlers, such as sea stars, sea urchins, amphipods, snails and sea cucumbers; or sedentary forms, such as barnacles, corals, some polychaete worms, sponges and sea anemones. Some epifaunal animals are very mobile, such as amphipods, mysids and shrimps.

Zoobenthos are the most diverse animal community in the Arctic, in terms of different species, different feeding habits and variable habitat requirements. About 250 to 300 species of benthic invertebrates are known in Arctic Canada's marine waters[7.137]. Although the taxonomy and distribution of major arctic zoobenthic groups are fairly well known, little quantitative information (numbers and standing crop) is available for arctic benthic communities, including those of Lancaster Sound. Benthic studies by Ellis (1960)[7.132] and Ellis and Wilce (1961)[7.133] in Pond Inlet and Arctic Bay are the most relevant for this region, and much of the following description is based on these studies.

Polychaetes, comprising bristle-worms, tube-worms and fan-worms, are the most ubiquitous and diverse benthic group, and are represented by about 140 species. Greatest numbers of polychaete worms are often found in shallow waters where organic detritus and seaweeds are abundant. These worms are usually included in the diets of most benthic-feeding birds, mammals and fishes. However, they contribute relatively little to total zoobenthos biomass (less than 20% in north Baffin Island waters)[7.132], and to their predators' energy requirements.

Arctic marine molluscs produce most of the zoobenthos biomass. Lamellibranchs (mussels, and clams with bivalve shells) comprise up to 60 to 80% of the total standing crop in north Baffin shallow-water communities[7.132]. Over 100 species of bivalves, snails, chitons and scaphopods (elephant's tusk shells) are known in Arctic Canada waters [7.134]. Most are tolerant of fluctuating salinities and temperatures and, therefore, exhibit a wide distribution. About 90% of clams and mussels are sedimentation feeders[7.135], whereas over 50% of chitons, scaphopods and gastropods are carnivorous[7.136]. In turn, molluscs, such as *Mya truncata*, are important food for Walruses and Bearded Seals[7.115, 7.116, 7.128] and, to a lesser degree, for sea stars, crabs, cod and sculpins.

About 100 species of echinoderms (sea urchins, sea cucumbers, sea stars, brittle stars and feather stars) are recorded in northern Canada from Labrador to the Alaskan border[7.137]. Along north Baffin Island[7.132], they provide 10 to 20% of the standing crop of shallow-water benthos. Brittle stars, such as *Ophiocten sericeum*, are often numbered in tens to hundreds/m². In Barrow Strait and Peel Sound, 14 species of echinoderms represented over 20% of the organisms counted within one square metre of substrate[7.24]. Since few birds or mammals appear to prey on echinoderms, their food value is obscure.

Crustaceans, such as amphipods and shrimp, comprise a small but important component of shallow-water arctic benthos. Less than 10% of benthic biomass was contributed by crustaceans in Pond Inlet and Arctic Bay, according to 1954-55 studies[7.132]. In contrast, recent data from Creswell Bay (Somerset Island) revealed that amphipods and other crustaceans abounded - up to 220 animals/m² - or about 25% of the shallow-water zoobenthos standing crop[7.24]. This is an important food source for Arctic Char, seabirds and White Whales.

The distribution and abundance of benthic invertebrates are determined, in part, by water depth. The standing crop of infauna in Pond Inlet and Arctic Bay increases with depth, ranging from 30g/m² in waters of depth 0 to 3 m, to 440g/m² in depths of 5 to 47 m, on sandy-mud bottoms [7.132]. The relative barrenness of the intertidal zone is caused by freezing, scouring by ice, heavy wave action and low salinity melt-water. Only the mobile epibenthos, such as mysids and amphipods, can briefly thrive here, being capable of retreating to deeper water when necessary. Below the intertidal zone, to depths of 20 metres, the shallow-water benthic community is often dominated by the bivalve *Macoma;* in localized areas such as at river mouths, other molluscs *Astarte spp., Portlandia arctica* and *Gomphina fluctuosa,* exist as distinct communities. However, densely populated *Macoma* communities are very widespread in arctic North America and are considered typical of regions such as Lancaster Sound. With increasing depth, below 20 to 50 m, the zoobenthos gradually changes composition to a forminifera-dominated community, named after the abundant lime-shelled protozoans[7.132, 7.133].

Benthic communities are seldom scattered uniformly over the seabottom, due to animal associations with different substrate types. For example, a rocky bottom is unsuitable for burrowing worms and clams but offers a stable surface for the firm attachment of sea anemones and barnacles. In Pond Inlet and Arctic Bay, below the barren uppermost 5 metres, densities range from 990 animals/m², on muddy bottoms, to 1800 animals/m², on sandy-mud substrates. The measured biomass also exhibits this trend, varying from 200g/m² to 440g/m², respectively[7.132]. Comparable values are suspected, but unproven, for Lancaster Sound.

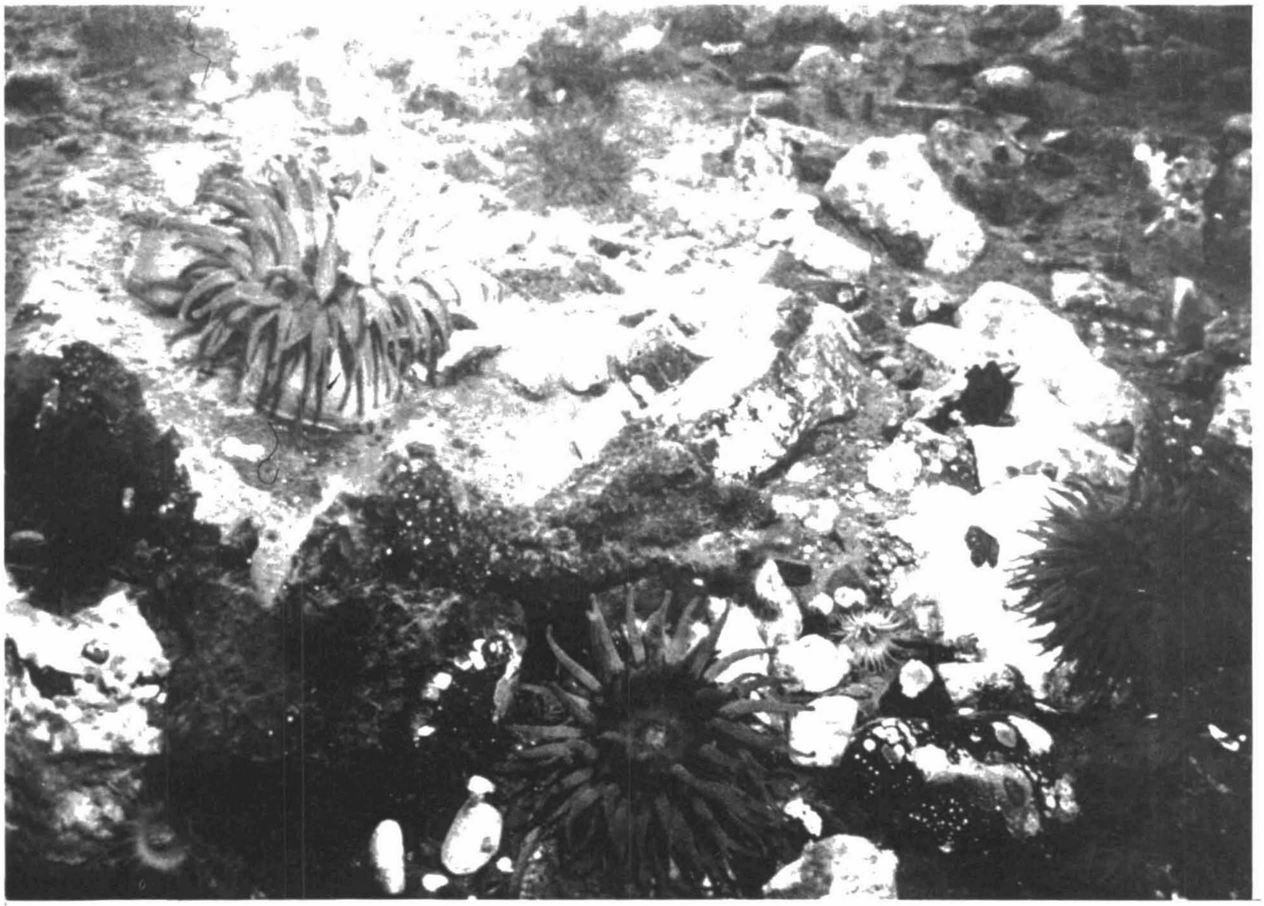
These estimates of arctic zoobenthos biomass are similar, if not greater than those of warmer, temperate waters. However, this does not imply a higher rate of production. In general, arctic zoobenthos grow slower, attain sexual maturity later and live longer than their southern counterparts. Predation is low, as evidenced by the paucity of predacious polychaete worms, snails and sea stars. The annual turnover of zoobenthos is probably less than the standing crop measured at any one time. In warmer regions, the annual production may be 2 to 5 times greater than the standing crop[7.132]. Few benthic animals produce pelagic larvae, and therefore their dispersal to new areas is very slow. Together, these characteristics ensure that re-establishment of an arctic benthic community, from a damaged state, can take many years. If coastal bottom sediments of bays and lagoons become oil polluted, the slow recuperative powers of zoobenthos will be limited still further.

7.2.2 Epontic (Under-ice) Invertebrates

A relatively complex community of invertebrates thrives by 'grazing' on the dense layer of diatom algae which grows seasonally beneath arctic sea ice (section 7.1.1). Ice algae contributes significantly to the Arctic's primary production[7.1], and offers a concentrated food source for protozoans (flagellates, ciliates, heliozoans), nematodes (round worms), polychaete worms, copepods and amphipods[7.9, 7.12]. Qualitative evidence of this arctic grazing community is scanty and cursory, often based on incidental observations by SCUBA divers under landfast ice and along channel ice-edges. Systematic measurements of abundance and distribution are lacking for most arctic regions, including Lancaster Sound. Of necessity, the following description is brief and general.

The under-ice environment is like an 'inverted' seabottom which attracts typically-benthic organisms - sometimes in large numbers. Amphipods *Anonyx* and *Onisimus spp.* are reported in contact with the ice-underbelly, in dense swarms of hundreds to thousands per square metre[7.43]. Other amphipods *Gammaracanthus spp.* are occasionally associated with ice stalactites and small holes in the ice[7.12].

In turn, several groups of epontic invertebrates are very important food for fishes, seabirds and marine mammals. Small numbers of 12 to 14 cm long Arctic Cod are usually observed under the sea ice by SCUBA divers[7.12]; presumably these fish are feeding on amphipods hidden among the ice crystals, grazing on ice algae or scavenging on detritus. In spring and early summer, large numbers of Thick-billed Murres, Black Guillemots and Common Eiders concentrate to feed along ice-edges of Wellington Channel and Resolute Passage[7.138]. In fact, seabird densities are 5 to 10 times greater (and sometimes up to 300 times greater) along these ice-edges than in adjacent open seas[7.139]. This affinity for landfast and floe ice-edges is probably related to their under-ice diving and foraging habits on Arctic Cod and amphipods[7.140]. Similarly, Narwhals are closely associated with spring sea-ice in Pond Inlet and Eclipse Sound; their



Sublittoral Benthic Invertebrates in Strathcona Sound, north Baffin Island (photo: N. Snow) diving behaviour suggests that they are actively foraging, in part, on epontic Arctic Cod[7.99, 7.103].

Local extinction of epontic organisms could occur in oil-polluted, landfast ice and along ice-edges in Lancaster Sound. The ecological significance of this threat may be serious, especially if amphipods and Arctic Cod actively concentrate at ice-edges, and if the seasonal trophic value of these organisms is critical to the maintenance and reproduction of seabirds, White Whales, Narwhals and Ringed Seals. This has yet to be determined.

7.2.3 Zooplankton

Most published literature about zooplankton of Lancaster Sound emphasizes the animals' taxonomy and distribution. Exceptions are studies of the arrow-worms breeding cycle[7.30], the value of amphipods as seal food[7.31], the development rates of copepods[7.32], and measurements of zooplankton biomass and abundance[7.4].

The upper 250 metres or so of Lancaster Sound and adjacent water masses probably support zooplankton of strictly Arctic origin, having, characteristically, few animal species in large number. For example, 72 to 90% of the total zooplankton biomass in Lancaster Sound is represented by a single copepod genera[7.4]. In waters deeper than 250 m, zooplankton populations of Atlantic origin may intrude from Baffin Bay and comprise more species but fewer individuals. This deep water community has not been studied in Lancaster Sound.

Average zooplankton numbers are estimated at about 1,100 animals per cubic metre of seawater, but range as high as 3,700/m^3 at the north entrance to Navy Board Inlet. These values are similar to those recorded in other Arctic regions, (Table 7.5). Some variability is a function of different sampling techniques.

Zooplankton biomass, in Lancaster Sound, is relatively high for arctic waters (Table 7.6). Biomass estimates range from 59 to 696 mg/m^3, averaging about 230 mg/m^3. Highest zooplankton biomasses are recorded at Cape Warrender and in Navy Board Inlet. Biomass tends to diminish between July and September, although a midsummer peak is observed at some stations in the Sound (Figure 7.6).

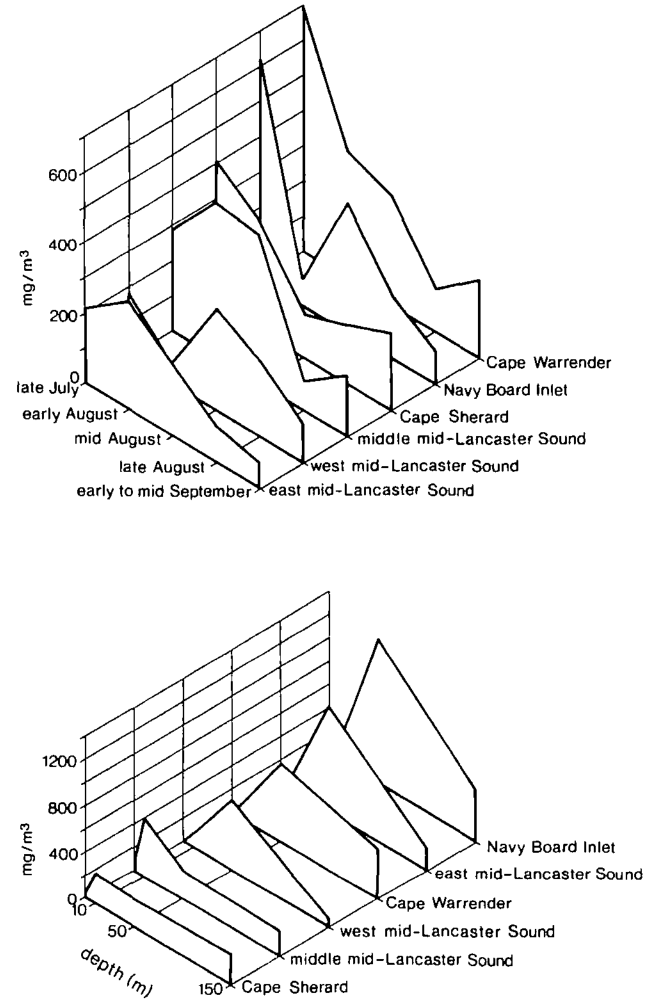


Figure 7.6 Zooplankton biomass (expressed in mg/m^3) varied with *location, depth and time* in Lancaster Sound, July 22 to September 13, 1976. (from Sekerak et al, 1976b)[7.4].

Table 7.5 Comparison of Zooplankton Standing Crop in the Surface Waters of Lancaster Sound and other Arctic Regions. (modified from Sekerak et al, 1976b)[7.4]

Location	Depth (m)	Net Mesh Size (um)	Time of Year	Nos./m^3		Reference
				Average	Maximum	
Frobisher Bay (Baffin Island)	0 - 50	73	July, August & Sept.	–	15,000	Grainger, 1971
Assistance Bay	0 - 50	233	July & August	3,405	11,577	Mohammed and
(Cornwallis Island)	0 - 50	233	July & August	3,405	11,577	Grainger, 1974
Slidre Fjord (Ellesmere Island)	0 - 50	233	July & August	477	719	Mohammed and Grainger, 1974
Creswell Bay (Somerset Island)	0 - 43	233	July & August	666	1,322	Mohammed and Grainger, 1974
Lancaster Sound :						
Cape Warrender	0 - 150	239	July, August & Sept.	1,286	2,571	Sekerak et al, 1976b
Cape Sherard				746	1,459	
East mid-Sound				652	1,516	
Middle mid-Sound				1,304	1,850	
Navy Board Inlet				2,483	3,733	
West mid-Sound				1,306	2,038	

Table 7.6 Comparison of Zooplankton Biomass in the Surface Waters of Lancaster Sound and other Arctic Regions. (modified from Sekerak et al, 1976b) [7.4]

Area	Depth (m)	Season	Biomass (mg/m^3)	Reference
Bering Sea	0 - 800	Summer	180 - 840	Motoda and Minoda, 1974
N.W. Atlantic Ocean (coast)	0 - 400	Summer	840	Riley and Gorgy, 1948
Frobisher Bay (Baffin Island)	0 - 50	Summer	160 - 330	Grainger, 1971
Foxe Basin	0 - 50	Summer	29 - 61	Grainger, 1962
S.W. Foxe Basin	0 - 100	Summer	55	Grainger, 1962
Assistance Bay (Cornwallis Is.)	0 - 50	July - Aug.	80	Mohammed and Grainger, 1974
Slidre Fjord (Ellesmere Isl.)	0 - 50	July - Aug.	84	Mohammed and Grainger, 1974
Creswell Bay (Somerset Is.)	0 - 40	July - Aug.	192	Mohammed and Grainger, 1974
Lancaster Sound:	0 - 150	July - Sept.	247 (79-696)	Sekerak et al, 1976b
Cape Warrender			240 (121-696)	
Cape Sherard			246 (164-406)	
East mid-Sound			181 (79-306)	
Middle mid-Sound			284 (84-446)	
Navy Board Inlet			263 (92-612)	
West mid-Sound			171 (59-293)	

Zooplankton numbers and biomass are greatest at a depth of 50 m, mostly due to copepods (Figure 7.6). The unusual gastropod molluscs, called pteropods, contribute significantly to the biomass of surface waters (0 to 10 m depth). All other groups of zooplankton exhibit unpredictable patterns of depth distribution. Approximately 64 species of zooplankton are collected in Lancaster Sound, and adjacent inlets. Over 30% of all zooplanktons are copepods having, by far, the greatest abundance, biomass and diversity (Table 7.7).

7.2.3.1 Copepods

Copepods are the "foundation" of the zooplankton community of the Arctic, Lancaster Sound being no exception. During 1976 biological oceanographic studies in eastern Lancaster Sound, numbers of copepods were highest (about 1,500/m^3) at Navy Board Inlet. Elsewhere in the Sound, their abundance ranged between 400 and 830 individuals/m^3, and biomass varied between 130 and 244 mg/m^3, generally declining over the summer (Table 7.8). Copepods comprised over 75% of the zooplankton biomass in the upper 150 m of Lancaster Sound (Table 7.9), comparing favourably with 77 to 86% in the Arctic Basin and off East Greenland.

Pelagically, the three most common copepods are *Pseudocalanus spp.* (381 individuals/m^3); *Calanus hyperboreus,* and *C. glacialis,* (each about 145/m^3). *Pseudocalanus spp.* is, by far, the most abundant, but *C. hyperboreus* contributes most biomass, due to its large size[7.4].

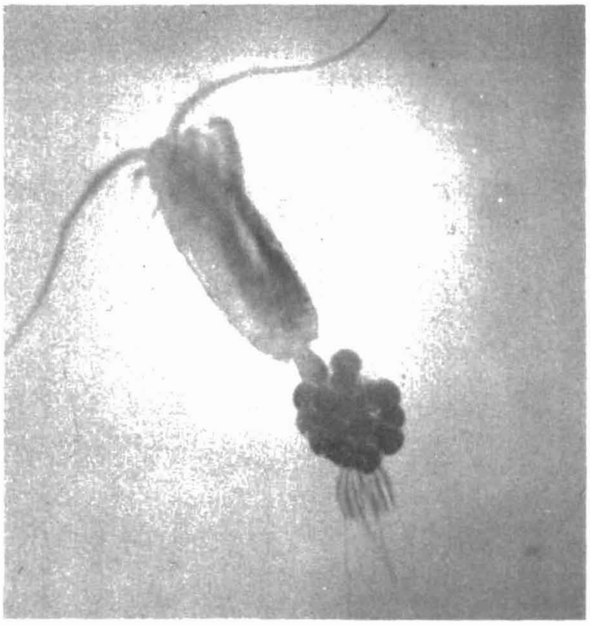
Grainger (1965)[7.32] speculates that the large numbers of copepods, in Lancaster Sound (and Arctic waters in general), is a function of the synchronization of the *Pseudocalanus* breeding cycle with the summer phytoplankton bloom. It is one of the few Arctic copepods to do so.

Copepods are common prey for the larger carnivorous planktors, such as arrow worms, comb jellies, amphipods and fish larvae. Recent seabird studies[7.34] reveal that copepods are the most commonly-taken food of Northern Fulmars and Black-legged Kittiwakes in Lancaster Sound. However, the tiny copepods' contribution to the total caloric intake of these surface-feeding birds is far outweighed by fish.

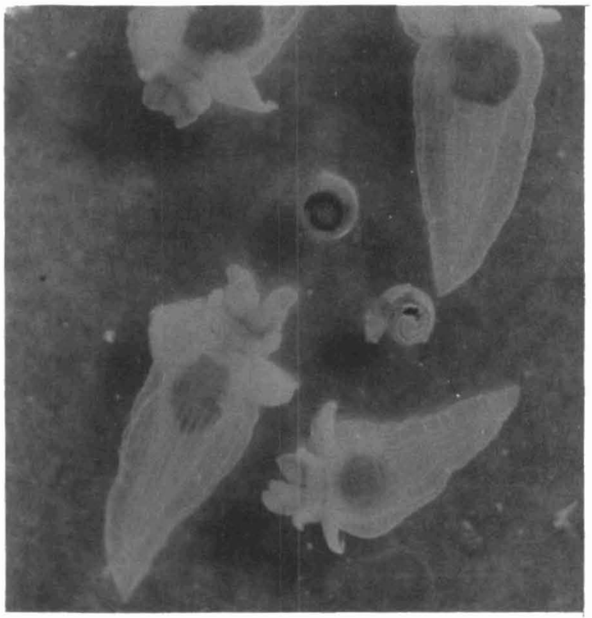
Table 7.7 Number of Species within each Zooplankton Group in the upper 150 m of Lancaster Sound, July 22 to September 13, 1976. (from Sekerak et al, 1976b)[7.4]

No. of species	Group
1, or so, each of	Bivalve larvae, polychaete worms (& larvae), ostracods, cirripede, larvae, isopods, euphausiids, echinoderms, salps.
2, or so, each of	ctenophores, pteropods, larvaceans, foraminiferans, radiolarians.
3, or so, each of	young of young fish
5, or so	amphipods
6	medusae (jelly-fish)
20	copepods

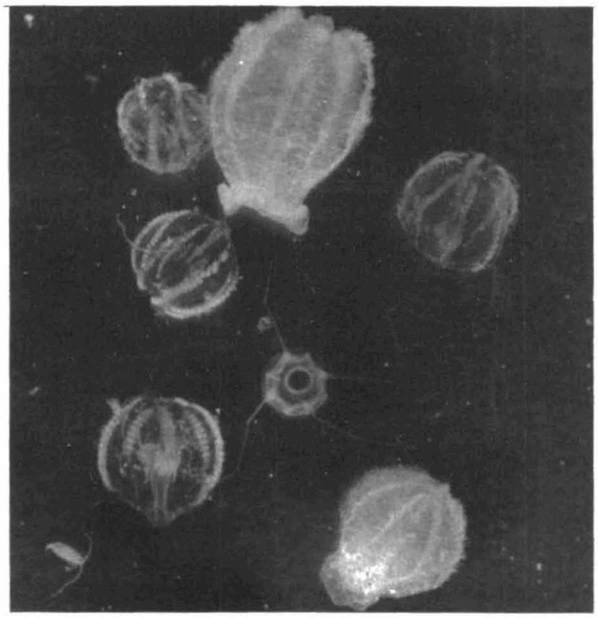
Amphipods



Copepod

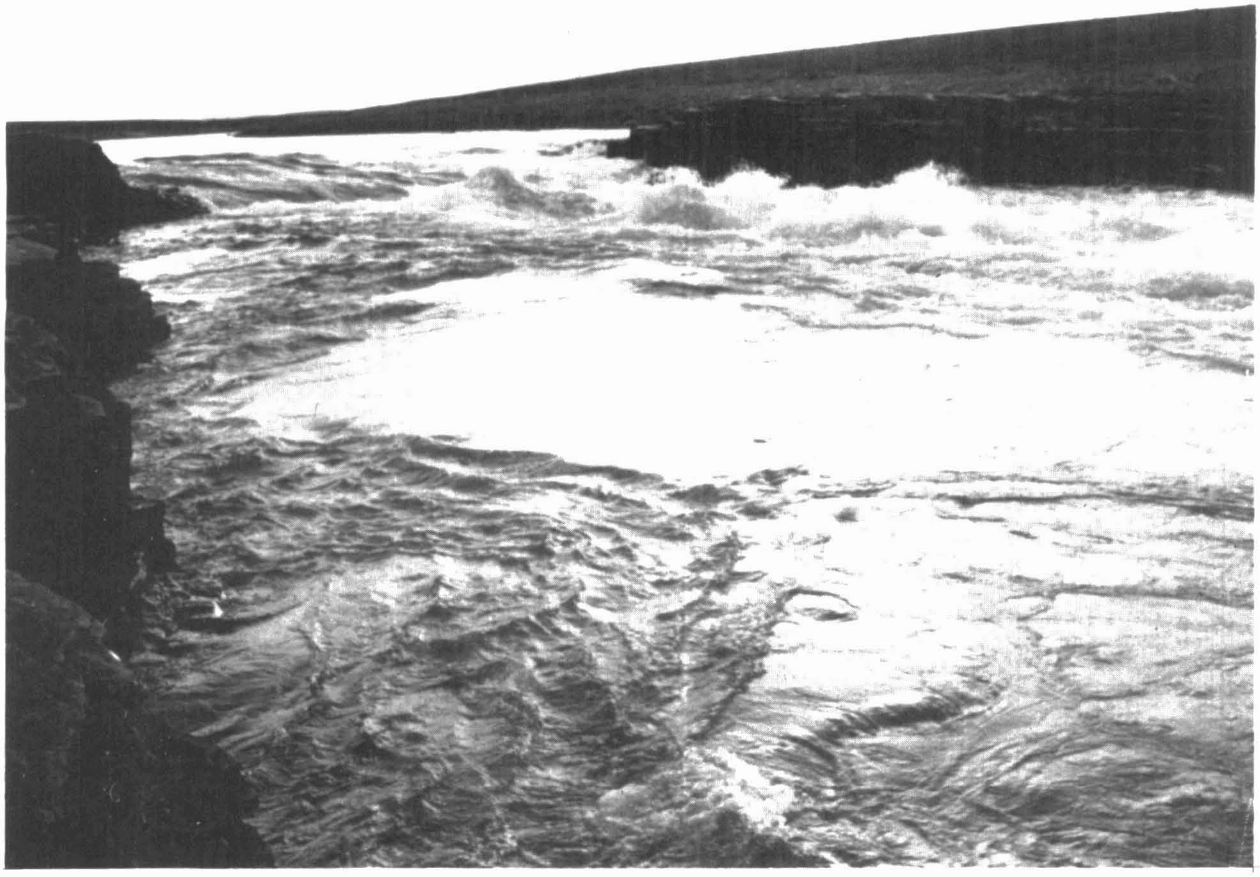


Pteropods



Ctenophores

(photos: D. Herlinveaux)



Robertson River, north Baffin Island (photo: A. Milne)

Drying Arctic Char (photo: B. Smiley)

Table 7.8 Distribution and Average Abundance (nos/m^3) of Major Zooplankton Groups in the upper 150 m of Lancaster Sound waters, July 22 - September 13, 1976, (from Sekerak et al, 1976b)[7.4]

Major Group	Station					
	Cape Warrender	Cape Sherard	E. Mid-Sound	Middle mid-Sound	Navy Bd. Inlet	West Mid-Sound
Copepods	833.59	538.49	402.35	763.07	1471.20	826.89
Larvaceans	376.82	188.55	215.05	409.20	563.32	360.32
Pterpods	25.72	3.26	7.07	48.46	377.87	57.47
Ctenophors & Cnidaria	11.04	5.92	6.33	16.19	4.49	1.67
Chaetognaths	2.49	1.83	1.13	1.41	2.55	1.69
Amphipods	1.54	0.83	0.60	0.51	1.25	0.45
Others	35.31	7.95	19.80	65.30	422.75	57.61
Total Numbers:	1286.51	746.83	652.33	1304.14	2483.43	1306.10
Total Biomass (mg/m^3)	399.88	246.43	181.22	283.82	263.43	171.17

Table 7.9 Total Biomass (per cent) contributed by major Zooplankton Groups in the upper 150 m of Lancaster Sound waters, July 22 to September 13, 1976 (from Sekerak et al, 1976b).[7.4]

Major Group	Station						
	Cape Warrender	Cape Sherard	E. Mid-Sound	Middle Mid-Sound	Navy Board Inlet	W. Mid-Sound	Overall (%)
Copepods	71.8	83.3	72.0	72.0	83.2	89.8	78.7
Larvaceans	0.9	0.5	0.6	1.4	4.2	1.7	1.6
Pteropods	7.4	3.0	14.8	14.7	3.3	0.5	7.3
Medusae	3.2	2.4	3.5	5.7	1.7	1.0	2.9
Chaetognaths	5.6	2.5	4.4	1.5	3.9	6.4	4.0
Amphipods	10.8	8.1	4.3	2.9	2.5	0.5	4.8
Others	0.2	0.1	0.2	1.8	1.1	0.1	0.7
Total:	99.9	99.9	99.8	100.0	99.9	100.0	100.0

7.2.3.2 Amphipods

Amphipods contribute less than 5% of the total zooplankton biomass in Lancaster Sound waters. Vertical plankton net tows[7.4] from 150 m depths seldom yield more than 15 individuals per 10 m^3 of sea water, or a biomass of about 37 mg/m^3. About 25 species of amphipods are known in Lancaster Sound and Baffin Bay but less than 5 are common in plankton samples or in the diet of fishes, birds and other animals. Two *Parathemisto spp.* are, by far, the most abundant amphipods. The more numerous *P. libellula* is large, up to 6 cm long, and prefers surface waters from 10 to 50 m in depth. In contrast, *P. abyssorum* reaches maximum numbers 150 m deep or deeper[7.4].

Amphipods are predators of copepods, and in turn, are important prey of higher arctic animals — seabirds in particular. For example, the diet of Fulmars, Murres and Guillemots is composed of 20 to 30% amphipods in terms of total energy intake; Dovekies have an energy intake of 65% amphipods[7.34]. *Parathemisto* is an important summer food for Ringed Seals[7.31]and is a key link in the arctic food chain. Other species which are, at times, numerous in the pelagic zooplankton community, or selected in the diets of coastal feeding seabirds are *Onisimus glacialis* (a pelagic amphipod often associated with pan ice), *Onisimus littoralis* (intertidal, shallow water amphipods), *Apherusa glacialis* and some *Gammarus spp.* (typically intertidal and sublittoral).

7.2.3.3 Pteropods

Pteropods swim actively in the water column, unlike most snail-like molluscs which are confined to a sea bottom existence. Only two pteropod species (*Clione limacina* and *Limacina helicina)* are present in arctic waters, including Lancaster Sound, but both are amongst the 15 most common Arctic zooplanktors[7.32]. It is interesting that *Clione* feeds exclusively on *Limacia,* a species (a diatom "grazer") often 70 times more abundant[7.4].

Averages of recent plankton samples from Lancaster Sound show pteropod densities of 100/m^3. Exceptionally large numbers (1,400/m^3) are found at Navy Board Inlet; lowest densities are found at or near the confluence of Lancaster Sound and Baffin Bay[7.4]. Despite the widespread occurrence of pteropods in Lancaster Sound, their numbers can vary by a factor of 100. These variations are attributed to different forms such as larvae, juveniles or adults comprising the samples, and to possible diurnal migrations of *Limacina* from deep waters during the day, to shallow at night.

Biomass estimates are variable because these two species of extreme size difference are not uniformly distributed throughout the Sound. Pteropods exhibit a depth preference, being found in thin layers at 10 m and 50 m but seldom in surface or deep waters[7.4].

The value of pteropods to the arctic food chain is not clear. The "diatom/herbivorous pteropod/carnivorous pteropod/Fulmar and Kittiwake" food chain can be presumed from the scanty published literature.

7.2.3.4 Chaetognaths

Chaetognaths (or arrow worms) are common, carnivorous planktors which prey mostly on copepods. Only three species are known in the Canadian Arctic, all three being found in Lancaster Sound, but seldom in large numbers. In the upper 150 m, about 2 worms/m^3 are collected in plankton tows; very few of these found in surface waters. The highest biomass of chaetognaths measured in Lancaster Sound is near Cape Warrender (40 mg/m^3)[7.4].

Sagitta elegans and *Eukrohnia hamata* are the most common arrow worms in the Sound. The latter species is restricted to offshore waters of high salinity and low temperatures[7.32]. *Sagitta* is more a coastal animal, tolerant of salinity and temperature fluctuations. Depth preferences recorded in Lancaster Sound confirm this feature of its biology, near surface waters supporting high numbers of *Sagitta,* whereas highest numbers of *Eukrohnia* are found at 150 m depth[7.4].

7.2.3.5 Other Zooplankton

Table 7.7 shows that remaining invertebrate groups contribute little to the density and biomass of the zooplankton community. Coelenterate medusae, comb jellies, siponophores and larvaceans are in this group. Although relatively few, these creatures are important grazers on smaller zooplankton. The interested reader is encouraged to refer to Grainger (1965)[7.32] and Sekerak et al (1976b)[7.4] for further information.

7.2.4 Marine and Anadromous Fishes

The Canadian High Arctic, including the Sverdrup Basin, Ellesmere Island and Parry Channel (of which Lancaster Sound forms a part) is a region of low fish diversity where only 20 or so species are known to occur. This number can be compared with the 86 species from West Greenland[7.35]. Most Arctic fish are small bottom-dwellers, all are slow in growing and take considerable time to attain maturity. A complete species list for Lancaster Sound cannot be assembled because of lack of fisheries research in the area. Information on fish abundance, distributions, food habits, and food chain importance is based, almost wholly, on speculation. The reader is referred to Ellis (1962) [7.36] for distribution and ecology notes on arctic fish captures near Arctic Bay and Pond Inlet. Arctic Char *(Salvelinus alpinus)*, Arctic Cod *(Boreogadus saida)*, three sculpin species *(Cottids)*, a fish doctor *(Gymnelid)* and an eel pout *(Lycodid)* dominated the collection.

In this report, only Arctic Cod and Arctic Char are discussed in detail. Char are fished locally and, since some are sea running fish, are vulnerable to coastal oil pollution at river mouths. Arctic Cod may be singly the most important link between marine invertebrates and higher birds and mammals.

7.2.4.1 Arctic Cod

The most abundant fish in the arctic and the species providing most biomass is the Arctic Cod, a circumpolar species and the most cold loving of the *gadids.* (It does not spawn until the water temperature falls below 5°C). In the Soviet Union, Arctic Cod are conspicuously absent from the coastal areas of the Kara Sea during the summer but, occasionally, biologists have observed enormous concentrations, mainly along floe edges[7.37, 7.38]. Arctic Cod are not true pelagic fish. Sometimes they live at the surface, among ice floes, near ice edges or under sea ice; sometimes cod are captured at depths greater than 900 m. In Strathcona Sound (about 70 km south of Lancaster Sound), Arctic Cod are the most common fish below a depth of 100 m, and occur, in appreciable numbers, down to 300 m[7.39].

Elsewhere in the Canadian Arctic, cod are seen in melt ponds on the sea ice[7.40]. Greenlanders and Pond Inlet residents catch them in ice cracks[7.41, 7.42]. SCUBA divers observe cod beneath the landfast ice of bays[7.12], or in the springtime at floe edges blocking major channels into Lancaster Sound[7.5].

In fall, enormous numbers of cod approach shores, presumably, as pre-spawning migrants in search of coastal waters with temperatures from 0 to 4°C. Conditions favourable to food production also attract cod to coastal areas[7.38]. Either explanation may account for the hundreds of adult Arctic Cod seen in Allen Bay, Cornwallis Island (near Resolute Bay) in August and September, 1967[7.43]. Spawning activity peaks in January and February, but whether the spawning sites are in coastal waters or offshore along the ice edge, is still debated[7.45, 7.47, 7.46].

The incubation period of their pelagic eggs is not long; the eggs hatch in April and May, sometimes as late as July[7.37, 7.46]. Initial growth is relatively fast; newly hatched larvae are about 5 mm long and, by the end of their first growing season, are 30 to 70 mm long[7.4, 7.45, 7.47]. Their life span is 7 years; most fish maturing sexually at 5 years but spawning only once a lifetime[7.37]. Arctic cod are opportunistic feeders, their diet depending on the seasonal availability of phytoplankton, copepods, bottom crustaceans (such as amphipods), shrimp, fish eggs and fry. For example, copepods were eaten by 65% of small cod caught in Strathcona Sound during the summer[7.39]. Other biologists state that Arctic Cod feed on phytoplankton during the spring[7.45].

According to Sekerak et al (1976b)[7.4], the average density of young-of-the-year cod in the upper 150 m of Lancaster Sound is about 52.0 fish/m^3 (Figure 7.7). Most of the Sound's cod fry inhabit depths between 10 and 50 m; seldom are they caught on the surface[7.4].

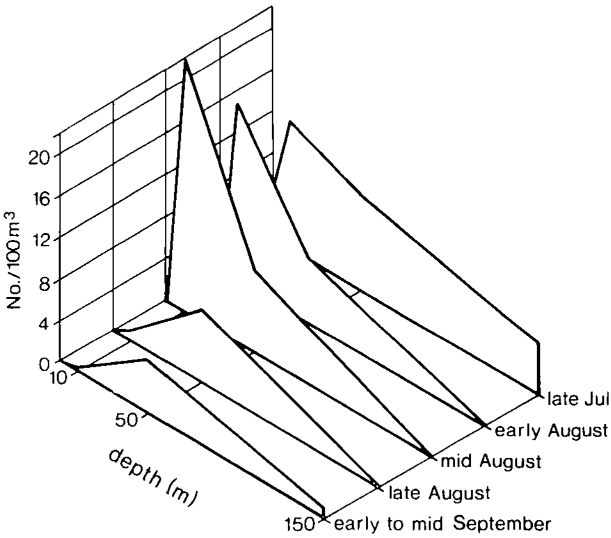


Figure 7.7 Pelagic larval cod standing crop (expressed as no.s/100 m^3) varied with *time and depth* in Lancaster Sound, July 22 to September 13, 1976. (from Sekerak et al, 1976b)[7.4].

In terms of fish standing stock, the *Boreogadus* density in Lancaster Sound is twice that of the Chukchi Sea[7.48], and 10 times greater than in the Beaufort Sea[7.49]. A crude estimate of cod production in Lancaster Sound waters and nearby inlets is 400,000 metric tons per year[7.49].

With such abundance, it is not surprising that Arctic Cod are eaten by almost every warm blooded animal in the Arctic. Arctic Foxes and Polar Bears scavenge fish which are washed ashore by gales during spawning migrations[7.37]. Seabirds such as Fulmars, Kittiwakes, Murres and Guillemots rely on cod as their primary food source; over half of their summer's energy consumption in Lancaster Sound is supplied by cod[7.34]. Despite the small size of the Arctic Cod, they are potentially of commercial value for man. During the winter, its large liver (up to 10% of body weight) contains about 50% valuable oil[7.37]. However, nowhere in the Canadian Arctic are cod regularly eaten by man. Inuit women and children sometimes "jig" for cod and sculpins through the spring ice cracks inside bays, or at the edges of inlets, such as near Pond Inlet and Arctic Bay[7.42].

7.2.4.2 Arctic Char

Arctic Char, a circumpolar fish, is found in inshore marine waters, lakes and rivers of the New Siberian Islands, Novaya-Zemlya, Spitzbergen, Greenland and the Canadian Arctic Archipelago. Arctic Char is distributed more northerly than any other freshwater fish. Most populations are anadromous, feeding at sea but spawning in rivers and lakes; but some are confined entirely to freshwater.

In Arctic regions, char spawn usually in September or October, over the gravels of lake shoal or river pools. The young hatch in April emerging from their gravel nurseries about 4 months later. Young anadromous char migrate downstream only when they are 5 to 7 years old[7.50]. During their early years, the fry feed on midge fly larvae, copepod crustaceans, and aerial insects[7.51]. Growth rates are slow, particularly in High Arctic waters. When first migrating to sea, the fish are only 16 or 17 cm long, whereas a maturing female of 14 years or so, is about 45 cm long[7.49]. Full size is attained at age 20 years. The average weight of a sea run char is 1 to 4.5 kg[7.52, 7.53].

Anadromous char, which overwinter in lakes, descend to the sea in spring. They return before or during river break up in the autumn of the same year. Downstream migrants usually remain in the vicinity of estuaries, where marine food is abundant[7.52].

Char populations are unknown along the north and south margins of Lancaster Sound. However, within our area of concern are two important char supporting systems – the Robertson River which empties into Koluktoo Bay and Milne Inlet, and the Utuk Lake-Salmon River drainage system near the settlement of Pond Inlet. The Robertson River supports an estimated standing stock of 64,000 breeding char (weighing about 145,000 kg); the total population is 500,000 fish, excluding fry less than 2 years old[7.49]. The river is not fished heavily by Inuit because of its long distance from settlements. However, the Utuk Lake drainage, situated only a few kilometres west of Pond Inlet, is the site of a char fishery, which yields about 2,300 kg of char meat each year. The stock is much smaller (about 100,000 fish over 2 years old) than that of the Robertson River. Of these, the breeders number less than 13,000[7.49].

Within Navy Board Inlet, Eclipse Sound and Pond Inlet, small, scattered char populations exist in coastal streams and rivers[7.42]. Figure 7.8 shows the foci of domestic fishing for Pond Inlet residents; some are in river mouths, but others are places where cod and sculpin are sometimes jigged or netted.

7.2.4.3 Other Marine Fishes

Besides Arctic Char, Greenland Shark has been singled out as potential commercial species[7.54]. This large, 5 to 8 metres long, docile shark is widespread in most arctic waters, including Lancaster Sound. Its biology is practically unknown. Though apparently a deep water species, the Greenland Shark is often attracted to surface water where offal from sealing or whaling operations is disposed. It is an opportunistic feeder, stomach contents revealing a diet of amphipods, brittle stars, skate egg cases, char, gastropods and urchins[7.55]. Greenland sharks have been caught near Pond Inlet; in fact some experimental shark fishing was attempted here in winters of 1957-1959[7.56]. In Soviet waters, the Greenland Shark inhabits coastal waters and bays – usually in the winter. On the shores of West Greenland, sharks are caught under the winter sea ice with fishing rods and light lures[7.37].

Historically, shark liver was valued for its oil by Inuit; the skin and meat provided dog food and tools. Today, sharks are occasionally killed by Inuit hunters of Pond Inlet and Arctic Bay during their open water whaling pursuits. Shark by-products have little or no commercial or domestic value.

Sculpins, members of the Cottid family, are caught in almost every net or bottom trawl when sampling for fish in Lancaster Sound, often comprising most of the catch. Sculpins are a diverse group; for example, 3 or 9 fish species caught near Arctic Bay and Pond Inlet by Ellis (1962)[7.36] were sculpins. Four-horn sculpins *(Myoxocephalus quadricornis)* and staghorn sculpins *(Gymnocanthus tricuspis)* are common. Sculpins are frequently included in the diets of diving seabirds and marine mammals; and therefore form a critical bond between these higher animals and benthic invertebrates.

7.2.5 Marine associated birds

Over eight million seabirds breed in Atlantic Canada and the eastern Canadian Arctic, 73% of these nesting in the latter region north of 55°N[7.57]. Five species dominate the Arctic's seabird community – Northern Fulmar, Glaucous Gull, Black-legged Kittiwake, Thick-billed Murre and Black Guillemot. Their ranges are somewhat restricted by ice to Jones Sound, Lancaster Sound, west Davis Strait and Hudson Strait. Approximately 25 species are found in Lancaster Sound waters. Several of these occur in small numbers and some are at the peripheries of their ranges; these include the Common Loon, Yellow-billed Loon, Red Throated Loon, Canada Goose, Red Phalarope, Pomarine Jaeger, Parasitic Jaeger, Long-tailed Jaeger, Skua, Thayer's Gull and Sabine's Gull.

Lancaster Sound ranks high in importance for migrating, breeding and feeding seabirds. For example, of the 694,000 Northern Fulmars nesting at ten colonies in Arctic Canada, at least 230,000 nest in Lancaster Sound and nearby Barrow Strait[7.60]. Likewise, about 800,000 of eastern Canada's five million Thick-billed Murres nest in a single colony on north Bylot Island. Dr. L.M. Tuck of the Canadian Wildlife Service, in 1957, described Lancaster Sound as "one of the ornithological wonders of the world"[7.58].

Most seabirds return to land to breed and raise their young. Colony sites are usually chosen near waters rich in food and in habitats where it is safe from predators such as Arctic Foxes. Sites exhibiting both these biological and physical assets are scarce. This underscores the critical nature of the seven major colonies and nearby foraging waters situated within 300 km of proposed drilling in Lancaster Sound (Figure 7.9). The closest and largest colony, just west of Cape Hay, is the most vulnerable to accidental oil pollution.

Seabirds do not disperse at random throughout Lancaster Sound. Ice conditions usually dictate where they rest and feed during spring and early summer. After break up, their search for food-rich waters causes birds to concentrate, often in shallow coastal waters. Locales of high bird densities at different times occur along north Bylot Island and Borden Peninsula. Unfortunately, this behaviour increases the birds' vulnerability to oil pollution.

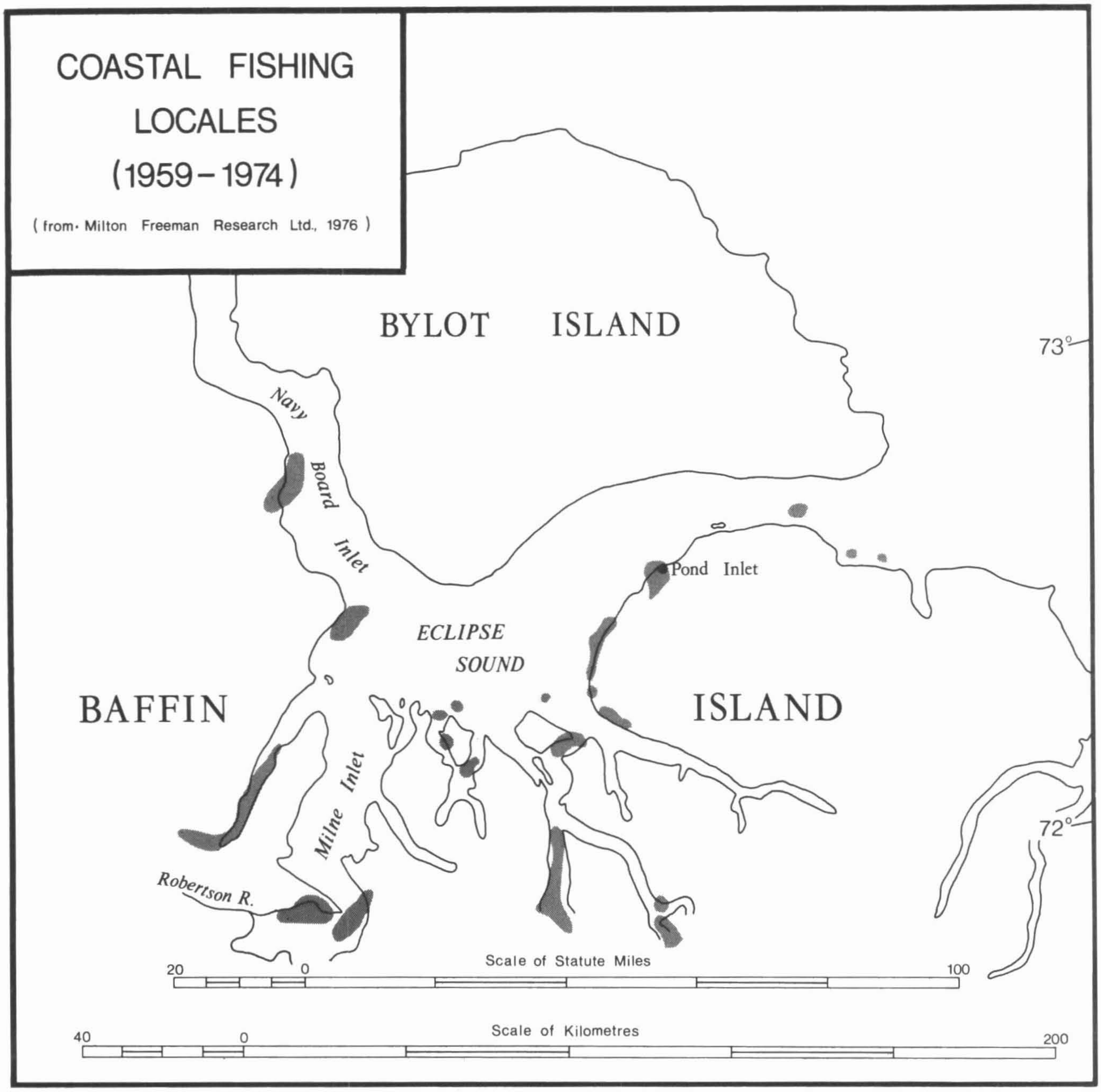


Figure 7.8

In the following species-by-species accounts, the reader is encouraged to note which birds are where, when and in what numbers. This understanding is paramount to interpreting threats from an offshore oilwell blowout to the Sound's bird population. Overall, hundreds of thousands of birds fly through Lancaster Sound from April to October; some fly to more westerly breeding grounds but most remain to feed, court, nest, raise broods, and moult.

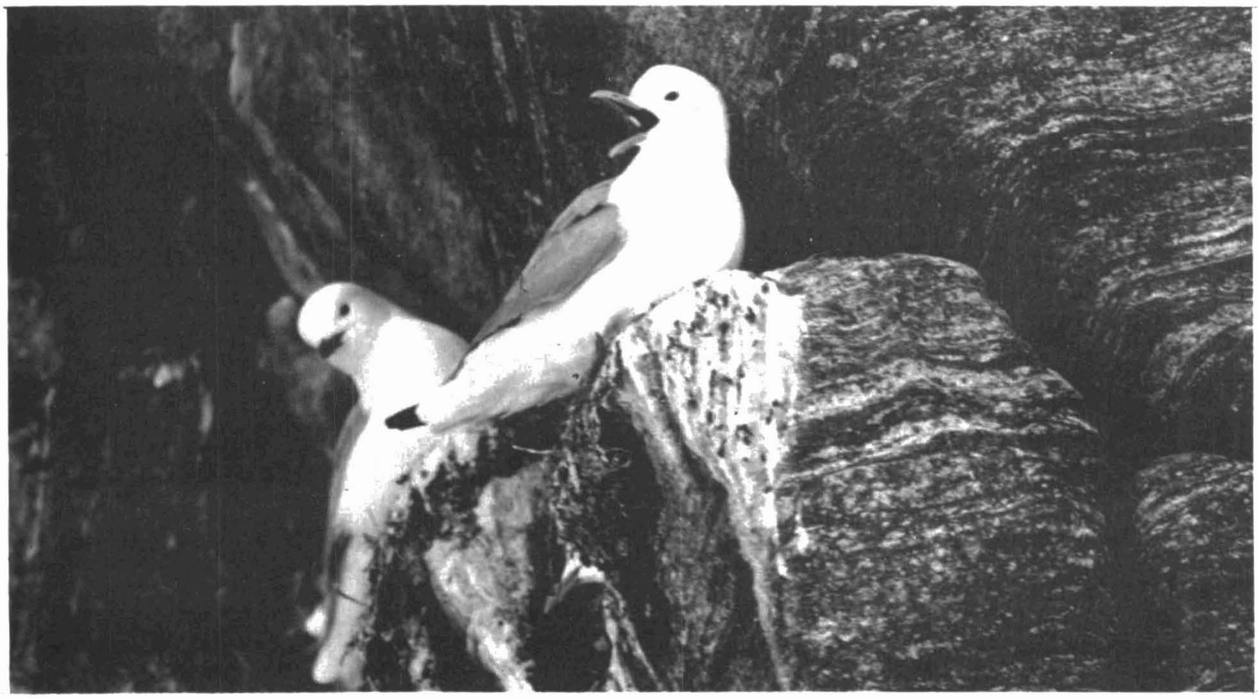
However, cautionary notes are necessary: (1) The descriptions are, intentionally, very general. Actual data are given as support, but scientific "qualifiers" such as observer bias, sampling discrepancies, and differing experimental design, are omitted. Sceptics are referred to the original documents for details. (2) The Arctic is a dynamic environment and one year or season cannot be regarded as "average". The timing of bird migrations, breeding or moulting can vary by days – sometimes weeks – depending upon the lateness of spring, the presence of heavy sea ice, and so on. One year's data, on which we are often forced to rely, is inadequate.

7.2.5.1 **Northern Fulmar**

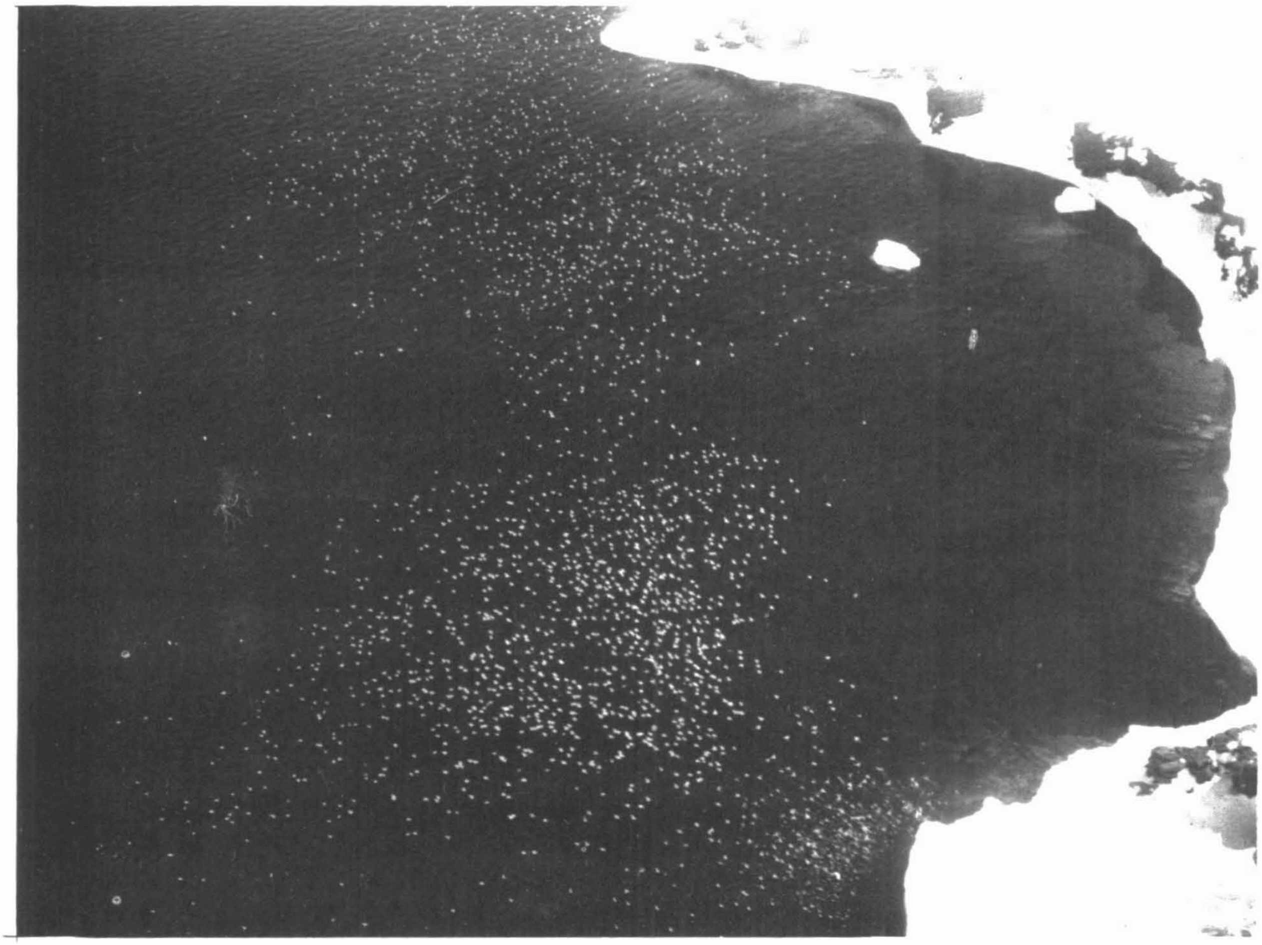
The Northern Fulmar *(Fulmarus glacialis)* nests in the Arctic and sub-Arctic of both the New and Old Worlds, and is one of the most numerous birds in Lancaster Sound. The closest nesting colonies to the proposed drilling site are tens or several hundreds of kilometres west and southwest – near Baillarge Bay, Hobhouse Inlet, Cape Liddon and on Prince Leopold Island. The combined size of these relatively large colonies is about 180,000 breeding birds. The total population of Fulmars in Lancaster Sound and Barrow Strait is estimated at 230,000[7.60]. Fulmars from Jones Sound (Cape Vera 50,000 birds) probably pass through eastern Lancaster Sound on migration. Thus, more than two thirds of Canada's Fulmars could be affected by petroleum exploration in Lancaster Sound and northwest Baffin Bay.

These Fulmars winter in Baffin Bay, Davis Strait and in the North Atlantic, far offshore from the coasts of Greenland, Labrador, Newfoundland and the Maritime

Cape Graham Moore Kittiwake Colony, Bylot Island (photo: H. Silverman)



Nesting Black-legged Kittiwakes at Cape Graham Moore, Bylot Island (photo: H. Silverman)



Flock of Black-legged Kittiwakes at Cape Hay, Bylot Island (photo: H. Silverman)

Ivory Gulls (photo: H. Silverman)

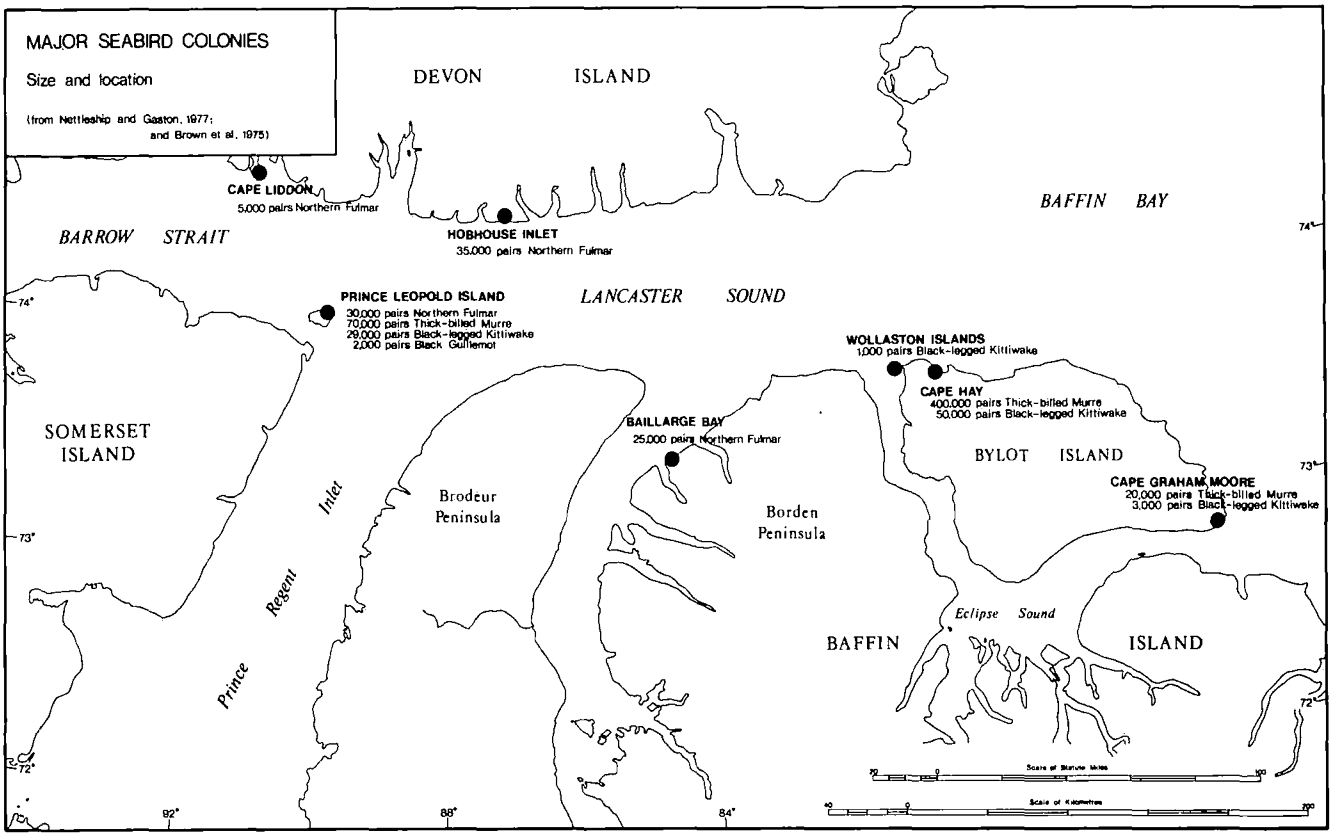


Figure 7.9

Provinces[7.66]. Almost nothing is known about migration routes to and from Lancaster Sound.

Spring migrant Fulmars arrive in Lancaster Sound by late April[7.51]. Birds are also seen on the breeding cliffs of Prince Leopold Island in April of some years[7.50]. In May, Johnson et al (1976a)[7.62] observed about 10,000 Fulmars (1.6 birds/km^2) scattered throughout eastern Lancaster Sound. A major wave of migrants arrived in late June, most preferring the continuous band of fast ice anchored to the south margin of the Sound. Fulmar densities are less offshore; about three quarters of the 64,000, or so, birds were found there on June 27 and 28[7.62].

During July, dense concentrations (500-700 birds/km^2) focus along the persisting ice edges of Croker Bay and Navy Board Inlet. A major shift from offshore to nearshore occurs in late July, especially along southeast Devon Island coast (Figure 7.10). Densities can reach 100 to 300 birds/km^2 by August and early September of some years. Estimated numbers of Fulmars within a 60-km radius of Norland's proposed drilling site was 88,000 on September 12 and 13, 1976. Only 20% of the fulmar population remained by mid-September[7.62]. Less than 5% of the Prince Leopold breeders linger until the month's end,[7.60] however some birds are spotted as late as October 19 in Admiralty Inlet[7.63].

Why Fulmars concentrate in coastal waters at some times and offshore at other times is uncertain. Variable patterns and timing of spring ice break up are probably major factors during the early part of the breeding season. Later, availability of food is considered important, especially in bays, along the fast-ice edges or where streams flow into the sea[7.60].

Fulmars are at nesting colonies for nearly six months; the nesting cycle of egg incubation, chick rearing and fledging is relatively long. More than any of the Sound's seabirds, Fulmars spend long periods away from their nesting colonies and forage over great distances. The important feeding waters of southeast Devon Island attract large concentrations of Fulmars from colonies 150 km, or more away[7.60, 7.62, 7.64].

The food habits of Northern Fulmars point clearly to the dietary importance of Arctic Cod, especially during chick rearing. Bradstreet (1976)[7.34] reported that 63% of Fulmar energy intake is comprised of fish – mostly cod. However, the birds have flexible eating habits, and often prey on amphipods. The amphipods consumed are diverse; most are pelagic, but ice-associated and shallow water amphipods are also eaten, depending upon the season, the foraging area and the bird's status. For example, birds foraging along the south Devon Island coast eat, primarily, the amphipod *Parathemisto* (79% of total amphipod dry weight in stomach contents), whereas *Onisimus* amphipods account for 95% of crustacean diet for Navy Board Inlet feeders during the same period of study[7.34]. Most Fulmars eat squid, but whether or not they do so in Lancaster Sound remains unknown.

Such food habits, far-ranging movements and clumped distribution exhibited by Fulmars contribute significantly to their risk and vulnerability in the event of oil pollution in eastern Lancaster Sound.

7.2.5.2 Black-legged Kittiwake

Of the gull family, only the Black-legged Kittiwake *(Rissa tridactyla)* is truly pelagic outside the breeding season, coming to coastal shores only to nest on protected cliffs, such as those in Lancaster Sound and Barrow Strait. The two largest Kittiwake colonies in eastern North America are found here – one at Cape Hay, north Bylot Island (100,000 breeding birds) and the other on Prince Leopold Island (60,000 breeding birds). Smaller colonies (10,000 or less birds) are located at Cape Graham Moore (southeast Bylot Island), Coburg Island (near Jones Sound) and a few much further to the west[7.57, 7.65].

Kittiwakes winter pelagically in waters off British Columbia, the Gulf of St. Lawrence and the Maritime Provinces[7.66]. The spring migrants destined for Cape Hay and Prince Leopold Island likely enter Lancaster Sound from the east, arriving as early as the first week of May[7.62, 7.63].

Recent aerial surveys by Johnson et al (1976a)[7.62] revealed a large movement of Kittiwakes through the Sound during the third week of May (Figure 7.11). In some years, this movement is one or two weeks earlier[7.67]. Presumably, these birds are en route to Prince Leopold Island. About 80% of the migrants travel offshore, and not along the landfast ice or shorelines. The Cape Hay colony birds arrive in early June and concentrate in the shallow waters close to the colony's cliffs. For much of the summer, nesting birds remain nearby and along the Navy Board Inlet ice edge (Figure 7.11). In 1976, the average density was about 275 Kittiwakes/km^2 but sometimes reached 1,600 birds/km^2. These estimates are undoubtedly low[7.62] since survey aircraft remained several kilometres offshore in order to avoid disturbing the colony and colliding with birds.

In late August, Cape Hay Kittiwakes and their fledglings disperse throughout all coastal waters of eastern Lancaster Sound[7.62]. This contrasts with the behaviour of Murres and Guillemots which do not linger but depart south soon after the chicks fledge. A marked increase in number (estimated up to 45,000 Kittiwakes in 1976)[7.62] occurs offshore by mid-September. Many of these are probably migrating from Prince Leopold Island and other colonies. Kittiwakes are still in Lancaster Sound by late September, but in much reduced numbers (40 birds/km^2) along the Sound's coastal margins[7.62]. Their final departure timing is not known.

Kittiwakes are heavy eaters of fish. Bradstreet (1976)[7.34] reported that Arctic Cod form more than 85% of the Kittiwake's diet, as measured by energy intake, in Lancaster Sound. The remaining portion of their diet is copepods, pteropods and amphipods. Cod also comprises much of the food brought to the chicks. Kittiwakes forage up to 50 km from the colony, or even further afield as the chicks grow older[7.60].

By virtue of their clumped distribution near breeding colonies such as Cape Hay and in foraging locales near Navy Board Inlet, Kittiwakes are highly vulnerable to oil pollution on open water and along ice-edges.

7.2.5.3 Thick-billed Murre

The Thick-billed Murre *(Uria lomvia)* is the Arctic Canada's counterpart of the penguins of the Antarctic. Murres are heavy bodied, swimming birds with legs placed far back on the body. Although clumsy on land, they are fine swimmers and divers and obtain their food by pursuit beneath the water. Unlike penguins, Murres are fairly strong fliers.

The Thick-billed Murre is holarctic in distribution, breeding circumpolarly around the fringes of the Arctic Ocean. The world population is between 37 million and 75 million[7.68]. This species is abundant in Lancaster Sound; an estimated one million breeding birds nest on the cliffs of Cape Hay, Cape Graham Moore and Prince Leopold Island. The Cape Hay colony housed 800,000 breeding birds in 1957[7.58], but this number has probably declined about 30% since the observation was made 20 years ago[7.73, 7.67]. Nonetheless, Cape Hay remains one of the four largest colonies in Canada's eastern Arctic. The colony at Prince Leopold Island, about 200 km to the west contains about 140,000 breeding Murres[7.57].

Murres, once leaving their High Arctic colonies in Baffin Bay and Lancaster Sound, take advantage of the strong southward-flowing Baffin Land Current and eventually cross over to the highly-productive West Greenland waters[7.59]. There is evidence of tagged Murres from Lancaster Sound overwintering off the coasts of Greenland in Davis Strait, along with Newfoundland birds[7.69].

In Lancaster Sound, large numbers of Murres arrive in early May of some years. For example, an estimated 96,000 Murres were concentrated in the offshore cracks and leads of the pack ice from May 9 to 11, 1976[7.62]. Many of these birds were probably through migrants en route to Prince Leopold Island. Numbers peaked at 180,000 birds, and more, by mid-May (Figure 7.12). Most are scattered offshore, but very high densities occur near the Cape Hay colony and Navy Board Inlet. Overall densities were about 175 murres/km^2; a single flock of 13,000 birds was spotted along the ice edge adjacent to the nesting cliffs on May 24[7.62].

Thick-billed Murre eggs hatch in late July and early August. During the late stages of incubation and chick rearing, parent Murres forage in waters within 30 to 110 km of the colony, depending on ice conditions, food availability and so on[7.60]. About 18 to 25 days after hatching (late August), when still about half the size of adults, Murre chicks have grown waterproof feathers. Though their flight feathers have not yet appeared, they flutter to the water, hundreds of metres below nesting ledges. The chicks immediately begin to swim out to sea, accompanied by an adult or parent[7.68]. At the time of this migration, the adults are moulting, also flightless, and extremely vulnerable to floating oil pollution. The waters near Cape Hay and Prince Leopold Island are virtually abandoned by Murres by early September.

Murres are primarily fish-eating birds, although crustaceans are important diet components at certain times and places. Food brought to nestling Murres at Cape Hay and Prince Leopold Island is mostly Arctic Cod and to a lesser degree, sculpins[7.57, 7.58]. Recent food studies[7.34] in Lancaster Sound reveal that 88% of Murres' energy intake was derived from Arctic Cod. The pelagic amphipod, *Parathemisto* makes up a significant portion of their diet, particularly in the years of low numbers of cod.

Historically, Thick-billed Murres provided food for man. The birds' meat and eggs have often been eaten by 18th century European explorers, and whalers. As far back as Viking days, Norse raiders knew of the now-extinct Great Auk of Iceland and its close relative, the Murre. Today, the Murre population of Lancaster Sound is hunted by Greenland Inuit. From October to May, an estimated 75,000 Thick-billed Murres are killed annually on their winter range near the West Greenland districts of Egedesminde and Holsteinborg[7.70]. A Murre cannery is operational in Upernavik[7.71]. In addition, between 1968 and 1973, the West Greenland salmon fishery by Denmark annually killed 500,000 to 750,000 Murres which had accidentally become entangled in fish driftnets[7.72]. The apparent decline of colony sizes at Cape Hay and Prince Leopold Island during the past two decades may, in part, be a result of this heavy mortality[7.67]. The bulk of the Greenland harvest is comprised of Murres from eastern Canadian arctic colonies. Even though a 1976 international agreement now restricts the Danish gill-net catch of salmon and the incidental bird kill, the Murres' population recovery is predicted as slow[7.67]. The annual toll of Murres by Canadian commercial fishing is not known in the North Atlantic.

Pond Inlet residents often travel to Cape Graham Moore in late July to gather Murre eggs and meat. This seasonal food is a welcome change from the staple seal meat.

7.2.5.4 Dovekie

The Dovekie *(Plautus alle)* smallest of the Atlantic alcids, nests in the crevices of rocky cliffs in far northern Greenland, Jan Mayen Island, Spitzbergen, and Franz Josef

Land. Dovekies are not known to nest in Canada. They have an affinity for ice-infested waters and winter close to pack ice of Baffin Bay, Davis Strait, Labrador Sea and east Newfoundland.

When migrating from these southerly wintering grounds to West Greenland latitudes north of 76°N, hundreds of thousands of Dovekies pass through Lancaster Sound. A few hundred were first sighted here during the second week of May, 1976[7.62]. Within days, an estimated 1.5 million Dovekies or more inhabited the offshore cracks and leads of the Sound (Figure 7.13). Flocks of 13,000 were common, as were densities of 100 to 500/km^2, especially in the extreme east. These birds remained for less than two weeks. These observations were significant and surprising since, prior to 1976, Dovekies were considered uncommon in Lancaster Sound. It is postulated that Dovekies may rely on the Sound's open water and available food for egg development prior to the breeding season[7.73].

Much fewer Dovekies, probably non-breeders, inhabit the Sound's offshore waters during summer (Figure 7.13). Estimates of 11,000 Dovekies reported during aerial surveys in June to September 1976, were likely low, due to the difficulty of seeing these tiny, dark coloured birds on open water[7.62].

In late August, Dovekies begin to disperse southward from their Greenland breeding colonies. Autumn sightings of hundreds or even thousands of Dovekies are reported in Lancaster Sound and further west in Prince Regent Inlet [7.59, 7.62, 7.63, 7.74]. At this time (and more so in the spring) they are extremely vulnerable to oil pollution in Lancaster Sound. The fall migration from all High Arctic waters, in late September and October, likely follows the west margin of Baffin Bay rather than the ice free West Greenland coast[7.71].

Dovekies mostly eat soft-bodied crustaceans. Bradstreet (1976)[7.34] found that this species, more than any of the more common seabirds in Lancaster Sound, relied on amphipods for 65% of its energy intake, primarily *Parathemisto* and *Apherusa*. In contrast, fish comprised only 35% of their diet.

These fat little birds are sometimes food for Greenland Inuit, who catch them in dip nets as the flocks wheel around their nesting grounds.

7.2.5.5 Glaucous Gulls

One of the largest gulls, the Glaucous Gull *(Larus hyperboreus)* is a circumpolar species that breeds throughout the Canadian Arctic. This gull is common and widespread in the vicinity of proposed drilling in eastern Lancaster Sound. It winters on both the Atlantic and Pacific coasts, and the islands of southern Canada[7.66].

Scattered, solitary nesting pairs occur on cliffs and stacks along most of the Sound's coastline, but five small colonies with a total of 130 nesting pairs are known. The sites are at the Wollaston Islands, Dundas Harbour, Cape Warrender, a location 20 km west of Cape Hay, and Croker Bay. About 200 pairs of Glaucous Gulls nest on Prince Leopold Island[7.64]. This species is usually found near large seabird colonies where it preys on eggs and chicks.

Glaucous Gulls are present in eastern Lancaster Sound in the first week of May, but most do not arrive until the month's end. In 1976, their numbers remained stable at about 600 birds until July, when their numbers sharply increased to about 2,500 by early September[7.62]. The reasons for this trend was probably the late spring arrival of non-breeding birds, the mid-summer fledging of the young, and the start of fall migration from areas further west. The last gulls are not forced from the Sound until freeze up - usually in late October or in November[7.71].

Glaucous Gulls are coastal birds, about 90% spending their time feeding within 1 km of the shore or ice edge[7.62]. The birds congregate in some places, particularly Bethune Inlet, Dundas Harbour, Croker Bay and a location near Navy Board Inlet. The waters immediately adjacent to the south Devon Island glaciers support the highest densities of Glaucous Gulls - up to 70 birds/km^2 in early August, 1976[7.62].

7.2.5.6 Ivory Gull

The Ivory Gull, *(Pagophila eburnea)*, like most Arctic seabirds, is circumpolar in distribution. This bird is one of few avian species to remain in the arctic the year round. It manages to forage along leads and broken pack ice, from the Arctic coasts to north-eastern Newfoundland[7.71, 7.75]. The Ivory Gull is probably the most rare of Canadian Arctic gulls; a colony of 200 pairs on Seymour Island (north of Bathurst Island, 700 km northwest of Lancaster Sound) is presently the only known breeding colony in Canada[7.76]. Other breeding locales are suspected; for example 386 Ivory Gulls, (155 of them which were young-of-year) were observed at Grise Fjord on September 28, 1976[7.77].

Usually, the birds are spotted singly or in pairs, but sometimes in flocks of 18 to 25. A total of about 250 birds were seen during surveys of eastern Lancaster Sound from May to September 1976[7.62]. They were not present in significant numbers until mid-June. The highest density recorded is 0.05 birds/km^2, in mid-July, consisting of a flock of 29 gulls.

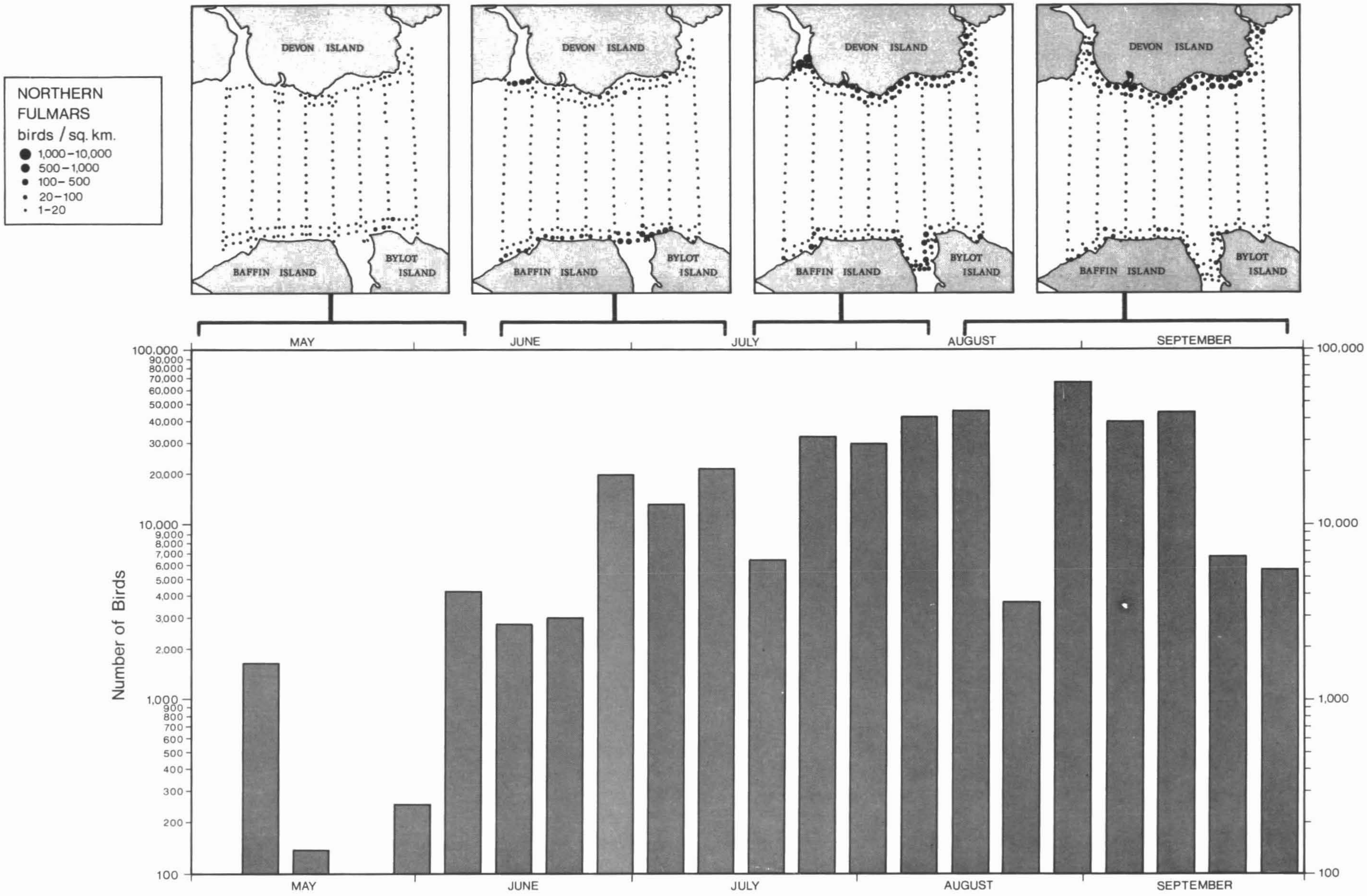
Ivory Gulls prefer the coastal marine waters along south Devon Island, particularly near the glacier fronts entering the Sound between Cape Sherard and Philpots Island[7.62]. How long they remain in Lancaster Sound is unknown; the shifting winter pack ice might provide suitable overwintering habitat. The September migrants from Greenland, en route to Davis Strait, prefer to travel along the west side of the Baffin Bay ice field[7.71]. This behaviour increases the threat to these gulls from oil pollution in Lancaster Sound.

7.2.5.7 Black Guillemot

The Black Guillemot *(Cepphus grylle)* is a member of the alcid family, along with the Dovekies and Murres. As a circumpolar species, it breeds in both the New and Old Worlds. In Lancaster Sound, Black Guillemots are widespread and common. Large numbers nest along the rocky coasts of south Devon, Bylot and north Baffin islands, where cliffs, talus slopes and rock rubble provide hidden crannies for eggs and young. Known nesting sites are on Prince Leopold Island, the Wollaston Islands, Cape Hay and areas near Cape Warrender and Dundas Harbour. The colonies are relatively small. Only the colony of 2,000 to 3,000 pairs at Prince Leopold Island warrants plotting in Figure 7.9.

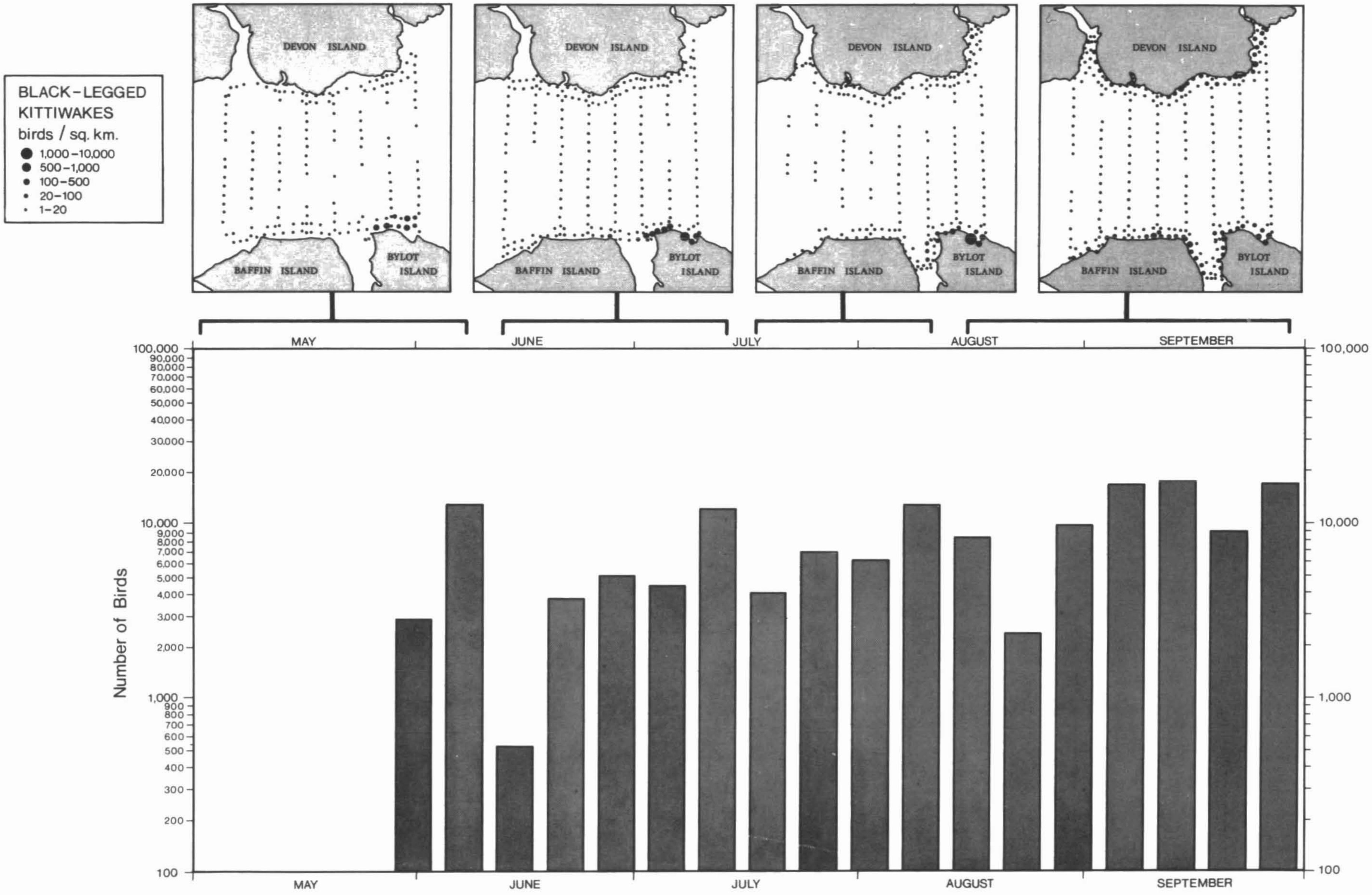
Some Guillemots overwinter in Lancaster Sound and in the eastern Canadian Arctic[7.78, 7.79] but the majority migrate southward in October and November to Baffin Bay, Davis Strait and as far south as Atlantic Canada. The migration patterns and timing to and from Lancaster Sound are unknown.

Low numbers of Guillemots inhabit the cracks and leads of Lancaster Sound's offshore pack ice by late April and May. Increasing numbers of Guillemots concentrate along shores and coastal fast ice particularly near colonies by early June. Although the density reached 30 or so birds/km^2 near Cape Hay in June, 1976, the summer's average was less than 5 Guillemots/km^2; this represented only a few hundred pairs[7.62]. Once the young Guillemots have fledged in late August, the birds disperse throughout Lancaster Sound, both nearshore and offshore, away from



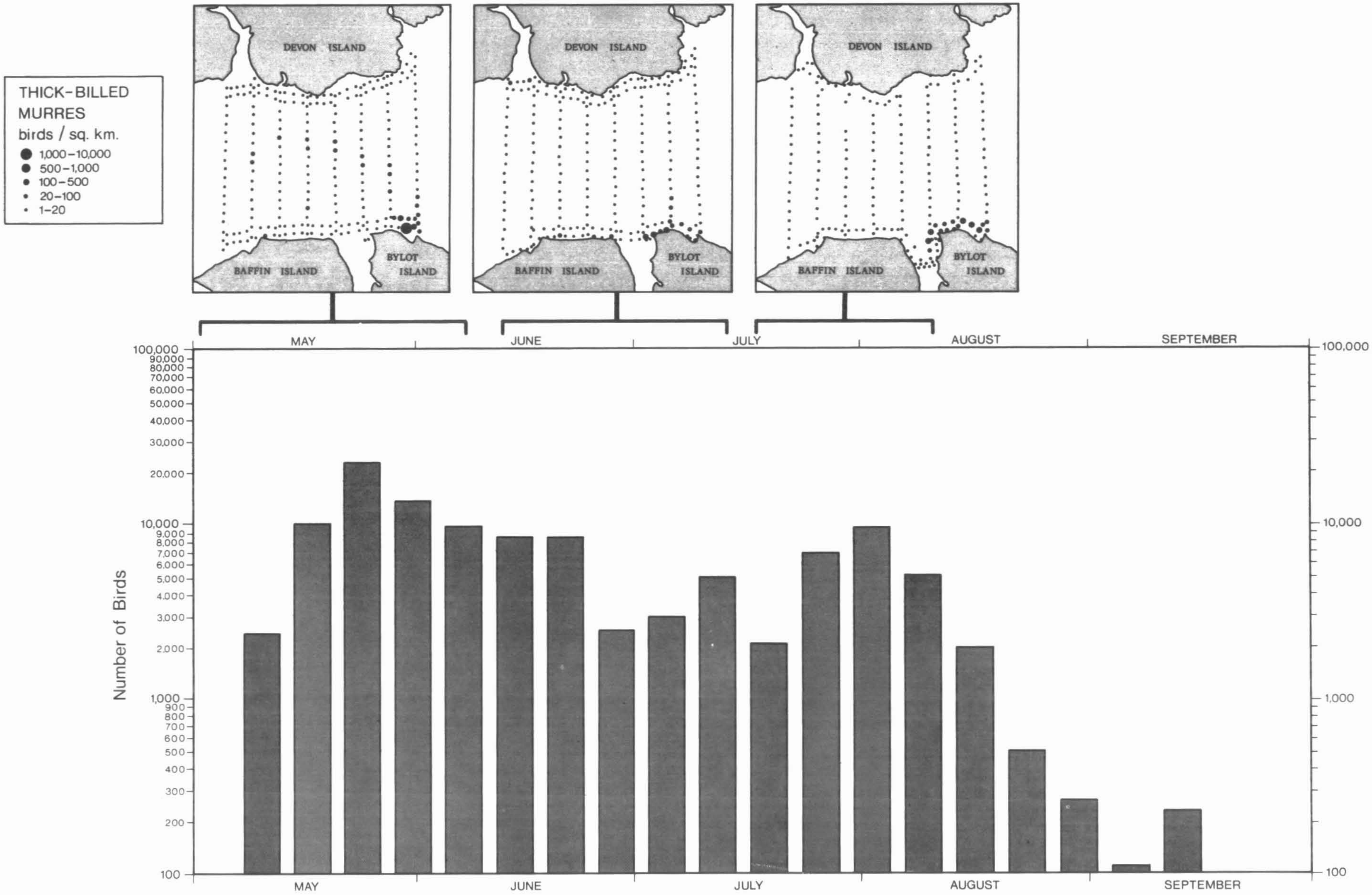
NORTHERN FULMARS ABUNDANCE AND DISTRIBUTION
(from Johnson et al 1976a)

Figure 7.10



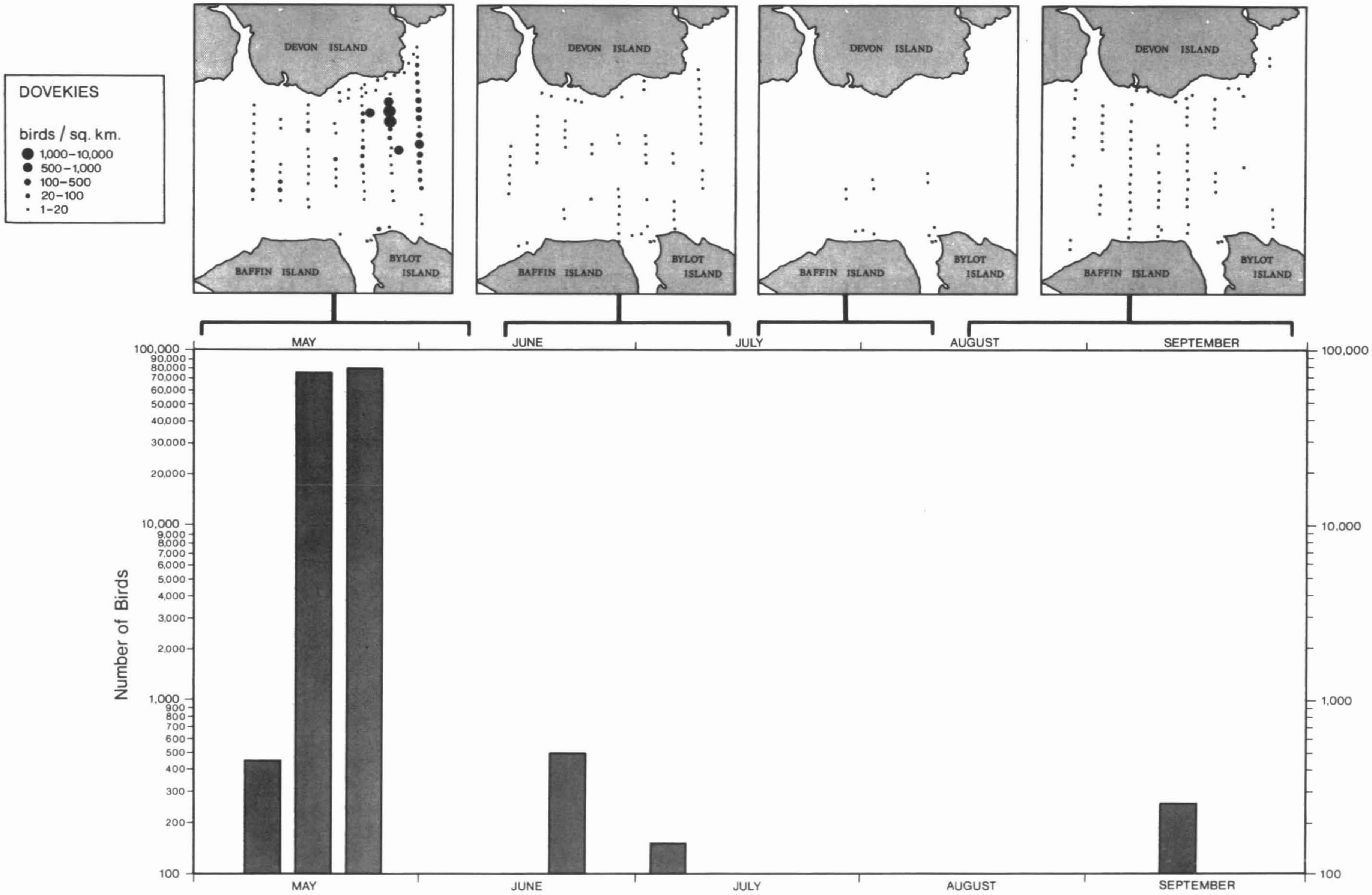
BLACK-LEGGED KITTIWAKES ABUNDANCE AND DISTRIBUTION
(from Johnson et al 1976a)

Figure 7.11



THICK-BILLED MURRES ABUNDANCE AND DISTRIBUTION (from Johnson et al 1976a)

Figure 7.12



DOVEKIES

ABUNDANCE AND DISTRIBUTION
(from Johnson et al 1976a)

Figure 7.13

the colonies. At least 1,000 remained in eastern Lancaster Sound in September, 1976[7.62].

The Guillemot's diet is similar to that of the Thick-billed Murre. Most energy intake is provided by fish, the remainder amphipods[7.34, 7.65].

7.2.5.8 Arctic Tern

The Arctic Tern *(Sterna paradisea)* breeds circumpolarly at high altitudes, completely around the Northern Hemisphere from as far north as northern Greenland, south to Cape Cod on the Atlantic coast, and in the British Isles and Norway[7.66]. The migration to wintering grounds in the Southern Hemisphere, including the Antarctic, is spectacular in length; for example, a bird banded near Disko Bay off West Greenland was recovered 10,000 miles away in South east Africa.

Arctic Terns are only moderately common in Lancaster Sound. During 1976 aerial surveys, less than 650 terns were counted[7.62]. This species was regarded by Duvall and Handley (1948)[7.74] as the most conspicuous nesting bird (about 75 individuals) along the west shore of Croker Bay. They also nest on sandspits,deltas, gravel beaches and rocky shores of northwest Baffin and Bylot islands, Admiralty and Navy Board inlets.

Terns are late spring migrants to Lancaster Sound. Most do not arrive until late June and are widely dispersed offshore. This distribution pattern quickly changes and, for most of the summer, they prefer the shallow coastal areas along southeast Devon Island. Bethune Inlet and waters adjacent to Cape Sherard supported the highest densities of 4 to 8 birds/km^2 in summer 1976[7.62]. Most Arctic Terns depart from the Sound by mid-September.

7.2.5.9 Eiders

Two Eider species — Common and King — inhabit Lancaster Sound waters for eight months of the year. The King Eider *(Someteria spectabilis)* is the more "common" by a factor of about 2.5[7.62]. Both species are holarctic breeders which overwinter in the Northern Pacific and Atlantic Oceans. The sub-species which nests in, or migrates through Lancaster Sound, spends its winter months along the coasts of southwest Greenland, south and southeast Baffin Island, Labrador, Newfoundland, the Maritime Provinces and the Gulf of St. Lawrence[7.66, 7.71].

King Eiders are primarily solitary nesters and prefer well drained habitat near lakes or ponds, a considerable distance inland. In contrast Common Eiders *(Somateria mollissima)* usually nest colonially on islands and coasts near salt water[7.62].

The earliest spring records of Common and King Eiders in Lancaster Sound are in early mid-April[7.61, 7.81]. These birds are the vanguard of many thousands to follow, which use the Sound as a major migration corridor to nesting sites on central Arctic Islands. The birds depend upon the Sound's areas of predictable open water — scarce elsewhere during the arctic spring. The first major wave of migrants, mostly paired birds, arrived in late May and early June, 1976. The density of King Eiders reached 260 birds/km^2 and 340/km^2 along ice edges of the Sound's south and north shores, respectively. Large flocks of 500 to 2,000 birds were found between Capes Sherard and Warrender, and the total estimated numbers in the eastern Sound was 20,000 or more[7.62].

During the first week of July, a second movement commences. At this time, male King Eiders (both successful and non-breeders) depart from the Sound en route to moulting waters off southwest Greenland[7.82]. Most males of this species abandon the females after the eggs are laid, and immediately migrate. They prefer to travel along the coastal waters of north Baffin and Bylot islands. Near Cape Hay, densities can reach 200 King Eiders/km^2.[7.62].

Male Common Eiders are slower to desert the breeding grounds. During the third week of July, they form a major constituent of a small but defined eastward movement of eiders. In 1976, peak numbers were recorded near southeast Devon Island, although the coastal waters adjacent to north Borden Peninsula were also concentration areas (45 birds/km^2)[7.62].

Some male eiders moult their flight feathers in Lancaster Sound. In August and September, 1976, flocks of flightless males (about 1,000) were observed in the shallow freshwater bay formed by the Cunningham Glacier's morrain on south Devon Island[7.62]. Dundas Harbour, Croker Bay and Cape Hay provide important moulting habitat for hundreds and possibly thousands of males, in some years[7.65, 7.74].

The fourth major movement of eiders occurs in early August, when thousands of female eiders fly east along the north Baffin coast, then south into Navy Board Inlet. Here, densities of 80 birds/km^2 have been reported; these are probably females which fail to breed and are en route to distant moulting areas[7.62].

An estimated 3,500 King and Common Eiders were present in Lancaster Sound in late September, 1976. Most were breeding females and their broods. These linger as late as October or until the young are capable of flight. The females lead the chicks, when only a few weeks old, to marine waters and continue to accompany them during the two month fledging period. Recent surveys by Johnson et al (1976)[7.62] recorded 194 females and 742 young; over 80% of these were sighted within 200 metres of the shoreline, along south and southeast Devon Island. Navy Board Inlet may also provide "nursery accommodation" for eider broods, since the adjacent coast is a known King Eider nesting area[7.65].

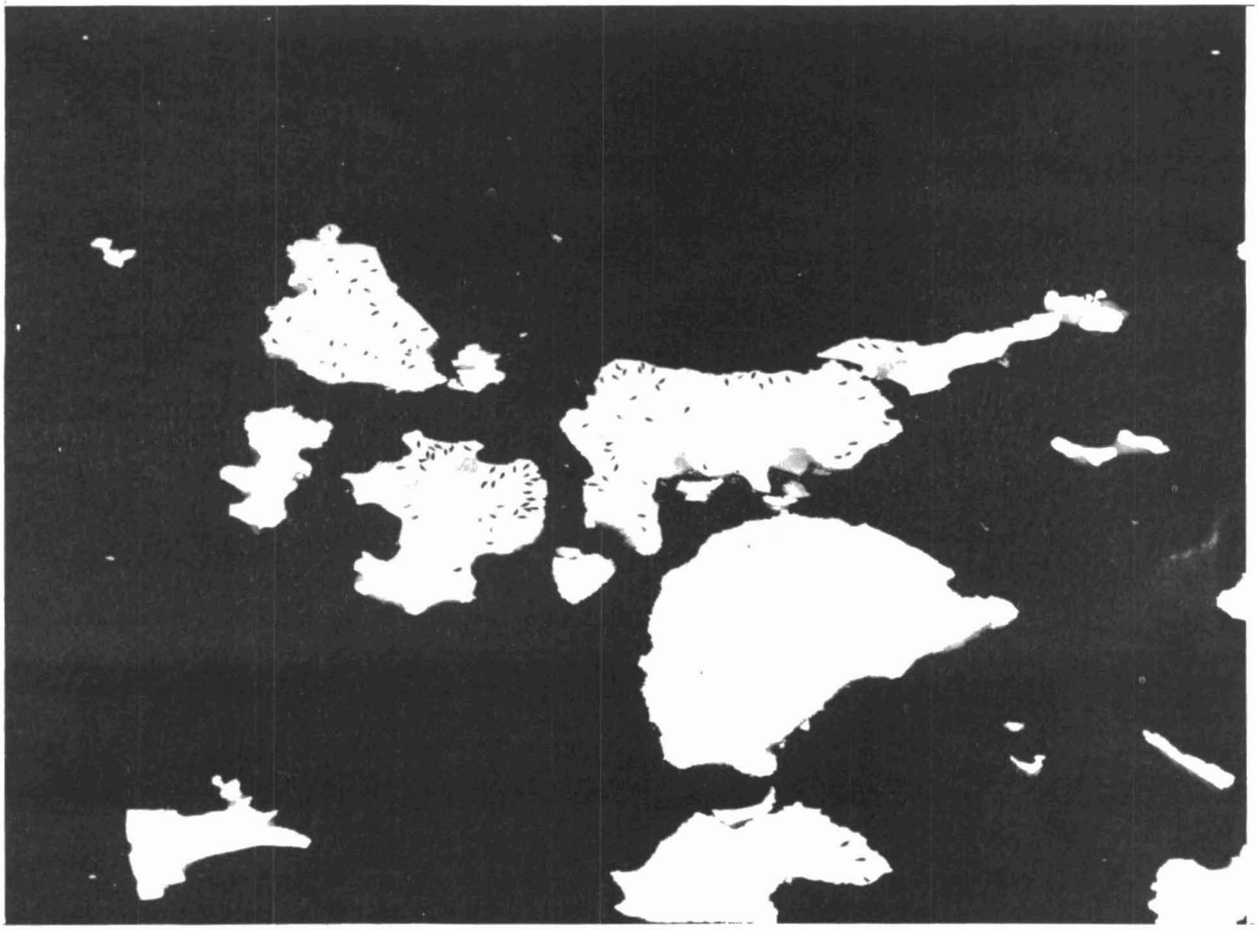
Moulting and brood rearing periods are vulnerable times of the eider's life cycle. Although Lancaster Sound is not a prime nesting ground or an important moulting area for eiders, an oilwell blowout could contaminate some of the known locales used by staging, moulting or brood-raising eiders, especially near Bylot Island and Navy Board Inlet.

7.2.5.10 Oldsquaw

This circumpolar sea duck is relatively common in eastern Lancaster Sound. It breeds on the High Arctic tundra, about as far north as land extends, and winters just south of sea ice in Davis Strait, Baffin Bay and the North Atlantic. The only suitable nesting sites, with vegetated lowlands, are the raised beaches near Croker Bay and the tidal ponds of Philpots Island — neither of which is extensive.

Small numbers of Oldsquaw *(Clangula hyemalis)* inhabit the Sound in May, however the main influx of migrants begins in early June and peaks by the month's end. Johnson et al (1976a)[7.62] estimated that there were 5,000 Oldsquaw in eastern Lancaster Sound on June 21. The birds were concentrated at specific locations such as the shallow bays, river mouths and reefs on southeast Devon Island and north Borden Peninsula, and at the entrances to Navy Board Inlet and Croker Bay. Oldsquaw are exclusively coastal birds. Ninety-seven per cent of sightings were close to the shore, two thirds of these occurring along north Baffin and Bylot islands in 1976[7.62].

In July and August, numbers of Oldsquaw steadily declined — especially along the Sound's south margin. This suggests that most of the earlier migrants were en route to better nesting areas than those in Lancaster Sound. Some flocks of moulting Oldsquaw persisted (estimated at 4,000 on September 26-28) along the Devon Island coast, particularly near Croker Bay and the Cunningham Glaciers[7.62].



Harp Seals hauled out on pan-ice in Navy Board Inlet (photo: B. Smiley)

Feeding Northern Fulmars in Arctic Bay, Adams Sound (photo: W. Renaud)

Greater Snow Goose Nesting Area on Southwest Bylot Island (photo: A. Milne)

During September 1976, the post breeding and non breeding birds reappeared in relatively large numbers (estimated at 4,000). Besides repopulating their favourite summer locales in Navy Board Inlet and Dundas Harbour, Oldsquaw concentrated between Cape Sherard and Bethune Inlet[7.62]. They tend to "raft" together in these waters after moulting and prior to their fall migration[7.62, 7.83]. Autumn freeze up finally forces the birds south.

7.2.5.11 Snow goose

Of the three goose species which summer in Lancaster Sound, only the Greater Snow Goose *(Chon caerulescens atlantica)* occurs in appreciable numbers. They nest locally in colonies or scattered pairs through the Canadian Arctic Islands and Greenland. Their preferred habitat is low, hummocky, coastal plains with ponds, shallow lakes and streams, or sometimes the protected slopes of ravines[7.66]. Within 100 km radius of proposed exploratory drilling, several known nesting areas are located — the marshy lowlands of Philpots Island, the coastal rivers of northeast Borden Peninsula and the extensive fluvial plains of southwest Bylot Island. The latter locale supports North America's largest nesting concentration of Greater Snow Geese, an estimated 7,500 pairs[7.84]. Inuit of nearby Pond Inlet who know of these birds make special hunting trips there each summer[7.42].

Snow Geese winter coastally on the Pacific (British Columbia to California), on the Gulf of Mexico (Mexico to Florida) and on the Atlantic ocean (New Jersey to South Carolina). Arrival of breeding geese in Lancaster Sound begins in early June, and they complete their southward movements out of the Sound by early September[7.62].

Snow geese cannot be considered as true seabirds as they are seldom confined to breeding and feeding in marine waters. However, many of their life habits, whether nesting, moulting or brood rearing are spent *near* salt water. For example, Johnson et al (1976a)[7.62] observed about 1,800 Snow Geese in eastern Lancaster Sound, of which 25% were sighted on marine beaches, salt water lagoons and coastal waters. Geographically, the most important areas for moulters and family groups of geese are near Croker Bay, Dundas Harbour and along the west shore of Navy Board Inlet. More than 2300 Snow Geese were sighted at the latter locale during aerial coastal surveys July 23 to August 20, 1975[7.85].

Numbers of Snow Geese inhabiting marine waters and shorelines are high in Navy Board Inlet and Eclipse Sound — both water bodies adjacent to the Bylot Island nesting grounds. Oil pollution trajectories predict that these waters, and those mentioned above, will be polluted in the event of an oilwell blowout, consequently threatening Snow Geese populations.

7.2.6 Marine Mammals

Eleven species of marine mammals inhabit Lancaster Sound. Some are permanent residents and others seasonal visitors. The ubiquitous Polar Bears and Ringed Seals survive year round among the region's pack ice, the latter species being the most numerous year-round inhabitant. Walruses and Bearded Seals select shallow marine locales to overwinter where currents and winds maintain open water. These areas are not found in Lancaster Sound but exist within a distance of several hundred kilometres. The remaining seven species are migratory transients which use the Sound for travel, feeding and perhaps breeding during the six months of broken ice and open water. Lancaster Sound is the most important travel "artery" for marine mammals of eastern Arctic Canada. Each year, tens and even hundreds of thousands of White Whales, Narwhal and Harp Seals pass along its shores en route to breeding sanctuaries or summer feeding locales in connecting channels, bays and inlets. However, thousands remain in or near Lancaster Sound during July and August, at known sites such as Croker Bay and Dundas Harbour (south Devon Island), Navy Board and Pond inlets (north Baffin Island). A major sector of the Archipelago's population of Walruses summer at traditional sites in the Sound's coastal waters. Bowhead Whales, Bearded Seals, Hooded Seals, Harbour Seals, and Killer Whales are regular but relatively scarce visitors.

Our knowledge about the principal mammal species — Narwhal, White Whale, Ringed Seal, Polar Bear and Harp Seal — is barely adequate for judging the potential threat from proposed offshore drilling. The following accounts of marine biology do not exhaustively describe migration options, feeding opportunities, population dynamics, and so on, of the Sound's marine mammals. In many cases, data is based on a single year's study at one site. Since the distribution of marine mammals is largely dependent on ice conditions, descriptions of the "average" timing of migrations, locations of usual summering sites and usual food habits are only as useful as descriptions of "average" ice conditions. The Arctic is a region of annual and seasonal extremes. Animals counter these by sometimes surprising opportunistic responses. Ultimately, harm from oil pollution and other related disturbances depends on the real life situation which is always unique to the event. Thus, "average" based impact predictions are inherently weak.

Population estimates of some marine mammals are unknown, and others are under revision. For example, using observations from 1976 aerial surveys in eastern Lancaster Sound, the Narwhal population of 6,000 thought to inhabit these waters was revised to between 20,000 and 30,000[7.86], now comprising over 80% of Narwhals in eastern North America. Another example of differing population estimates occurred during two similar migration watches in 1957 and 1976, at Cape Hay. The number of Harp Seals swimming past were 136,000 and 16,000, respectively[7.58, 7.87]. It is uncertain how much year to year variability is real and how much is merely an artifact of experimental design.

7.2.6.1 White Whale (Beluga)

White Whales *(Delphinapterus leucas)* are holarctic toothed whales which occur as far south as Nova Scotia. Of the estimated population of 30,000 White Whales in the North American Arctic, at least one third migrate through Lancaster Sound en route for summer feeding and breeding[7.88].

White Whales live for 30 or so years and breed once every three years. Their gestation period is 14.5 months, and calves are born in late July or early August. Lactation continues for about 2 years. White Whales attain sexual maturity in 5 years and 8 years for females and males, respectively[7.89].

Where Beluga winter is poorly understood, however they likely overwinter in Baffin Bay, Davis Strait and Ungava Bay, and then migrate to bays and straits of the Arctic Archipelago during the summer. Lancaster Sound may provide overwintering habitat with open water[7.88], but satellite imagery reveals that suitable open water is seldom present and never predictable, during winter. Some evidence exists that the "North Water" polynya is inhabited by wintering whales; the early March arrival of White Whales along south Devon Island lends to support this hypothesis[7.90].

In Lancaster Sound, the whale's spring migration extends progressively westward over 3 or 4 months. In some years, the first migrants appear at Cape Warrender by the second week of March, and seven weeks later, they have pushed 250 km further westward, to Maxwell Bay. Early travel westward is permitted by the persistent flaw-lead along the south Devon Island coast which connects the Sound with Baffin Bay[7.90]. The peak influx occurs in early June. For example, 8,233 White Whales were observed during aerial surveys on June 6 – all whales were swimming westerly[7.90]. Both margins of the Sound are travel routes, but the Devon Island side is two to ten times more popular (Figure 7.14)[7.91].

Spring migrants are often dispersed, usually in small groups (about 80% occur in herds of 20, or fewer). They exhibit a leisurely attitude toward swimming and migration possibly because of active feeding[7.90].

In contrast, the reverse fall migration is intense and abrupt, beginning in eastern Lancaster Sound by mid-September. Three or four weeks later, White Whales are no longer present in the region. A dramatic illustration of this exodus was the sightings of 7,400 whales migrating through these waters in just three days in September 1976. Often the herds were large – up to 1,600 animals; seventy per cent travelled in herds of 80 to 300 animals[7.90]. Most swim strongly along the south Devon Island shore, often less than 200 m from the beach[7.91]. Croker Bay, Cape Warrender and Bethune Inlet are fall "stop overs" for large numbers of migrants[7.90].

There are few or no White Whales in Lancaster Sound in August and early September. They merely pass through and disperse westward, into Prince Regent Inlet, Peel Sound, Franklin Strait and Wellington Channel. Here they concentrate in shallow, coastal waters, such as Cunningham Inlet, Elwin Bay and Creswell Bay (Somerset Island), or in Maxwell and Radstock bays (southwest Devon Island) to feed or calve. For example, about 3,900 whales were sighted in Creswell Bay during August 1975[7.92].

Inuit of Pond Inlet report that 10 to 15 White Whales irregularly occupy Eclipse Sound waters in August, together with 500 to 1,000 Narwhal[7.93].

Knowledge of whale's food habits is based on the examination of stomachs of animals killed by Inuit. The diet is comprised of fish, such as capelin, Arctic Cod, cisco, sculpin, flounder and Arctic Char, and marine invertebrates, such as octopus, squid, shrimp and large amphipods[7.94, 7.95]. The whale's food apparently depends on whether they are feeding in summer estuaries, such as Creswell Bay or Cunningham Inlet; along spring ice edges at Pond Inlet; in the south Devon Island flaw lead or in the open waters of Peel Sound and Barrow Strait. Seasonal food preferences and critical feeding locales are not generally known.

White Whales are of minor importance to the domestic economies of Inuit at Pond Inlet and Arctic Bay. White Whales are occasionally taken by Narwhal hunters using similar methods[7.42, 7.96]. Resolute Bay hunters have regularly killed about 50 animals each year between 1958 and 1967. In some years, the harvest has been almost twice this; in other years, almost none[7.97]. Today, subsistence whaling is much less important, having declined substantially in the past decade.

7.2.6.2 Narwhal

Along with its smaller White Whale cousin, the Narwhal *(Monodon monoceros)* is a co-member of the family Monodontidae – thought to be a primitive dolphin group. Narwhal are only found in the Atlantic sector of waters adjoining the Arctic Ocean. In Canada, their winter distribution centres in the loose pack-ice of Davis Strait and Baffin Bay, but they are known to range as far south as north Ungava Bay[7.94], and possibly north to the "North Water" polynya, between Ellesmere Island and northwest Greenland. During the spring and summer, Narwhals prefer broken landfast ice, ice floes and deep waters of fjords and inlets along Baffin, Ellesmere and Devon islands[7.102].

Narwhal reproductive biology is similar to that of White Whales. They are seasonal breeders in April and May. Calving takes place in June, July and August[7.98]. An estimated 30% of Narwhal calves are born before the spring migrants reach Lancaster Sound. Apparently north Baffin Island fjords and inlets are not essential as birth sanctuaries[7.99].

The population of Narwhals is not precisely known. Until last year, the combined northwest Greenland and eastern Canadian population was estimated to be 10,000 animals[7.87, 7.100, 7.101]. Based on recent surveys[7.85, 7.91], the estimate has been adjusted up to, at least, 20,000 to 30,000 animals[7.86]. However, this cannot be substantiated without a systematic aerial census of prime Narwhal summering locales, such as Admiralty Inlet, Navy Board Inlet and Eclipse Sound.

Early spring sightings of Narwhals in eastern Lancaster Sound begin in late April. These first migrants wend their way west from Baffin Bay, using the south Devon Island flaw lead[7.90]. In May and early June, only a few hundred Narwhals are scattered throughout the Sound (Figure 7.15). Most of them (60-80%) enter via offshore routes; densities of 1.6 and 2.5 Narwhals/km^2 are found along the fast ice edge of north Borden Peninsula and Navy Board Inlet[7.91]. The herds are small - usually less than 25 animals[7.90].

Spring migration reaches its peak in late June and early July. Mean density in the Sound increases to 0.2 Narwhals/km^2 but at times reaches 0.7/km^2 in some years. About one half of the animals migrate offshore; the others are found along both coastal margins[7.91]. Recent surveys on July 5 recorded densities of about 10 Narwhals/km^2 near Dundas Harbour and Navy Board Inlet. On the same day, an estimated 2,600 animals were passing through the Sound[7.91]. In late July, virtually every Narwhal is found along the Sound's south margin. Some are probably en route to more westerly summering ranges but many seem to await fast ice break up in the major fjords and inlets of north Baffin Island. For example, on July 22, 1976, about 1,300 Narwhals were counted along the Navy Board Inlet ice-edge and another 1,600 at the mouth of Admiralty Inlet[7.90].

Narwhal are rare sightings in Lancaster Sound during August. The several hundred, or possibly a thousand animals that migrate west as far as 98°W, arrive at Prince Regent Inlet by June of some years. Some continue into Barrow Strait, Wellington Channel or northern Peel Sound[7.92]. However the largest component of Arctic Canada's population remains in close proximity to Lancaster Sound – in the waters of Admiralty Inlet, Navy Board Inlet, Eclipse Sound and Pond Inlet. An estimated 10,000 Narwhals were reported in Admiralty Inlet during July and August, 1975[7.80].

Outmigrating Narwhal, often in herds of several hundred, reappear in eastern Lancaster Sound in peak numbers by late September. On September 28, 1976, an estimated 6,500 Narwhals were within a 60 km radius of Norland's proposed drilling site[7.91]. Of the 900 animals sighted, 50% were travelling offshore; about 33% were along the Baffin-Bylot coast and the remainder were off the south Devon Island coast. Highest coastal densities of 2 to 4.5 Narwhal/km^2 occurred at the mouths of Croker Bay and Navy Board Inlet, along Borden Peninsula and Cape Sherard. Densities were generally less offshore; However, total numbers here are considerably greater because of the hundreds of square kilometres of water.

By October, only a few tens of Narwhal remain, mostly offshore in extreme eastern portion of the Sound (Figure 7.15).

Over much of their range, Narwhal eat octopuses, molluscs, flounder, halibut, skate, squid, shrimp and Arctic Cod[7.94]. The latter three organisms were found in the

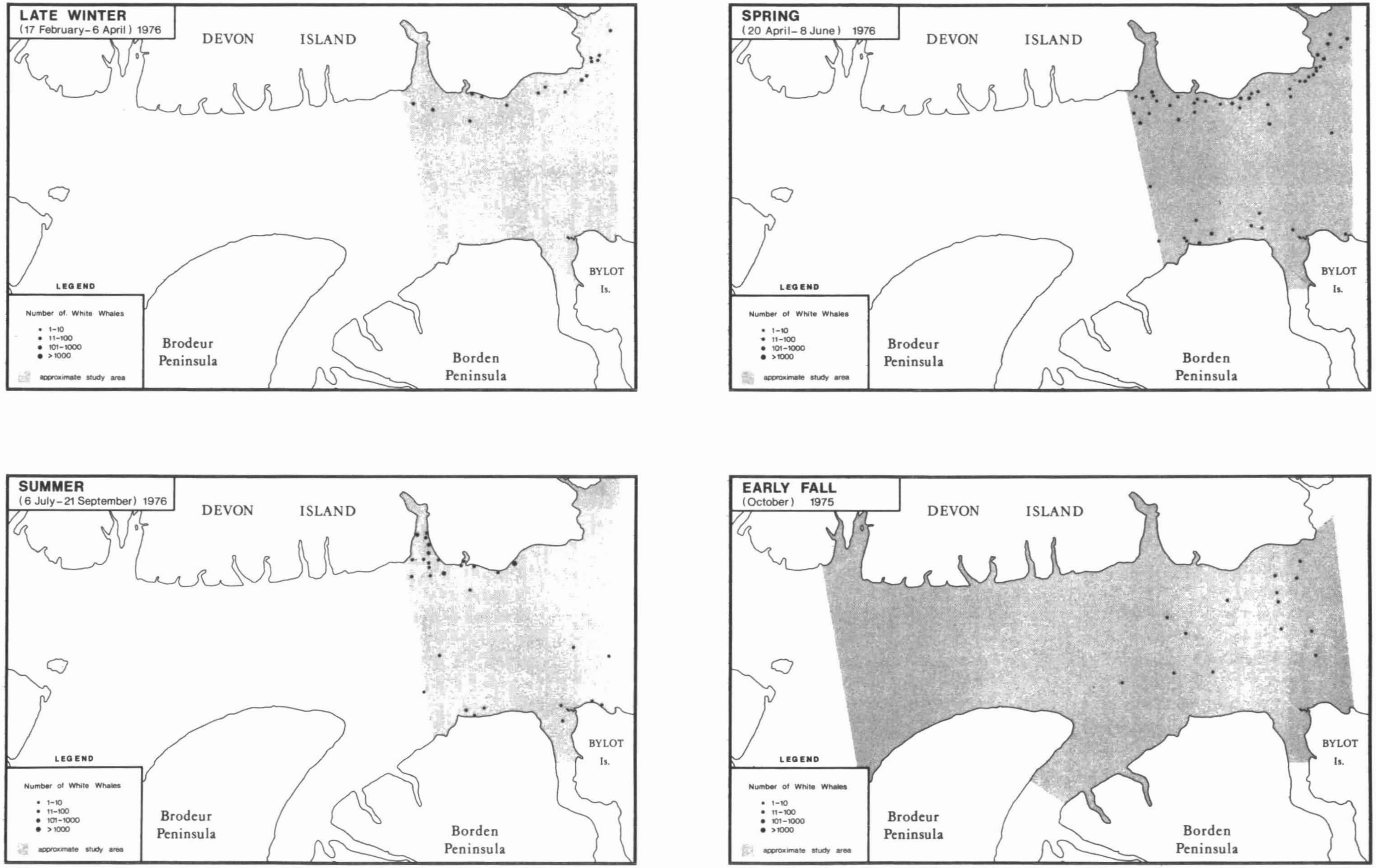


Figure 7.14

WHITE WHALES – SEASONAL ABUNDANCE AND DISTRIBUTION

(from Renewable Resources Consulting Services, 1977)

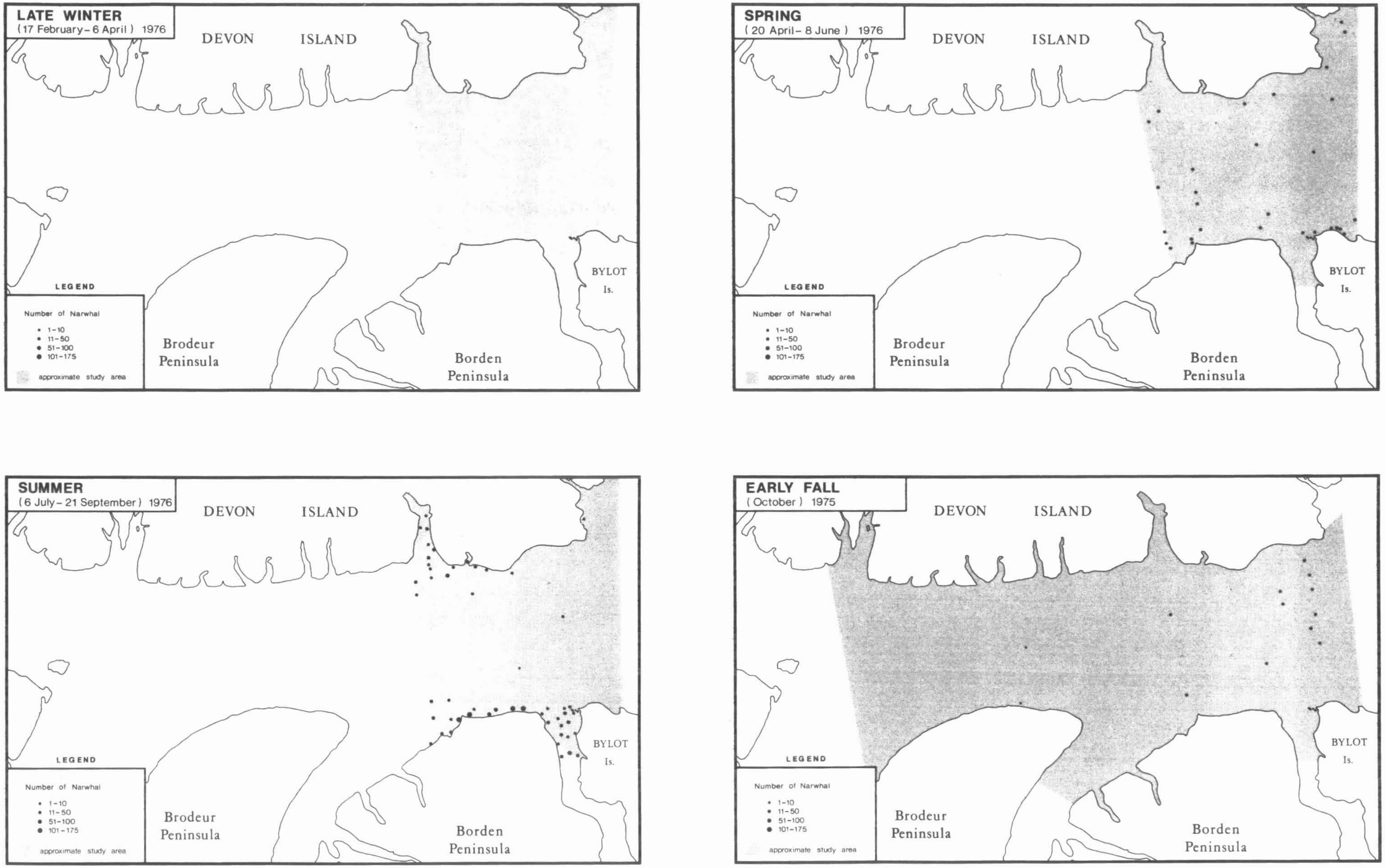


Figure 7.15

NARWHAL – SEASONAL ABUNDANCE AND DISTRIBUTION

(from Renewable Resources Consulting Services, 1977) stomachs of Narwhal killed by Inuit near Pond Inlet[7.103]. Fast ice-edges are especially important to feeding Narwhal prior to the open water season[7.99].

Killer Whales, rogue Walrus and Man are the Narwhal's enemies. European and American whalers hunted the Narwhal briefly during the failing years of bowhead whaling. In one season, as many as 2,800 were harvested from Eclipse Sound[7.94]. The value of Narwhal to the Inuit of Baffin Island, both historically and today, cannot be overemphasized. It is a source of food for people and dogs. The ivory tusk of the male Narwhal is traded for cash ($30 per lb) at the Hudson Bay or native cooperative. Inuit shun the meat and prefer the muktuk; however, both are excellent sources of protein in the winter and could substitute for costly, imported canned meats. In the words of Hay and Sergeant (1976)[7.100], "Narwhal is an indispensable resource of the Inuit of northern Baffin Island — but there is also a need for its more effective and complete utilization."

The major spring hunting locales of north Baffin Island are along the floe edges of Admiralty, Navy Board and Pond inlets. Open water hunting is popular in Admiralty Inlet (near Arctic Bay) and Eclipse Sound. Inuit pursue Narwhal in motorized canoes, and force the herds into shallow waters, where they are shot and harpooned. Since Narwhals are elusive and sink when dead, they are not hunted over deep water. The sinking loss in Eclipse Sound is about 15%[7.100].

A community annual quota of 100 Narwhals was recently introduced in Pond Inlet and Arctic Bay. Previously, the Government regulations specified 5 Narwhal per hunter. Other settlements such as Resolute Bay, Clyde Inlet and Grise Fjord seldom have the opportunity to hunt Narwhal[7.100].

7.2.6.3 Bowhead Whale (Greenland Right Whale)

Bowhead whales *(Baleana mysticetus)* are large (up to 20 m long) baleen whales, confined to arctic and sub-arctic regions, from Spitzbergen to Wrangell Island of the U.S.S.R. In eastern Arctic Canada, they are scattered throughout north Hudson Bay, Foxe Basin, Davis Strait, Baffin Bay and the waters adjacent to the Arctic[7.94]. Some Bowheads winter in Davis Strait, then travel northward along the West Greenland coast in spring. Eventually, they cross over to summer in Smith, Jones and Lancaster sounds.

From 1956 to 1971, numerous sightings of Bowheads were recorded throughout all of Lancaster Sound, Barrow Strait, Wellington Channel, Prince Regent Inlet, Admiralty Inlet, Navy Board Inlet, Eclipse Sound, Pond Inlet and northwest Baffin Bay[7.104]. Their numbers are much reduced from the large populations which supported commercial whale fisheries in the 1800's and early 1900's. The Bowhead whale has been protected from modern whaling since 1937, when the North American population was judged to be on the brink of extinction. Even today, this marine mammal is considered an endangered species by the United States. In June, 1977, the International Whaling Commission unsuccessfully attempted to place a total ban on Bowhead hunting, even by the Inuit. However, Canadian Inuit have volunteered to a zero quota.

Recent 1976 aerial surveys of eastern Lancaster Sound, recorded only 39 Bowheads between late March and late September[7.90, 7.91]. Most were scattered along the southern margins of the Sound in June (Figure 7.16). Twenty-three animals swam past an observation post on the Cape Hay cliffs during late June and July of the same year[7.87]. Although some Bowheads linger in Lancaster Sound during the open water season, most migrate further west. The autumn freeze up probably forces these whales to retreat south in October. The Bowhead's food is planktonic crustaceans; its baleen plates and lips are used to strain enormous quantities of these organisms from sea water. The Killer Whale is its only natural enemy[7.94].

7.2.6.4 Polar Bear

Polar Bears *(Ursus maritimus)* are circumpolar marine mammals, inhabiting all arctic seas and coastlines. Individuals have been spotted within two degrees of the North Pole[7.94]. In Arctic Canada, they are found north to Ellesmere Island but most commonly in the Beaufort Sea, Amundsen Gulf, Hudson Bay, and the waters adjacent to the Arctic Islands. Recent research has revealed that Canada's Polar Bears are subdivided into 15, or so, discrete populations[7.105]. At one time, it was believed that all the world's Polar Bears were of the same nomadic population.

Hundreds of Polar Bears inhabit Lancaster Sound and adjacent land masses year-round. The size of the population is unknown; a guess of 1,000 bears[7.106] is, to date, unsubstantiated. Nonetheless, numbers are probably high. Lancaster Sound bears are part of the sub-population to the west (Barrow Strait, Wellington Channel and Byam Martin Channel), and to the north in Jones Sound. Capture-recapture information[7.105, 7.106, 7.108] indicates that the Sound's bears travel great distances across the winter sea-ice, even to west Greenland. These movements are often 300 km — longer than for most other Arctic regions. Reasons suggested are the Sound's long, narrow configuration and its continuous ice motion[7.108].

In winter, Polar Bears prefer to hunt the floe-edges, particularly along landfast ice anchored to the shores of Devon and Baffin islands. This coastal band of unstable ice is a suitable platform from which bears can successfully hunt seals. From fall freeze-up to spring break-up, these floe edges are continually opening and re-freezing under the influence of winds and currents. The resulting patches of young, refrozen ice and pressure ridges are preferred habitat for Ringed Seals because of easier access to air and food. The lack of snow cover makes them vulnerable prey to Polar Bears.

The Devon Island coast is more important than the Baffin Island coast to overwintering bears; the Sound's northern flaw-lead is more active and persistent throughout the winter and spring[7.90]. The north shore of Bylot Island is reported by Inuit hunters to be another regular wintering area. At this locale, the edge of the landfast ice is only a few kilometres offshore[7.108].

Pregnant female bears are not active winter hunters. Instead they seek out coastal maternity dens on land in October and November. Insulated from the cold (and potential oil pollution), they remain in their dens until early April emerging with 4- or 5- month old newborn cubs. Few dens have ever been located, and most of these are on Bylot Island (Figure 7.17). Since much of the Sound's coastal margin provides suitable denning habitat, it is assumed that denning is widely dispersed. Suspected denning areas are on north Borden and Brodeur peninsulas and on localized areas of south Devon Island. These suspicions are based, in part, on the nearby sightings of bear sows and cubs in early April. Small young cubs, having left the protection of the den for less than three weeks, have difficulty in long travels, and restrict the female's movements to near the den[7.108].

Most dens are situated within a few kilometres of the shoreline; thus, shore-based industrial activities, such as drilling equipment staging, personnel base construction and airstrips, pose a threat to Polar Bear survival. Stirling et al (1975)[7.107] warn, "Because of the critical nature of Polar Bear cubs at birth, it seems likely that disruption of dens, prior to the time they would normally be deserted, would result in a high degree of mortality of newborn cubs." With present fragmentary information, biologists cannot accurately delineate important denning areas.

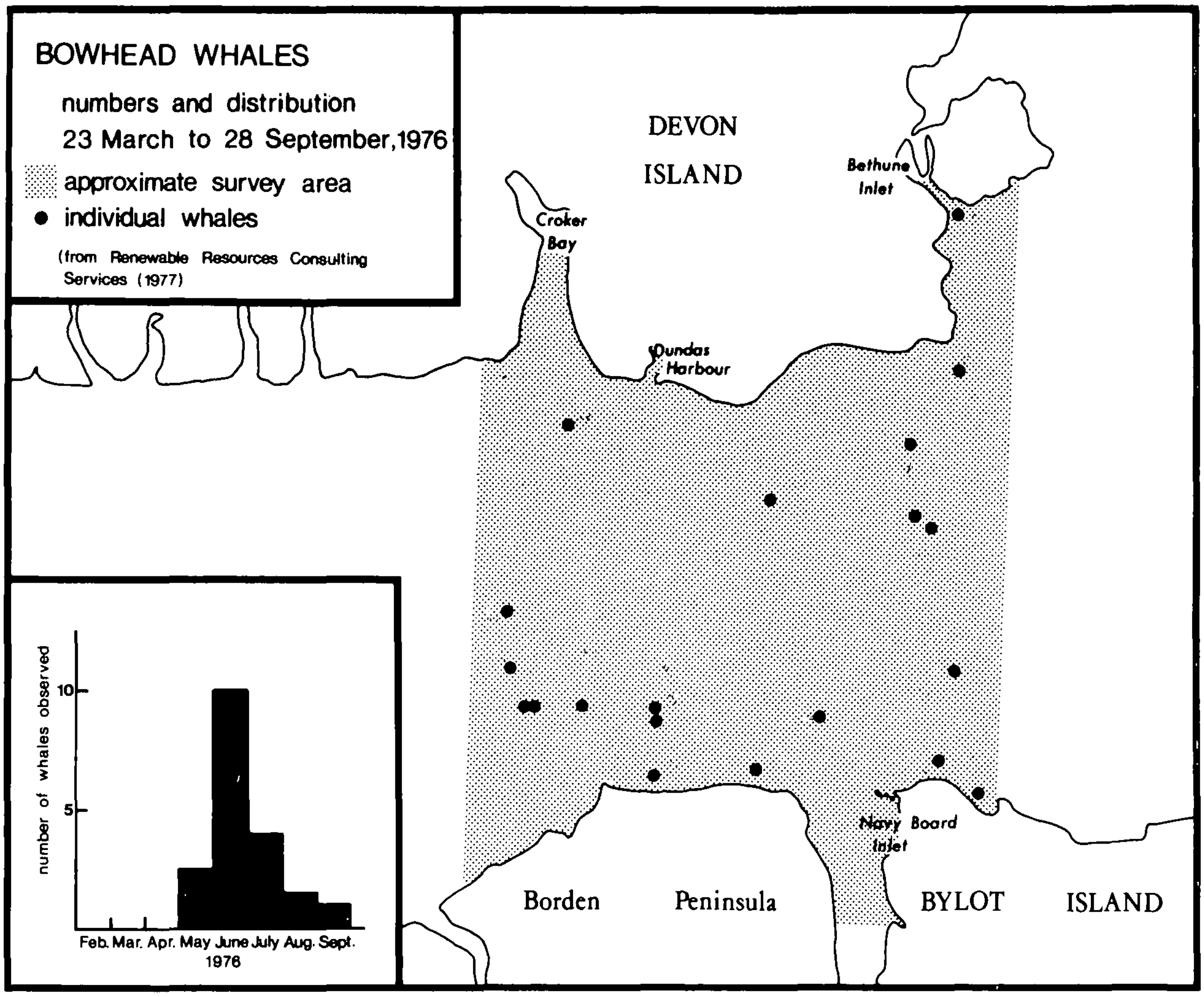


Figure 7.16

In spring, Polar Bears are found where seals concentrate—along floe edges, in unstable offshore sea-ice and on coastal landfast ice. For example, 36 bears were sighted in eastern Lancaster Sound during the period, May 2 to June 7; of these 53% were on landfast ice and 31% amongst offshore pan ice[7.91]. The months of May and June herald the birth of Ringed Seal pups, and the annual moult of adult seals. Polar Bears quickly take advantage of these easily accessible prey — seal pups are helpless within subnivean lairs, and the moulting adults are reluctant to enter the water. The bears' spring feast serves to replenish fat supplies depleted during denning and mating[7.108]. The coasts of south Devon Island, north Bylot Island, north Borden Peninsula and Admiralty Inlet are important spring habitats (Figure 7.18).

As the ice melts and disappears from the Sound in late spring and summer, many Polar Bears are forced into deep bays and fjords, where fast-ice persists and seals concentrate. Between June 13 and August 10, 83% of the 93 bears sighted by Johnson et al (1976b)[7.91] were on landfast ice, usually along the south Devon Island coast. Until mid-August, Croker Bay is a popular haunt for bears (Figure 7.19). When these last remnants of ice disappear, the bears remain on the adjacent land. Known summer "retreats" are on southwest Devon Island (Radstock and Maxwell Bays), north Brodeur and Borden peninsulas, Bylot Island, northwest Baffin and southeast Devon islands. North Somerset Island and west Borden Peninsula are also suspected as summering locales[7.106, 7.107, 7.108]. Coastal summer retreats seem especially important to female bears of all ages, sows with cubs and juvenile males. Here, they await freeze-up, before returning to sea-ice to hunt for their usual prey[7.108]. When restricted to land, they scavenge or feed on birds and vegetation. Meanwhile, the adult males float offshore on pan ice, if present, travel the coastlines or meander inland — sometimes over the ice-caps of glaciers[7.80, 7.108]. The value and significance of summer retreats to bears of different ages and sex are unknown.

The food of Polar Bears is best summarized in two words — Ringed Seals. Basically it is the availability or accessibility of Ringed Seals, determined by ice conditions, which dictates the bears' lifestyle and distribution patterns[7.107]. Polar Bears kill more sub-adult than adult seals. Presumably, these juveniles are easier to catch because they are relatively inexperienced with predators, and are often forced into marginal habitat (unstable offshore ice) by dominant seals[7.109]. Bearded Seals, Walruses, White Whales and Narwhal are also eligible prey. Polar Bears have also been observed as they dive beneath the water and catch swimming seabirds, or eat kelp[7.110].

Historically, Polar Bear meat was eaten by men and dogs. The hides were used for waterproof boots, pants, sleeping bags, and sled-covers[7.94]. Today, the Inuit of the eastern Canadian Arctic hunt bears, primarily for their skins — a fur of considerable market value. Recent prices of bear skins range from $500 to $1,700[7.108].

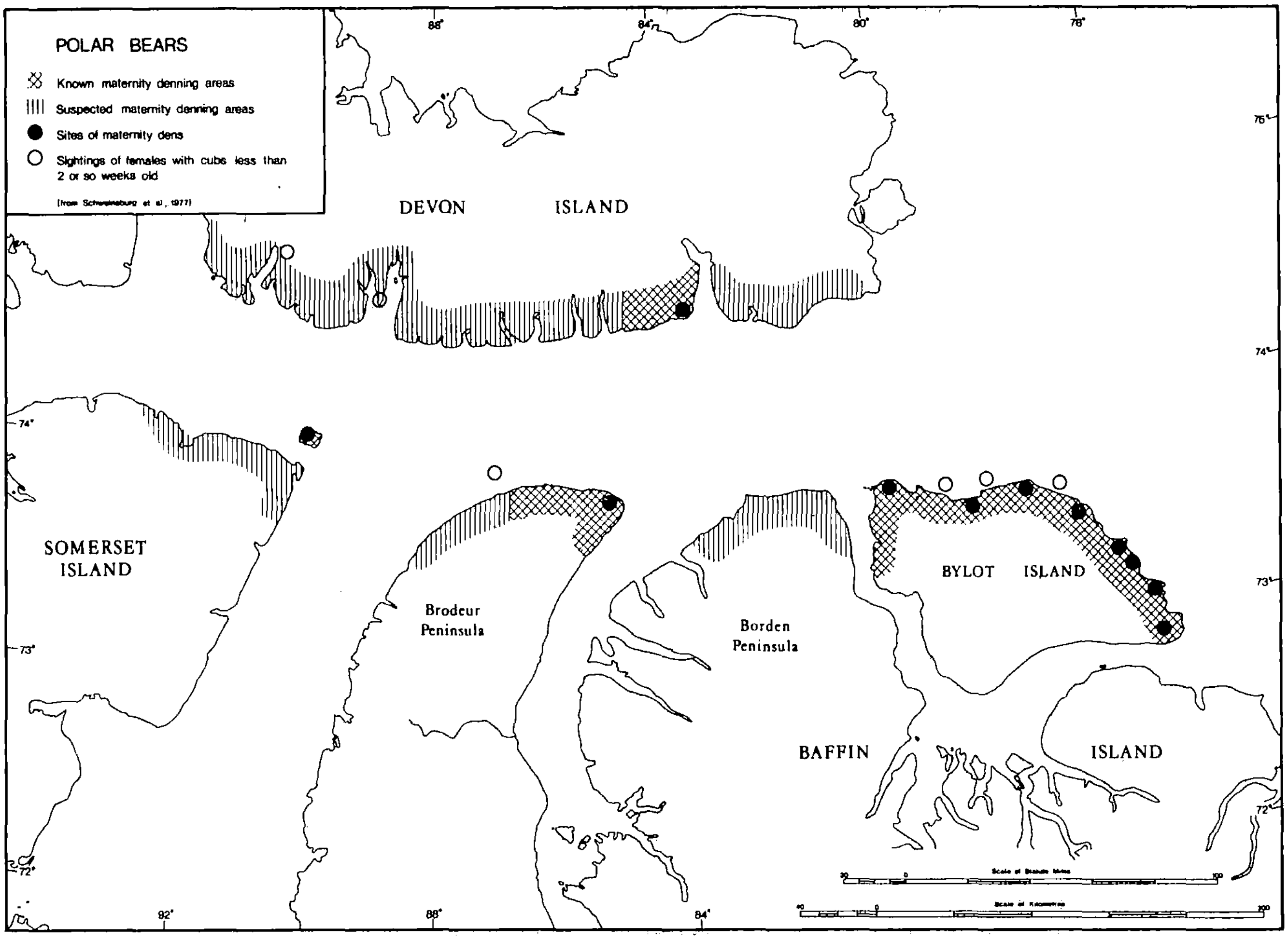


Figure 7.17

The principal hunting areas for Polar Bears in and near Lancaster Sound are outlined in Figure 7.20. Although communities such as Clyde (northeast Baffin Island) and Grise Fjord (Ellesmere Island) are hundreds of kilometres distant from the Sound, the Polar Bears killed by each settlement are, probably, of the same sub-population. Pond Inlet residents hunt far afield throughout the Pond Inlet-Eclipse Sound-Navy Board Inlet system, and along southeast Bylot Island. Arctic Bay Inuit restrict their bear-hunting to the northern two-thirds of Admiralty Inlet, although some expeditions travel to Prince Regent Inlet. The Government-imposed annual quotas of about 12 to 14 bears are quickly filled in each community during the period, January to May[7.42].

The kill of Polar Bears by Resolute Bay hunters far exceeds that of other hunting areas anywhere in Arctic Canada. For example, the three years prior to a quota of 40 (introduced in 1967), an average of 68 bears were killed each winter. Barrow Strait and Wellington Channel are prime hunting grounds, especially along spring floe edges.

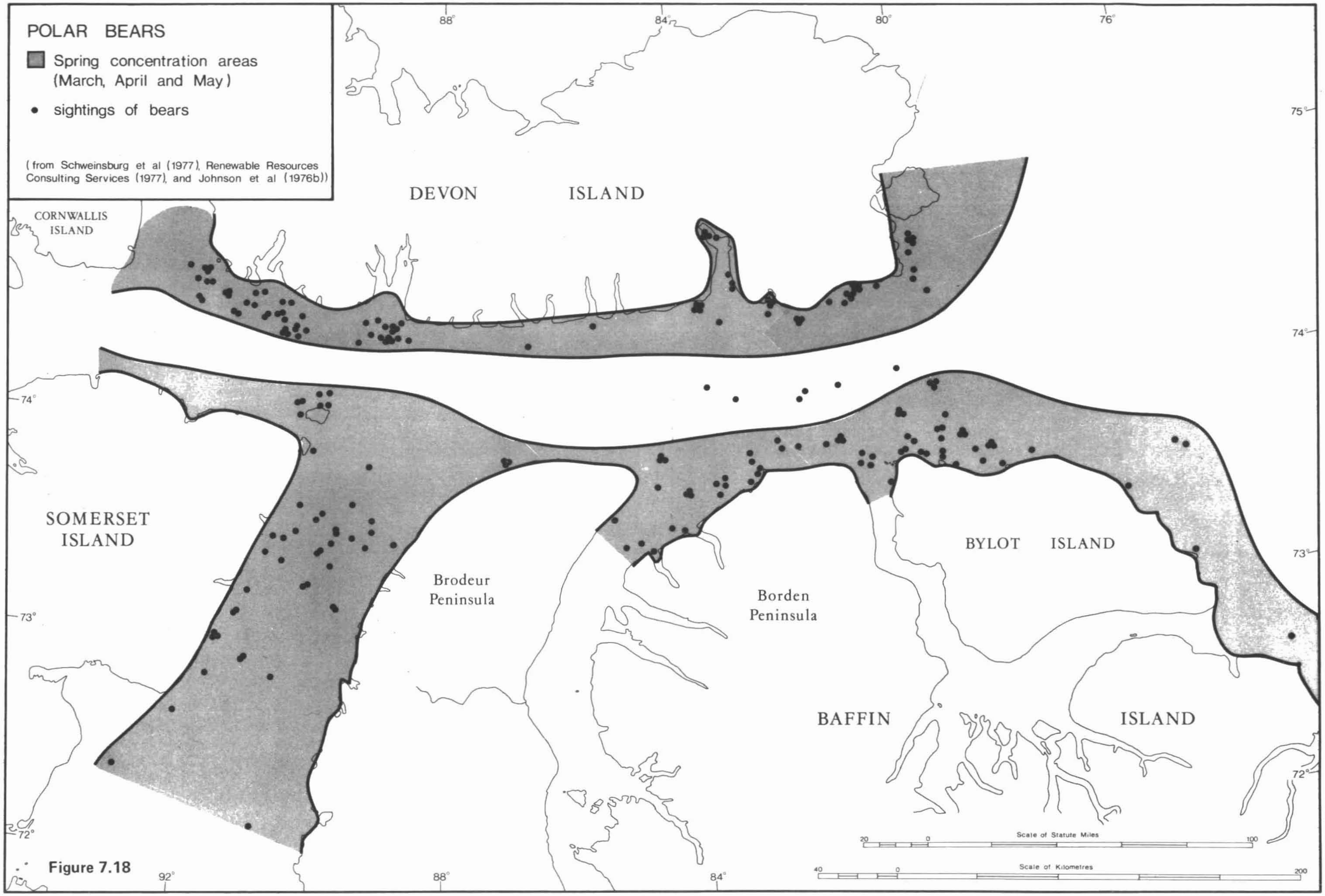
Between 1972 and 1975, the commercial sale of Polar Bear skins provided these three communities with an estimated $125,000[7.108]. In addition, Pond Inlet hunters received $18,000 for guiding non-Inuit sports hunters.

7.2.6.5 **Walrus**

Walrus *(Odobenus rosmarus)* of the eastern Canadian Arctic and West Greenland comprise one of three geographically-isolated populations in the North Atlantic region. The Sound's Walruses are probably the same animals as those found overwintering along West Greenland coasts[7.112]. The population size is estimated at about 25,000 animals. Relatively few Walruses, 1,000 or less, inhabit Lancaster Sound and waters to the west. However, several minor overwintering sites are known in the Arctic Archipelago - the polynyi of Penny Strait and Queen's Channel, about 500 km NW of Lancaster Sound[7.92]. The Sound itself offers little or no overwinter habitat; the only record is of "small numbers" of Walruses which wintered at Dundas Harbour in 1949-50[7.111].

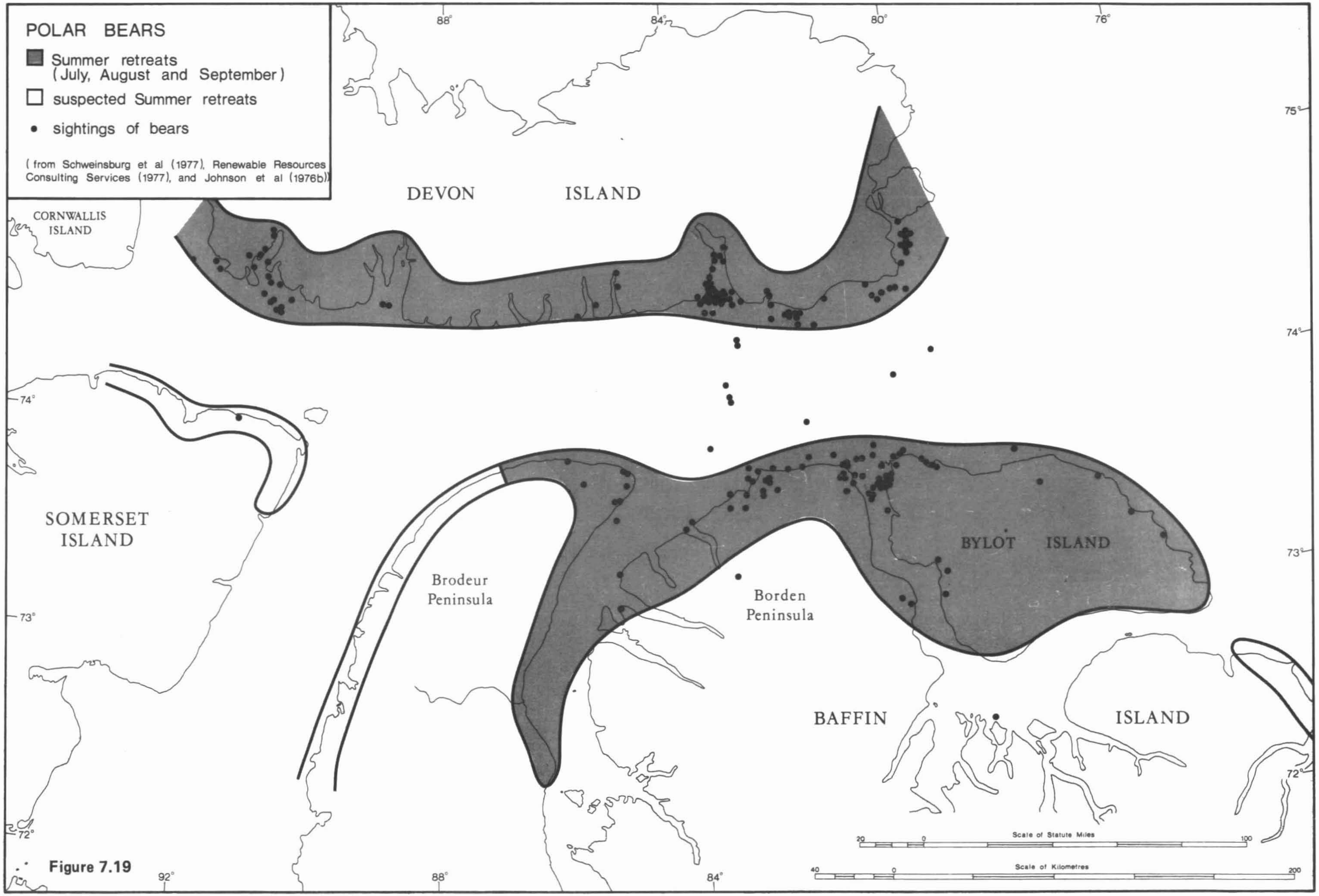
The reproductive rate of Walrus is an 8% per annum, or 0.35 calves per adult female[7.112]. Females can bear young every 2 years, but most produce calves 3 or 4 years apart. Mating occurs in April and May. A year later, calves are born. Mid-May is the peak calving period. The bond between female Walrus and their young is strong and persists for 2 years. Calves become independent feeders in their third summer[7.112].

The spring migration of Walruses, into Lancaster Sound, begins in late April. Usually, these westward migrants follow the south Devon Island flaw-lead. This probably accounts for an April 20 sighting of Walruses in Maxwell Bay, southwest Devon Island[7.90]. If ice conditions permit, Walrus may choose to travel along the Baffin/Bylot coastal migration route. Arctic Bay Inuit reported hunting Walruses along the fast-ice edge of Admiralty Inlet as early as April 30, in 1924[7.113]. The peak influx of Walruses into the Sound occurs from early June to early July – about the same time as that of Narwhals. Some of these Walrus migrants are en route to Crozier Strait[7.92], others are bound for Prince Regent Inlet and Wellington Channel[7.114]. Central Barrow Strait and Peel Sound are the western limits of the species' range[7.115]. However, unlike Narwhals or White Whales, hundreds of Walruses remain and summer in the Sound's waters. Between June



(from Schweinsburg et al (1977), Renewable Resources Consulting Services (1977), and Johnson et al (1976b))

Figure 7.18



(from Schweinsburg et al (1977), Renewable Resources Consulting Services (1977), and Johnson et al (1976b))

Figure 7.19

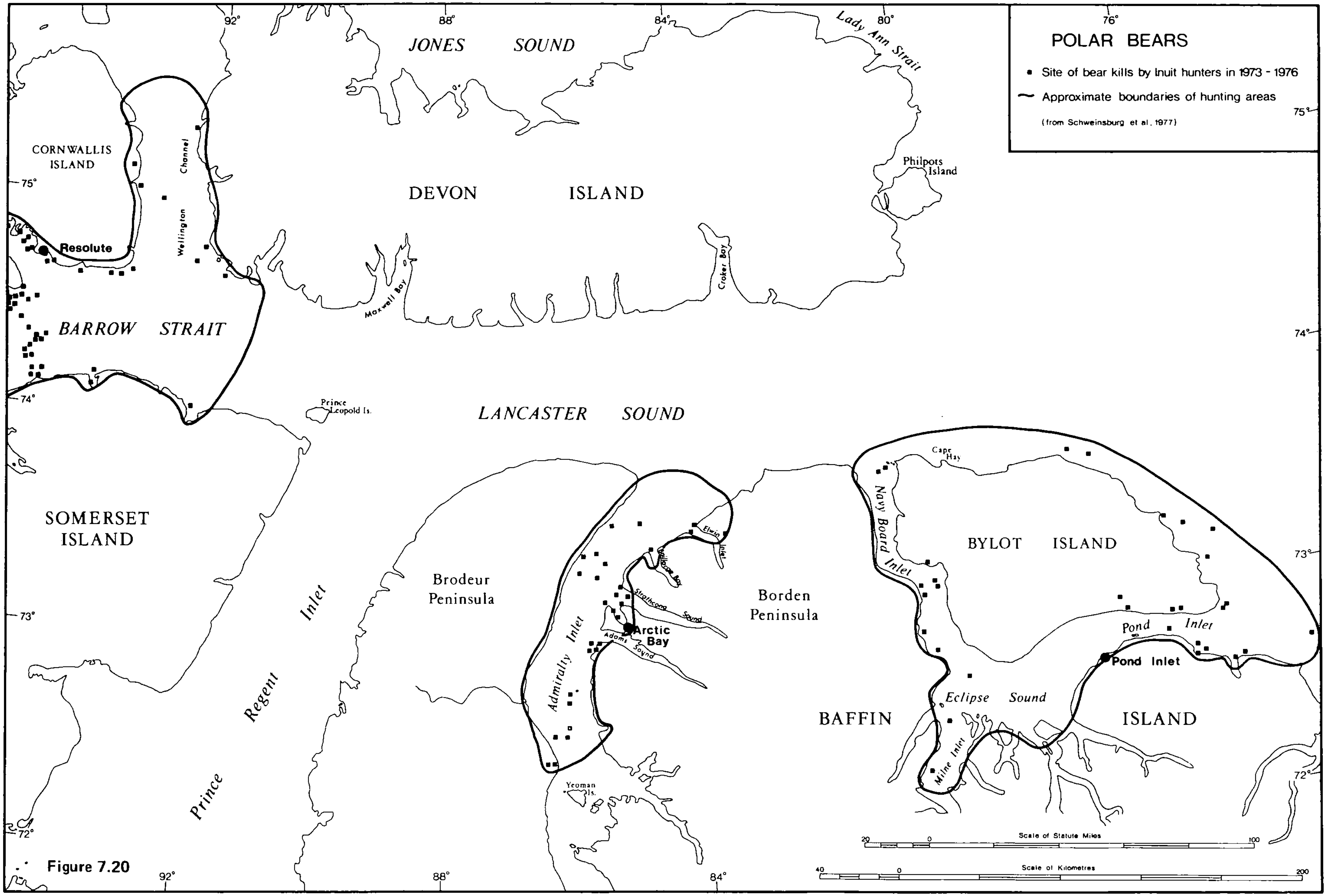

POLAR BEARS
Site of bear kills by Inuit hunters in 1973 - 1976
Approximate boundaries of hunting areas
(from Schweinsburg et al, 1977)
JONES SOUND
Lady Ann Strait
DEVON ISLAND
Philpots Island
CORNWALLIS ISLAND
Wellington Channel
Resolute
Maxwell Bay
Croker Bay
BARROW STRAIT
Prince Leopold Is.
LANCASTER SOUND
SOMERSET ISLAND
Prince Regent Inlet
Brodeur Peninsula
Admiralty Inlet
Arctic Bay
Adams Sound
Strathcona Sound
Elwin Inlet
Borden Peninsula
Cape Hay
Navy Board Inlet
BYLOT ISLAND
Pond Inlet
Eclipse Sound
Milne Inlet
BAFFIN ISLAND
Yeoman Is.
Scale of Statute Miles
20
0
100
Scale of Kilometres
40
0
200
92°
88°
84°
80°
76°
75°
74°
73°
72°

Figure 7.20

13 and August 10, Johnston et al (1976b)[7.91] sighted about 300 Walruses in eastern Lancaster Sound; about 65% of these were along the south Devon Island coast. The most popular, single oversummering locale is Croker Bay (Figure 7.21). Here densities of 3 to 4 walrus/km^2, and herds of 6 to 20 animals are common in some years. The shallow coastal waters and floating ice-pans in Dundas Harbour, in Bethune Inlet (south of Philpots Island) and off the Wollaston Islands (at the entrance to Navy Board Inlet) are also preferred habitats[7.90, 7.91]. As long as the ice lies over suitable feeding grounds, not more than 80 m deep, Walruses can rest between feedings on the floes. However, if the coastal ice disappears with the winds and currents, the herds haul out on land at selected rocky sites, called "uglit" by the Inuit. Known haul-out sites in eastern Lancaster Sound are on the eastern shore of Dundas Harbour, SE Philpots Island and the Wollaston Islands[7.91].

Until late September or October, most animals remain concentrated in Croker Bay and south of Philpots Island. The numbers begin declining one month earlier as they gradually migrate out of the Sound[7.91].

Two critical ecological requirements of the Walruses are continuously open waters in coastal areas, and gravel or mud bottoms at depths between 15 and 80 metres which support clams *(Mya* and *Saxicava)*, mussels *(Mytilus, Modeolus* and *Modiolaris)*, sea cucumbers, shrimps, hermit crabs, and a variety of worms[7.112, 7.114, 7.116].

The economic status of Walruses has drastically changed over the past decade. The Walrus was once an important game resource to Inuit; the meat and hide were used for human or dog consumption and for boat coverings, thongs, and dog traces. The bones provided material for tools and harpoon heads. Today, hunters from Pond Inlet and Arctic and Resolute Bays hunt Walruses opportunistically, in conjunction with seal and whale hunting. Hunters from Arctic Bay and Pond Inlet prefer to hunt floe edges in Navy Board or Admiralty inlets, but sometimes, kill Walruses in open water and at haul-out sites. Few north Baffin hunters set out to hunt for Walruses only, because of the animals' relative scarcity. Resolute Bay hunters killed large numbers (up to 37 Walruses per year) in the late 1950's and early 1960's along north Somerset Island, south Bathurst Island and in Penny Strait. Walruses abandoned a traditional haul-out site near Resolute Bay because of heavy hunting pressure in the 1950's[7.97].

In Holsteinborg, west Greenland, Walruses (some of which may include the Lancaster Sound population) have suffered heavy hunting-pressure since the advent of motors in the 1940's. Between 1940 and 1967, the harvest declined from 600 animals to 19 animals. Norwegian Walrus-hunters harvested about 2,000 animals in Davis Strait between 1949 and 1952. At Thule, west Greenland, the Inuit kill, annually, about 150 Walrus[7.112].

Bull Walruses fear few predators, apart from man. Younger animals are attacked by Polar Bears and Killer Whales[7.94].

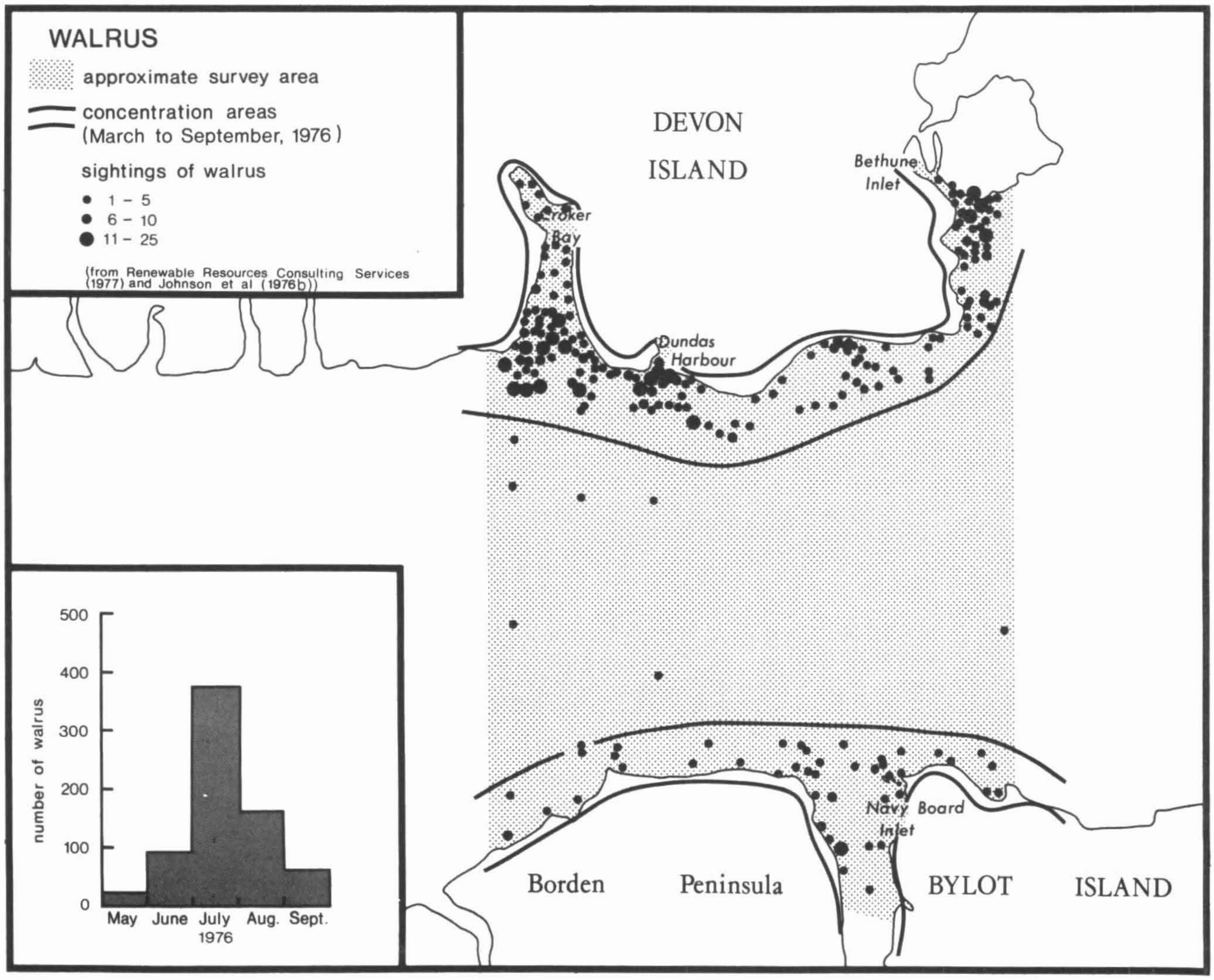


Figure 7.21

7.2.6.6 Ringed Seal

Ringed Seals *(Phoca hispida)* have a circumpolar distribution and are one of few resident marine mammals of the Arctic. In Canada, the centre of the Ringed Seal's range is around Baffin Island, especially along the fjords and islands of its eastern shore. Breeding Ringed Seals have been reported off the coasts of Newfoundland and Labrador[7.94]. Using rather crude data and arbitrary criteria, a population of about one million Ringed Seals is estimated for the eastern Canadian Arctic, north of James Bay to Lancaster Sound[7.117]. Such a sizeable population and wide distribution makes this species a principal component of all arctic food chains.

Ringed Seals are not gregarious mammals, although they tend to congregate according to their age, breeding classes and prevailing ice conditions. The landfast ice or very stable pack-ice is actively sought by the oldest, largest and breeding seals. Immature seals are generally dispersed offshore[7.117, 7.118]. Ellis (1957b)[7.119] observed that, in the vicinity of Lancaster Sound, the youngest seals were found near floe-edges, whereas the largest (and presumably oldest) were in bays and fjords where ice remained the longest.

Male Ringed Seals mature, sexually, at the age of 7 years; 40% of the 4-year old females are mature. There is an 81-day delayed implantation period, followed by a gestation of 9 months. The Ringed seals' annual increment is an estimated 7 to 8 per cent[7.118].

Ringed Seal pups are born in snow-covered lairs, above enlarged breathing holes, on fast-ice[7.120]. The peak of pupping is in late March to early April[7.118]. Newborn pups are helpless and are not weaned until spring break-up, about 2 months later. Annual, small-scale migrations of young seals disperse them away from prime breeding habitat[7.117].

The numbers of Ringed Seals residing in Lancaster Sound are uncertain. McLaren (1958a)[7.117] estimated 30,000 seals or more, based on a relatively high density of 13.5 seals/km^2 and 1.9 seals/km^2 for landfast and pack-ice respectively. Aerial surveys in 1976, during the seals' moult, revealed densities which are smaller by an order of magnitude; offshore, there were 0.2 seals/km^2; along coastal landfast ice, an average of 0.4 seals/km^2. These values yield an estimated 4,000 seals within a 60 km radius of Norlands' proposed drilling location[7.91]. Undoubtedly, this is a low number because of survey limitations. Others calculate that Admiralty Inlet and off northeast Baffin Island (Navy Board Inlet to Cape Adair, about 250 km SE of Pond Inlet), support over 100,000 Ringed Seals[7.117]. Such discrepancies emphasize need for detailed and systematic censusing of Ringed Seals in Lancaster Sound and its adjacent bays and inlets. Table 7.10 shows comparative densities of Ringed Seals found elsewhere in the Arctic.

In February and March, Ringed Seals are widely dispersed throughout eastern Lancaster Sound. Scanty data, displayed in Figure 7.22, suggest two areas of winter concentration - south of Croker Bay and along north Borden Peninsula. However, at this time of the year, aerial censusing is difficult, because snow tends to hide the breathing holes, and the seals are often underwater.

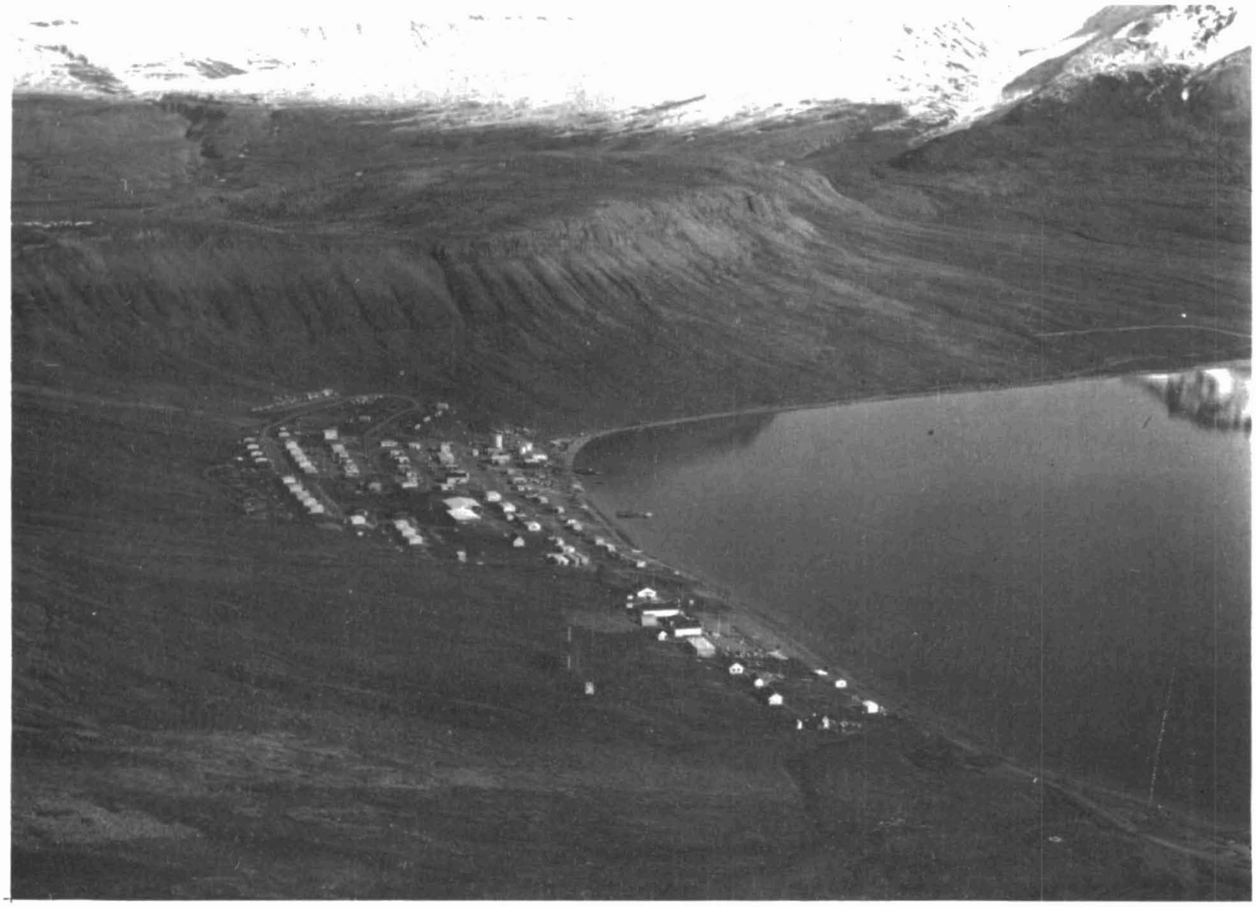
From late May to early June, at the peak of haul-out and moult activity, is the best time to count seals from aircraft. Johnson et al (1976b)[7.91] report that about 70% of the 341 Ringed Seals observed between May 2 and June 15 were offshore. A concentration of animals occurs along the coastal shelf of fast-ice, along north Borden Peninsula and at the entrance to Croker Bay and Navy Board Inlet. Along the ice edge of the latter locale, densities can reach 2.5 seals/km^2 [7.91]. An observed trend in an increase in seals from east to west[7.90]. The instability of sea ice in Baffin Bay and at the Sound's east "gate" may, in part, explain this.

Once pans of ice disappear from the Sound, seals become very difficult to spot from aircraft. It is assumed that Ringed Seals remain scattered and widely dispersed during the summer open-water season. Relatively high concentrations appear to continue in Croker Bay and Navy Board Inlet (Figure 7.22); this may be a survey bias, since the remnants of landfast ice greatly enhances the animals' detection. A shift in distribution from offshore to coastal waters is not likely[7.90, 7.91]. In October, and later during freezeup, Ringed Seal distribution is also widespread. The newly-forming fast-ice, in areas such as Admiralty Inlet, support comparatively high concentrations[7.90].

Ringed seals are opportunistic feeders, having a variable diet. Arctic Cod is often their food although, at times, seals prefer crustaceans, such as *Parathemisto* and *Mysis*[7.122, 7.123]. The locale (whether pelagic, near the coast or along a floe-edge) and the season determine, in part, the relative

Table 7.10

Locale	Seals/km^2	Source
Eastern Baffin Island		
Landfast ice in fjords	3.4	
Landfast ice around islands	2.5	Smith, 1973b[7.118]
Pack ice offshore	1.9	
Amundsen Gulf		
Pack ice offshore	0.9-1.8	Smith, 1973b[7.118]
Prince Albert Sound		
Landfast ice	2.8	Smith, 1973b[7.118]
Alaska Coast		
Pack ice offshore	0.6-0.8	Burns & Harbo, 1972[7.121]
Barrow Strait		
Pack ice offshore	0.7	Finley, 1976[7.92]
Aston Bay, Somerset Island		
Landfast ice	10.0	Finley, 1976[7.92]



Arctic Bay (photo: B. Smiley)

Stretched and drying Seal Skins, Arctic Bay (photo: B. Smiley)

Walrus Kill by Pond Inlet Inuit (photo: H. Silverman)

Walrus and calf at Stratton Inlet, south Devon Island (photo: A. Milne)

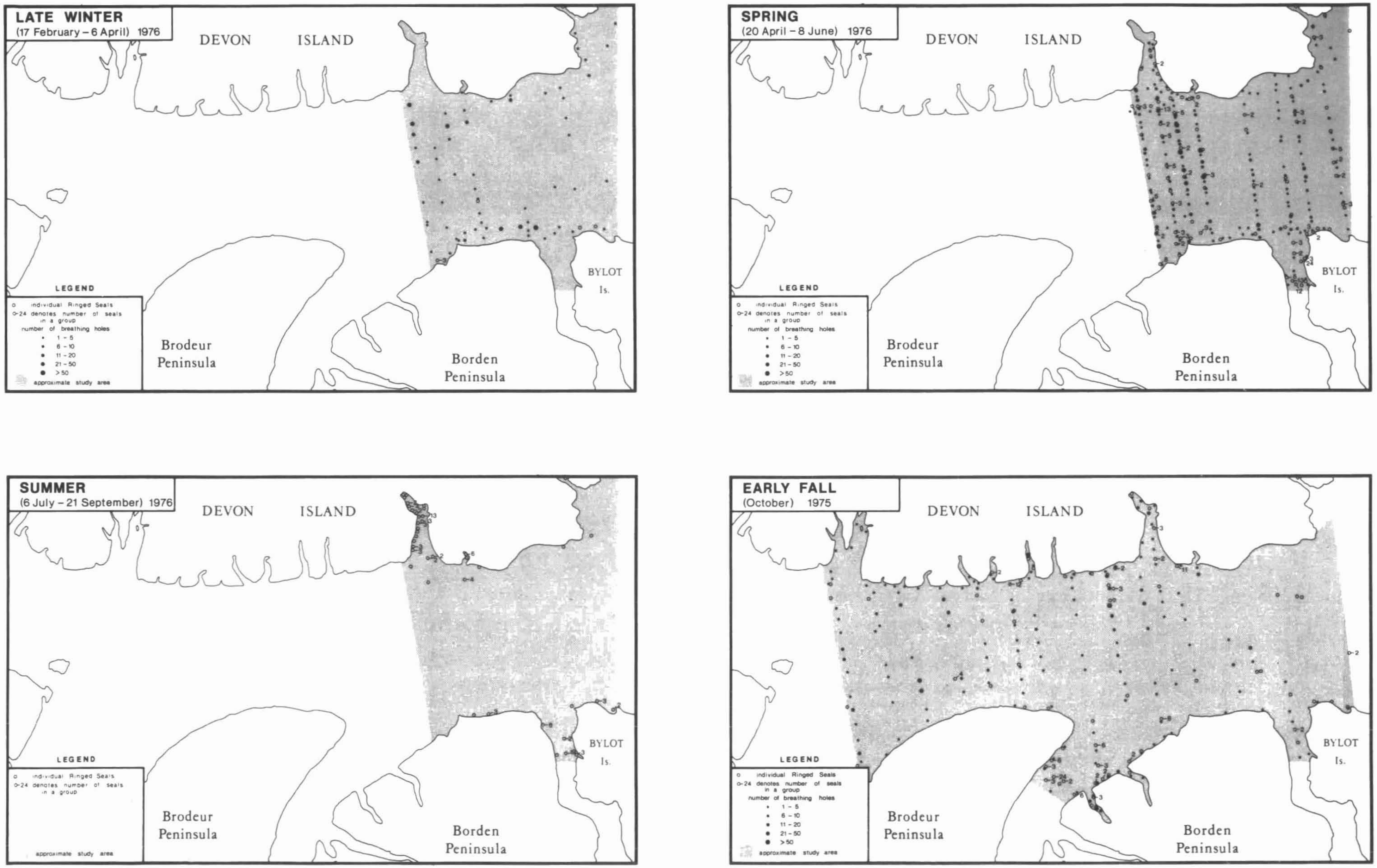


Figure 7.22

RINGED SEALS – SEASONAL ABUNDANCE AND DISTRIBUTION

(from Renewable Resources Consulting Services, 1977) importance of different prey. The availability of food does not restrict the Ringed Seals' distribution.

Banfield (1974)[7.94] states that "the Ringed Seal is the cornerstone in the native economy of the coastal Eskimos". This is as true today as it has been for generations. Seal meat is staple food for man and dog. The liver is a good source of vitamin "A". The skins are used for clothing, foot wear, thongs, and tents. Commercial sale of skins is a major source of income for Inuit of Pond Inlet and Arctic Bay[7.124]. The fat was used for light and heat - before the petroleum age.

The Inuit hunt seals at their breathing holes from late October to April break-up, especially in areas of refrozen cracks which open, predictably, each winter. Some netting is attempted by Pond Inlet people in southeast Eclipse Sound, and sometimes in Navy Board and Pond inlets. Hunting of seal pups at birth-lairs occurs from late March until early May. Seals are shot, opportunistically, from boats in open water and on ice floes[7.42, 7.117].

7.2.6.7 Bearded Seals

Bearded Seals *(Erignatus barbatus)* are large and robust (up to 2.8 m long) and occur along most arctic coasts of northern continents. Like Ringed Seals, this species does not inhabit heavy pack ice and polar floes. In Arctic Canada, Bearded Seals are distributed in the Beaufort Sea, the Arctic Archipelago, Hudson Bay, Baffin Bay and Davis Strait[7.94]. Arctic Canada's population of Bearded Seals is unknown, but estimates vary from 75,000 to 185,000[7.94, 7.117].

A unique aspect of their breeding biology is the birth of pups only every second year. Females must wait a year before mating again since the males are out of breeding condition when post-partum females ovulate in early June[7.94]. Most pups are born in late April on ice floes, and enter the water shortly after birth[7.125]. They are weaned within two or three weeks[7.126, 7.127].

In Lancaster Sound, Bearded Seals are not abundant and are outnumbered by Ringed Seals by about 18:1[7.90, 7.91]. This compares with a ratio of 16:1 in the Beaufort Sea. Aerial surveys of eastern Lancaster Sound, beginning in late February, 1976, reported less than 100 sightings for the 7½ month census[7.90, 7.91]. Bearded Seals were first observed in late March (Figure 7.23). Like Ringed Seals, however, they are more detectable in May and June during their annual moult and haul-out. Johnson et al (1976b)[7.91] sighted most (53%) hauled out on offshore ice floes. An onshore shift in population occurred in late September when 90% of Bearded Seals were found in shallow coastal waters, especially along the south Devon Island coast. Dundas Harbour and Croker Bay are notable areas of concentration[7.90]. This onshore shift is probably related to the disappearance of coastal fast ice and the seal's preference for benthic foods found in these shallow waters.

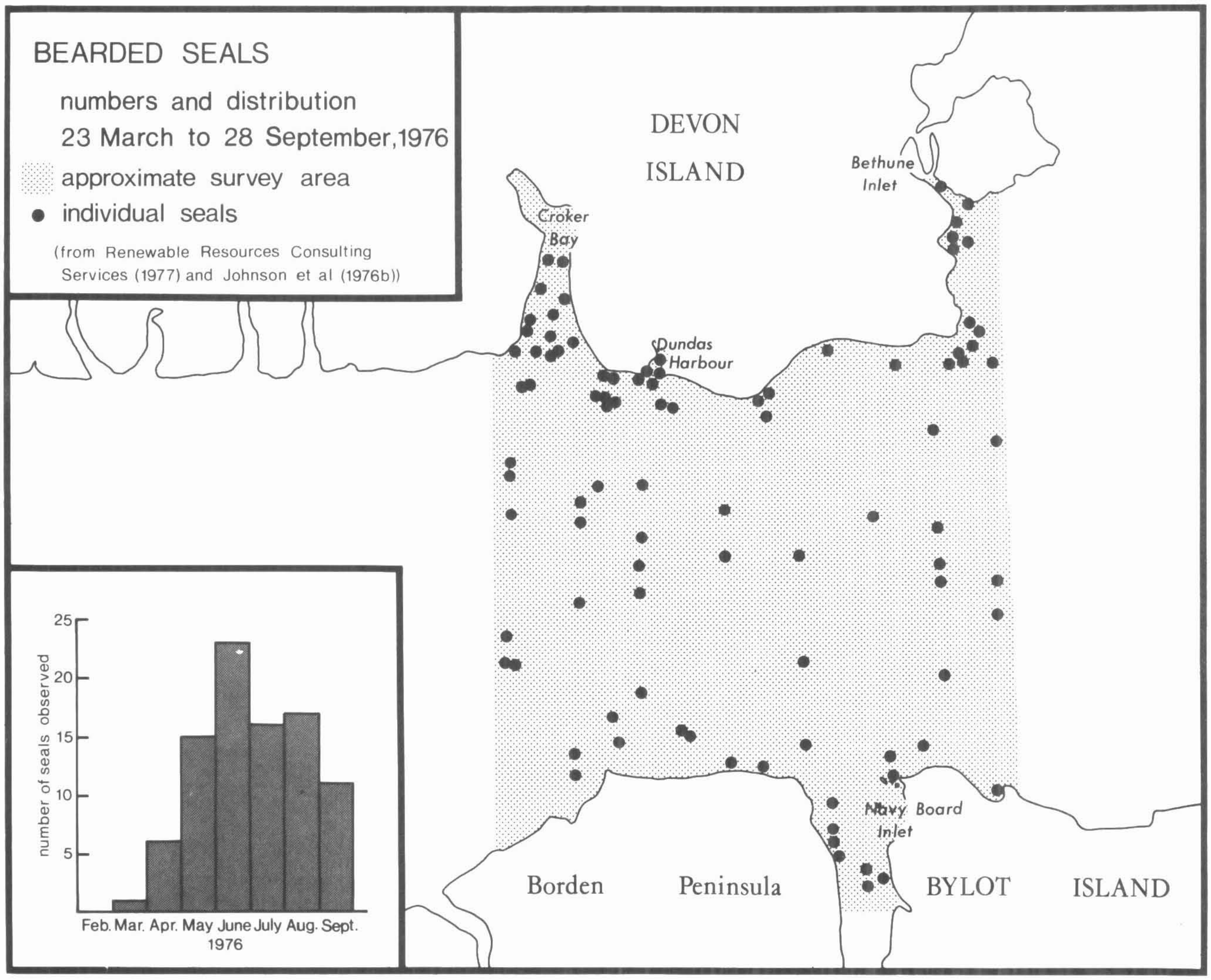


Figure 7.23

With scanty information, it is speculated that perhaps a part of the Bearded Seal population moves in and out of the Sound from Baffin Bay. Significant numbers migrate westward past Cape Hay, north Bylot Island, in late July[7.87]. There are reports of Bearded Seals arriving in Dundas Harbour in July of some years[7.74]. Very few Bearded Seals remain in eastern Lancaster Sound by October[7.90].

Bearded Seals have similar food habits to Walruses. They feed strictly on benthic organisms such as the molluscs *Buccinum* and *Serripes,* as well as sea cucumbers, shrimps, crabs, octopus, worms, fish eggs, sculpins, and Arctic Cod[7.92, 7.115, 7.128]. Their maximum feeding depth is about 300 m. In deeper waters, such as in mid-Lancaster Sound, they probably eat Arctic Cod from under ice floes[7.122].

Bearded Seals are of low economic importance to Inuit of the Baffin Island region because of the relative scarcity. Nonetheless, the large quantity of meat and tough skin provided by a single Bearded Seal, often weighing 400 kg, makes this resource one of importance and pride among hunters. The Pond Inlet residents hunt, almost exclusively, in Navy Board Inlet, Eclipse Sound, and Pond Inlet, often at spring ice edges. Inuit of Arctic Bay travel to the floe edge at northern Admiralty Inlet, or to the Inlet's more southerly reaches[7.96]. Although Bearded Seals are occasionally killed at breathing holes, Inuit usually hunt the spring floe edges or summer open waters, where *any* species of seal is shot when the opportunity arises[7.42].

7.2.6.8 **Harp Seals**

There are three distinct stocks of Harp Seals *(Phoca groenlandica)* in the North Atlantic Ocean – the West Atlantic population (a portion of which resides in or migrates through Lancaster Sound), the West Ice herd of Iceland, and the European White Sea herd[7.94]. The West Atlantic herd was estimated at 3 million seals in 1951 but, due to excessive commercial harvesting, a 50% decline in numbers followed during the next decade[7.115]. About 450,000 Harp Seals whelped in the Gulf of St. Lawrence in 1971[7.94].

Canadian Harp Seals spend most of the year along the edge of the Arctic pack ice. They winter in the Maritime region, from southeast Labrador to Prince Edward Island. In March, breeding and pupping occurs on the pack ice of the Gulf of St. Lawrence and east Newfoundland coast. Following the annual moult, Harp Seals begin appearing off west Greenland in late May. From here, portions of their population disperse throughout eastern Arctic Canada for the summer months, penetrating as far west as Barrow Strait, Prince Regent Inlet and Peel Sound[7.129].

Lancaster Sound is the principal migration route for tens and possibly hundreds of thousands of Harp Seals. Biologists camped on the Cape Hay cliffs have estimated that 20,000 to 136,000 Harp Seals swim eastward along the north Bylot coast in July[7.58, 7.87].

During 1976 aerial surveys, about 8,000 animals were sighted in eastern Lancaster Sound[7.90, 7.91]. The first record of Harp Seals in the vicinity of Norlands' proposed drilling site was July 5. This qualified the species as the last migrant marine mammal to appear in the Sound at the time of the major wave of Narwhal migration. Most of the Harp Seals move fairly rapidly along the Sound's margins for the remainder of the month of July, but by August their numbers have tapered off.

Averaged over the 1976 summer, the density of Harp Seals in Lancaster Sound was about 1 seal/km^2. However, high concentrations of 12 seals/km^2 and 44 seals/km^2 were found along the ice edges of Croker Bay and Navy Board Inlet, respectively, in July. Herds comprised between 15 animals and sometimes as many as 75 animals[7.90, 7.91]. Figure 7.24 demonstrates the shallow, coastal water preference of Harp Seals; they are seldom found offshore. Seemingly this observation contrasts to the survey findings of an aerial census in Barrow Strait. Here, "almost all of the Harp Seals . . . were found in the deep offshore area of Barrow Strait and were very often associated with pan ice."[7.92] Evidently the Harp Seals distribution is sensitive to changes in ice conditions, the offshore animals depending on the presence of ice.

Like Bowhead Whales and Walruses, some Harp Seals do not migrate through Lancaster Sound but remain to oversummer in habitual areas, such as Croker Bay and Navy Board Inlet. Admiralty Inlet is, possibly, the most important summering locale; an estimated 4,000 Harp Seals were present in July and August, 1975[7.85]. Some Arctic Bay hunters note that the best location to hunt Harp Seals is just off the Arctic Bay headland of Admiralty Inlet[7.42]. An estimated 2,000 to 2,500 Harp Seals migrate and summer as far east as Barrow Strait[7.92].

Fall outmigration is underway by mid-September. During one survey on 6 September[7.91], about 2,800 Harp Seals were hauled out on ice pans in the entrance of Navy Board Inlet[7.91]. Croker Bay is a popular locale, in autumn (58 seals/km^2) in some years. Most depart the Sound by October[7.90] but some linger around the Arctic Islands until November[7.129].

Unlike Ringed and Bearded Seals, Harp Seals are highly gregarious. They haul out on ice floes in dense herds to pup, mate, moult and rest between feedings. They can dive to considerable depths, down to 275 m[7.94]. Their arctic diet is comprised of Arctic Cod, squid, euphausids, mysids, and amphipods, such as *Parathemisto.* Arctic Cod is replaced by capelin and herring in southern Maritime waters[7.115, 7.131].

The Harp Seal is the basis of the traditional, and now controversial sealing industry of Newfoundland, dating back to 1750. About one half million seals were killed for their fur, leather, and fat rendered oil between 1820 and 1860. The harvest accelerated to 300,000 annually by 1961, apparently exceeding the population's natural recruitment. Today the harvest is limited to about 150,000 each year[7.130].

Harp Seals are of little or no importance of Inuit of Resolute Bay, Pond Inlet and Arctic Bay[7.96, 7.97]. The Ringed Seal is more easily taken, and is available the year round.

Natural enemies are Greenland Sharks, Killer Whales, and Polar Bears[7.94].

7.2.6.9 **Others**

Hooded Seals and Killer Whales inhabit the waters of Lancaster Sound on a regular basis, but, usually, in very small numbers. Possibly tens, or a few hundreds of these species summer in the eastern portion of the Sound and adjacent waters. The 1976 aerial surveys reported only 5 Hooded Seals on the Sound's offshore pan ice; no Killer Whales were spotted[7.90, 7.91]. Lancaster Sound is almost the northerly limit of the Hooded Seals' range. Most of Canada's western Atlantic population of 50,000 to 75,000 Hooded Seals summer along the coasts of east Greenland and Denmark but winter on the Grand Banks of Newfoundland[7.115]. Biologists have recently rediscovered, after a span of 150 years, a winter population of Hooded Seals in Davis Strait at 64°N.[7.130] Inuit hunters occasionally see small herds of Killer Whales in the vicinity of Norland's proposed drilling site (Lancaster Sound, Admiralty Inlet, Eclipse Sound, Navy Board and Pond inlets). The number of Killer Whale sightings is seldom more than 10 to 20 each year in Eclipse Sound and Pond Inlet[7.93].

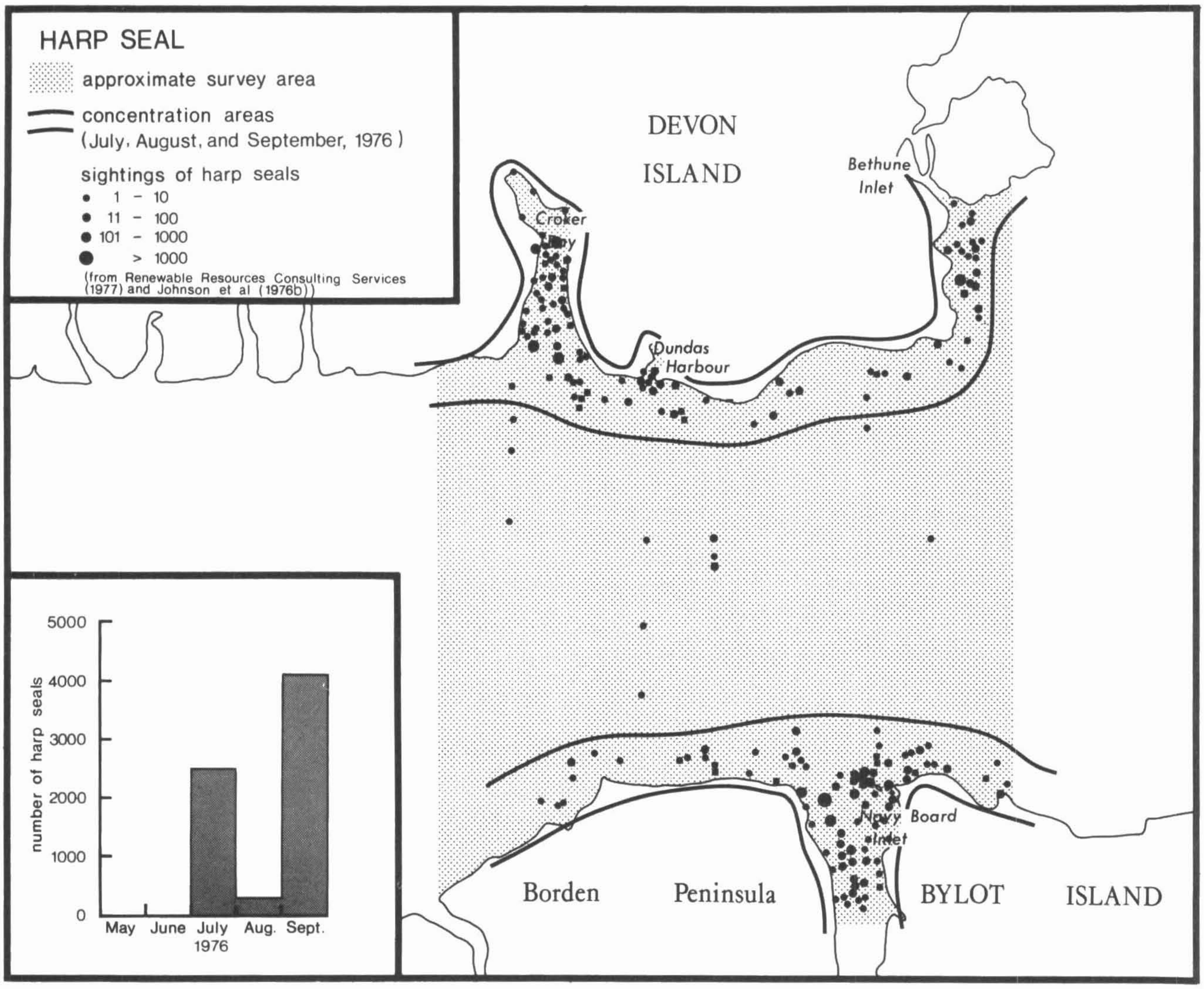


Figure 7.24

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8. Threats To Marine Life In Lancaster Sound

8.1 Biological Productivity in Context

Lancaster Sound is a biologically-active marine region of Canada's High Arctic and boasts relatively high diversity and large numbers of marine mammals, birds and lower life forms. In the North American or world context, Lancaster Sound ranks as a major wildlife waterway, staging centre and breeding area. This fact alone implies a serious threat of oil pollution from offshore exploratory drilling. The following generalizations highlight the national and international uniqueness of Lancaster Sound:

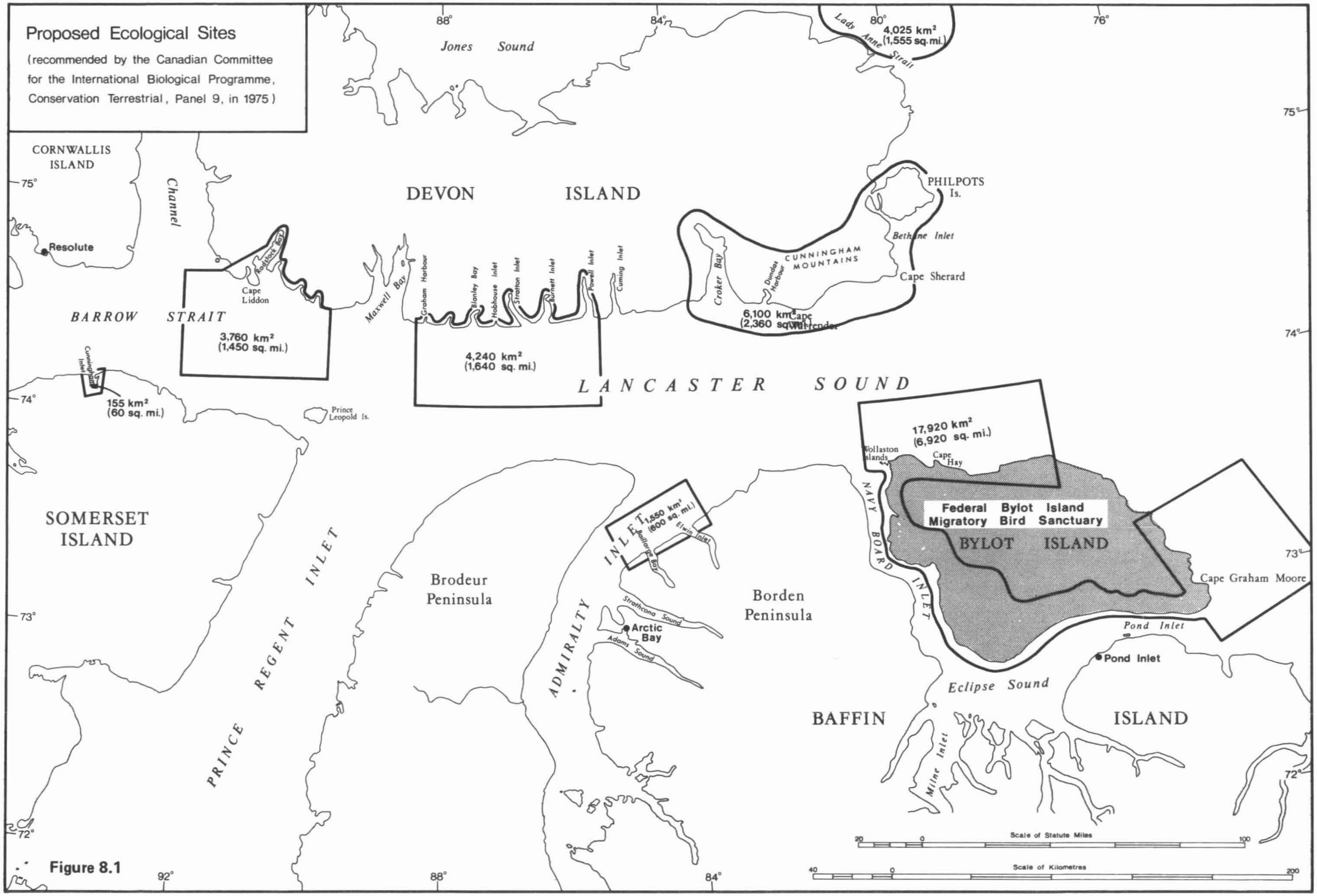
- Phytoplankton standing crop (22.8 x 10^5 plant cells/litre) is higher than in most marine waters of Canada's High Arctic;
- Phytoplankton diversity (125 species) is over 35% greater than in the southern Beaufort Sea;
- Zooplankton biomass (230 mg/m^3) is greater than in most marine waters of Canada's High Arctic and is about the same as in Frobisher Bay, 1,300 km to the south;
- Arctic Cod are twice as numerous (52 larval fish/1000 m^3) as in the Chukchi Sea (northwest of Alaska), and 10 times more numerous than in the Beaufort Sea;
- Marine-associated birds which migrate, nest or feed in the Sound number as high as 2 to 3 million birds, representing over 50% of Canada's entire Eastern Arctic population;
- Two-thirds (230,000 birds or more) of Canada's Fulmar population migrate through or forage in the Sound;
- 100,000 Black-legged Kittiwakes breed at Cape Hay, the largest known Kittiwake colony in eastern North America; 100,000 more migrate through the Sound en route to Prince Leopold Island, and other smaller colonies.
- About 400,000 to 800,000 breeding Thick-billed Murres nest at Cape Hay — one of the four largest Murre colonies in eastern North America; Another 540,000 breeding Murres pass through the Sound, or nearby, en route to Prince Leopold and Coburg islands;
- 1,500,000 or more Dovekies are dispersed in offshore eastern Lancaster Sound for several weeks, en route to west Greenland;
- One-third (approximately 7,500 geese) of the world's population of Greater Snow Geese breed on southwest Bylot Island, adjacent to Navy Board Inlet and Eclipse Sound:
- One-third (10,000 whales) or more of North America's White Whales migrate through the Sound en route to feeding and breeding grounds, such as Cunningham Inlet and Creswell Bay (Somerset Island):
- At least 85% (20,000 to 30,000 Narwhal) of North America's Narwhal population migrate through, or summer near Lancaster Sound;

More than any other channel in the eastern Arctic, Lancaster Sound provides a reliable wildlife travel-way for about six months of each year. The early break-up of sea-ice offers marine migrants their first opportunity to penetrate into breeding and feeding locales of the central Arctic. The eastern entrance to Lancaster Sound and Parry Channel (the famed Northwest Passage) is an 85 km wide "funnel" which concentrates millions of seals, walruses, whales and birds arriving from Baffin Bay, Davis Strait, Labrador Sea and wintering regions beyond. Often, the eastward fall migration from the central Arctic is the reverse pattern of the spring migration through Lancaster Sound.

Many of these animals pass quickly through the Sound in spring and early summer to preferred westward destinations, such as the Prince Leopold Island nesting colony, or the Creswell Bay calving estuary. For days and weeks in passage, they rely upon the Sound's coastal and offshore waters for food and rest. The Sound itself is a summer destination where large numbers of animals can breed in relative safety, and feed nearby. Such locales are few in the Arctic.

Why is plant and animal production so high in the Lancaster Sound? The reasons remain a matter of speculation for physical, chemical and biological oceanographers. Obviously, an ample supply of nutrients is essential for phytoplankton, the basis of all higher life-forms in the sun-lite surface waters. High Arctic regions, such as Jones Sound and the Beaufort Sea, annually experience complete exhaustion of one or more critical nutrients early in the open-water season — a result of phytoplankton growth itself[8.1, 8.2]. This exhaustion results from a water column that is highly stable, not allowing the recharging of limiting nutrients from deeper waters; hence no further plant-growth can proceed before the onset of freeze-up and winter darkness. In contrast, Lancaster Sound has several mechanisms, probably acting in combination, which replenish critical nutrients throughout the peak summer demand. Apollonio (1973)[8.1] suggests that runoff from the glaciers of south Devon and Bylot islands add nitrates and silicates to the Sound's surface waters. Strong ocean currents and upwellings can possibly recycle nutrients from deeper waters[8.3]. The deposition of guano from millions of feeding seabirds may enrich the surface waters with plant foods, particularly nitrates and phosphates[8.4].

In 1975, the Canadian Committee of the International Biological Program proposed that Lancaster Sound become one of several major ecological preserves. Of principal concern are four proposed ecological sites, encompassing over 40,000 square kilometres of coastal tundra and nearshore waters, mostly within 100 to 150 km of Norlands' acreage (Figure 8.1). Included are coastal waters of Bylot Island, the mouth of Admiralty Inlet and most of the south Devon Island coast. In most cases, the exceptional features warranting protective status or recognition are major seabird colonies, nearby foraging waters, Polar Bear summer retreats, marine mammal migration routes and



Proposed Ecological Sites

(recommended by the Canadian Committee for the International Biological Programme, Conservation Terrestrial, Panel 9, in 1975)

Figure 8.1

archeological sites. The concern of the Arctic Tundra Panel, the group of scientists and others from Universities, Federal and Territorial agencies, industry and the public, in identifying these Ecological Sites was:

> "There are areas of biological, geographical and historical importance in the North that urgently require special protection. Because of the vastness of the Canadian Arctic, this may not always be apparent. However, here as elsewhere, man's expanding activities increasingly threaten a number of unique areas and species." [8.5]

The IBP Panel can only recommend the establishment and protection of these and other sites. The decision of whether or not to act rests with the Federal and Territorial governments.

The Bylot Island Federal Bird Sanctuary was created in the late 1950's to protect the unique Snow Goose population on the Island's southwest lowlands and also the Cape Hay seabird colony. Special permission from the Canadian Wildlife Service is required to travel or land an aircraft on Bylot Island, and all overflights must maintain an altitude of 1,000 feet (304 m).

8.2 Vulnerable Wildlife Populations

It has been stated that ". . . pollution of the seas by oil poses the largest single threat to seabirds at the present time"[8.6] Reference is made to all sources of oil spills - deliberate, tank washings, oiltanker accidents, coastal waste disposal and offshore blowouts. In eastern Lancaster Sound, oil pollution is likewise a serious, potential threat to seabirds and other life in the event of exploratory drilling accidents. In Section 5, we have estimated that 6% of the oil pollution from a blowout at Norland's proposed drilling site would not be flushed out of the Sound by ice, currents and winds. This oil amounts to 18,000 tonnes or 132,000 barrels over one year, assuming a free-running blowout flow-rate of 950 m^3 per day. Floating oil slicks, driven by strong, persistant current and occasional high winds do not uniformly contaminate beaches, coastal waters, ice-edges and islands. Certain locales, such as north Bylot Island, Navy Board Inlet and northeast Borden Peninsula are directly "downstream" from the oil-pollution source. Here, spilled oil *and* wildlife tend to simultaneously concentrate. Since currents, winds and wildlife habits are poorly documented, neither the trajectories nor the locales are inclusive. Spilled oil does not simply disappear in Baffin Bay and cease to be a pollutant. Also, north Somerset, southwest Devon and Prince Leopold islands are not completely safe from pollution and the effects of pollution originating in eastern Lancaster Sound. These risks are not addressed in this report.

To appreciate the blowout threat to wildlife populations, the predicted oilspill trajectories in eastern Lancaster Sound must be related to known locales of wildlife vulnerability.

8.2.1 Offshore Lancaster Sound

For the duration of a free-running oilwell blowout, offshore waters of eastern Lancaster Sound will be continually polluted to varying degrees. In open water, floating oil spreads, emulsifies, evaporates and disperses with wind, currents and ice-drift. Eventually, some oil strands on the shores but most is "flushed" towards Baffin Bay, particularly during the long periods of ice-infestation or complete ice-cover. During the winter, offshore oil pollution is heaviest near the blowout site, and can drift in a 4 km-wide swath of oil-stained ice, stretching for tens, possibly hundreds of kilometres "downstream" from the blowout site. But varying ice conditions (Figure 4.3) and weather extremes can change this, such that no offshore locale is safe from some oil pollution.

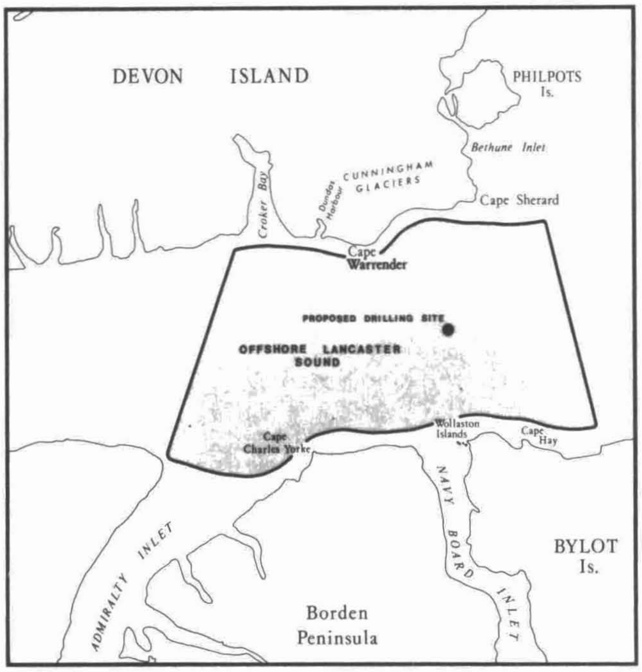


Table 8.1 summarizes the major seasonal activities of marine birds and mammals in offshore eastern Lancaster Sound. Clearly the most serious risk is from the oiling of scattered cracks, leads and small open-water patches in the Sound's pack ice during spring. This would prove catastrophic to Dovekies, Thick-billed Murres and, to a much lesser extent, Narwhals. The alcids are the most vulnerable, for two reasons: (1) very significant numbers of migrant Dovekies and Murres seek out these cracks and leads in May and June and (2) these diving and swimming birds are the most sensitive of any waterfowl to floating oil-slicks[8.7].

Densities of Dovekies reach 775 birds/km^2 among the offshore pack-ice in late May of some years, and numbers total about one and a half million. This may represent the bulk of the entire west Greenland breeding population destined for their colonies 500 km away. Unfortunately their migrations through the Sound's eastern "gate" overlap areas of oiled ice and leads expected from the blowout.

Dovekies are accompanied by hundreds of thousands of Thick-billed Murres. In May and early June, 1976, over one-third of migrant Murres were concentrated in large flocks in offshore cracks and leads. Some of these birds were probably en route to Prince Leopold Island[8.8].

Narwhals and, to a lesser degree, White Whales will be confronted with oil pollution in these same cracks and leads. Up to 70% of Narwhals migrated offshore, at least 7 km from the coast in May and early June 1976[8.9]. They might avoid the oil, but this may be difficult or impossible in heavy ice. The biological significance of delayed migration or restricted feeding to whales is unknown. Health or reproduction problems caused by oil-coating of their skin, eyes, and breathing-holes are also unknown.

In summer, marine birds do not suddenly disappear, along with ice, from offshore Lancaster Sound. From May to September, Northern Fulmars, Black-legged Kittiwakes, Thick-billed Murres, and Black Guillemots feed and travel throughout the entire Sound. Some are juveniles and unsuccessful nesters. Others are commuters from distant colonies, searching for rich foraging waters. Colony inhabitants from Cape Hay and Baillarge Bay probably comprise a large proportion of these birds. Overall, their density is relatively low - less than 35 birds/km^2 in 1976. However, this density multiplied by the Sound's area, indicates a significant offshore seabird population[8.8].

Table 8.1 * **OFFSHORE WATERS OF EASTERN LANCASTER SOUND**
(7 km or more from shore or landfast ice)

Major Wildlife Value or Use	Species	Approx. Numbers or Density	Dates	Habitat Preferences
Principal Migration route	Murres	100,000's (up to 23 murres/km^2)	May and June	Cracks and leads in pack ice
	Dovekies	1,000,000's (up to 755 dovekies/km^2)	mid to late May	Cracks and leads in pack ice, less than 50% ice-cover
	Fulmars	10,000's (up to 1 fulmar/km^2)	early May to early June	Cracks and leads in pack ice, 50-100% ice-cover
	Fulmars	10,000's	late September	Open waters
	Guillemots	1,000's (up to 10-20 guillemots/km^2)	May	Cracks and leads in pack ice
	Narwhal	1,000's (up to 1.5 narwhal/km^2)	May to early June	(Similar to above)
	Narwhal	1,000's (up to 2 narwhal/km^2)	late September	Open, offshore waters
Minor Migration route and Feeding area	Kittiwakes	1,000's	May to September	Open water with less than 25% ice-cover
	Bowhead whales	10's	May to September	
Important Feeding area	Murres	10,000's to 100,000's	July to September	Offshore from Cape Hay colony
	Fulmars	10,000's to 100,000's	July to September	Open waters, often near flotsam in areas of converging currents
Minor Spring Feeding area	Polar bears	10's	early May to mid-June	Broken pack ice
Important Moulting and Feeding area	Ringed seals	1,000's (up to 2.5 seals/km^2)	early May to mid-June	Broken pack ice

* **Note:** Tables 8.1 to 8.5 are based on References 8.8, 8.9, 8.12, 8.13 and 8.15

Heavy mortality to Thick-billed Murres is expected from offshore oil in late August and September. At this time, adult Murres are moulting and flightless, often accompanied by their flightless young. Recent surveys reveal that about 30% of Murres swim and feed in offshore waters during migration; some of them probably originate from Prince Leopold Island[8.8].

Surface currents which disperse oil into Baffin Bay, and south along the east Baffin Island coast, also propel swimming-migrating Thick-billed Murres from four major colonies - Cape Hay, Prince Leopold Island, Coburg Island and Cape Graham Moore. These alcids are probably joined by large numbers of flightless Dovekies from Greenland colonies. In the *Atlas of Eastern Canadian Seabirds*[8.10], northeast Baffin Bay waters are assigned a "vulnerable" rating for September and October, on the basis of this spectacular alcid migration.

8.2.2 Bylot Island and Navy Board Inlet

The most probable coastal destination of oil from an offshore blowout is north Bylot Island and its adjacent coastal waters (Figure 5.8). The Island's east shore and the north entrance to Navy Board Inlet will be also heavily oiled. Oil may travel as far south as Eclipse Sound or pass seaward of the eastern entrance to Pond Inlet. Regardless of the accuracy of these oil estimates or dispersion assumptions, the Bylot Island-Navy Board Inlet locale is directly "downstream" from the blowout. Beaches and coastal waters will share the pollution; oil will strand on the shores above high tide, encapsulate in landfast ice, herd against ice-edges and among grounded ice, or float near shore.

These same potentially oil-polluted habitats are sought by, literally, millions of seabirds and marine mammals from April to October. The south margin of Lancaster Sound is on a "mainstream" migration route and offers abundant food to migrants and summer residents (Table 8.2). In winter, Polar Bears and Ringed Seals inhabit coastal landfast ice of north Bylot Island and Navy Board Inlet. The shores of Bylot Island provide maternity dens and high-use summer retreats for dozens of Polar Bears.

The Cape Hay seabird colony is a prominent feature of north Bylot Island. Ledges on the near-vertical, 350 m high cliffs are lined with hundreds of thousands of breeding Thick-billed Murres and Black-legged Kittiwakes. Many feed themselves and their growing chicks on nearby abundant marine plankton and fish. The near-surface waters close to the mouth of Navy Board Inlet supported a high zooplankton biomass of 1,200 mg/m^3 in the summer of 1976[8.11]. Marine birds also concentrated here in densities

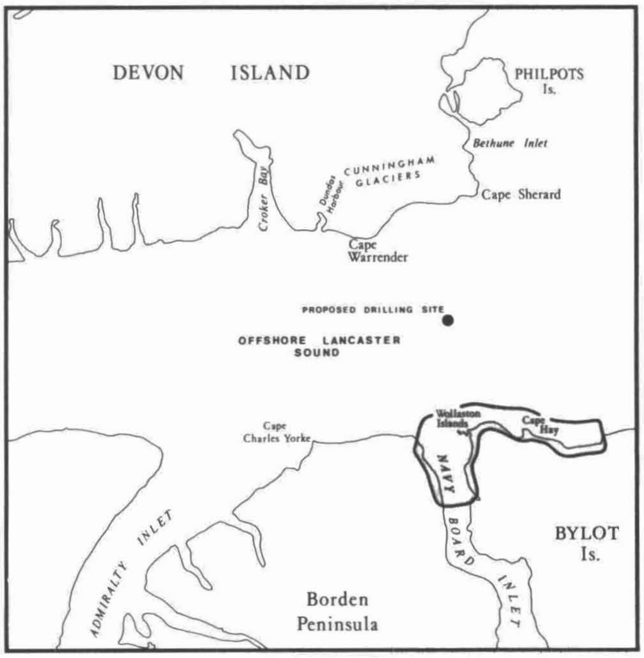


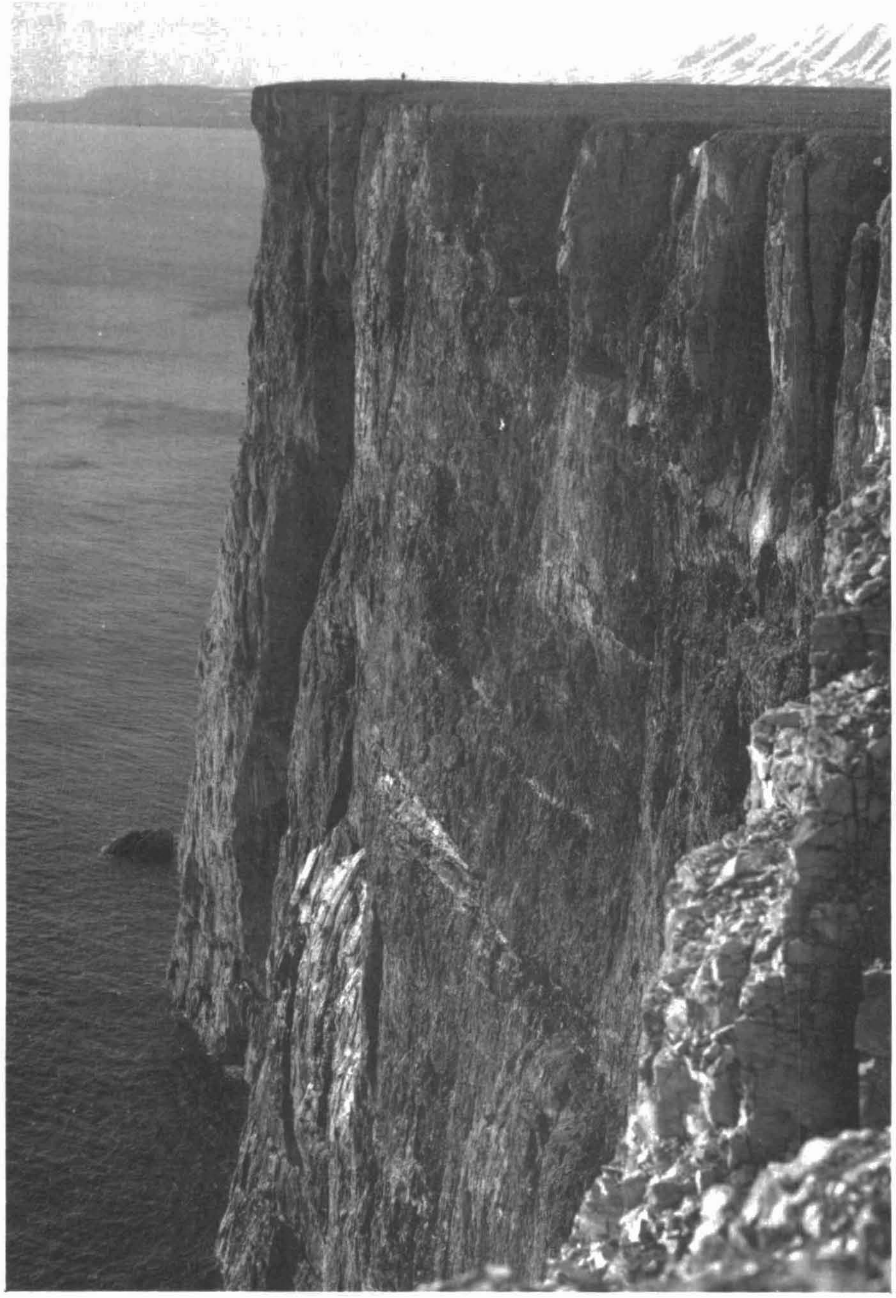
Table 8.2 * NORTH BYLOT ISLAND AND NAVY BOARD INLET
(Cape Hay, Wollaston Islands, N. E. Borden Peninsula)

Major Wildlife Value or Use	Species	Approx. numbers or Density	Dates	Habitat Preferences
Known maternity denning area	Polar bears	10's	October to early April	Maternity dens in snowbanks along N. and N.E. Bylot Island
Spring concentration area	Polar bears	10's	March, April and May	Coastal landfast ice and ice-edge
Important breeding and moulting area	Ringed seals	1,000's (about 2.5 seals/km^2)	late March to early June	Coastal landfast ice along N. Bylot Island and landfast ice of Navy Board Inlet
Principal migration route	Narwhal	1,000's (up to 10-20 narwhal/km^2)	early May to late July	Coastal landfast ice-edge with nearby pan-ice
	Narwhal	1,000's (up to 20-50 narwhals/km^2)	late September to mid-October	Shallow coastal waters
	Bowhead whales	10's	late June and July	Coastal waters along North Bylot Island
	Harp seals	100,000's	July	Shallow coastal waters near Cape Hay, ice-edge of Navy Board Inlet
	Murres	10,000's (up to 177 murres/km^2)	mid-May to late June	Coastal ice-edge near Cape Hay colony
	Oldsquaw	1,000's (up to 30 oldsquaw/km^2)	mid-May to mid-July	Coastal landfast ice-edge with nearby pan-ice near Navy Board Inlet
	Fulmars	1,000's (up to 90 fulmars/km^2)	early May to early June	Coastal ice-edge near Wollaston Islands
	Eiders	10,000's (up to 200 eiders/km^2)	late May to early August	Shorelines and coastal landfast ice-edge of North Bylot Island
Minor Migration route	White whales	100's (up to 10-20 beluga/km^2)	late May to mid-June	Coastal landfast ice-edge, with nearby pan-ice
	Bearded seals	100's	late July	Shallow coastal waters near Cape Hay
Major Feeding area	Fulmars	10,000's (up to 710 fulmars/km^2)	early June to mid-September	Coastal landfast ice-edge, persistent ice-edge in Navy Board Inlet, ice-free waters
	Kittiwakes	10,000's (1,600 or more kittiwakes/km^2)	late May to mid-September	Coastal waters near Cape Hay colony, persistent ice-edge across Navy Board Inlet
	Murres	10,000's (375 or more murres/km^2)	early July to late August	Coastal waters adjacent to Cape Hay colony, mouth of Navy Board Inlet
Minor Summering area	Narwhal	100's	July and August	Northern portion of Navy Board Inlet
	Guillemots	100's to 1,000's (up to 34 guillemots/km^2)	early June to mid-August	Coastal ice-edges and shallow waters near Wollaston Islands and Cape Hay colonies
	Walrus	10's	July, August and September	Mouth of Navy Board Inlet near Wollaston Islands
Known Summer Retreats	Polar bears	10's	July to September	Persistent landfast ice in Navy Board Inlet, shorelines of North Bylot Island
Important Moulting area	Eiders	1,000's	July	Coastal waters and bays near Cape Hay
Minor Brood-raising and Moulting	Snow geese	100's	mid-July to late August	Beaches and shallow coastal waters of Navy Board Inlet
Important Fall Concentration area	Harp seals	1,000's (up to 45 seals/km^2)	September	Coastal waters, with pan-ice, in Navy Board Inlet
Minor Fall Concentration area	Oldsquaw	1,000's	late September	East shore of Navy Board Inlet

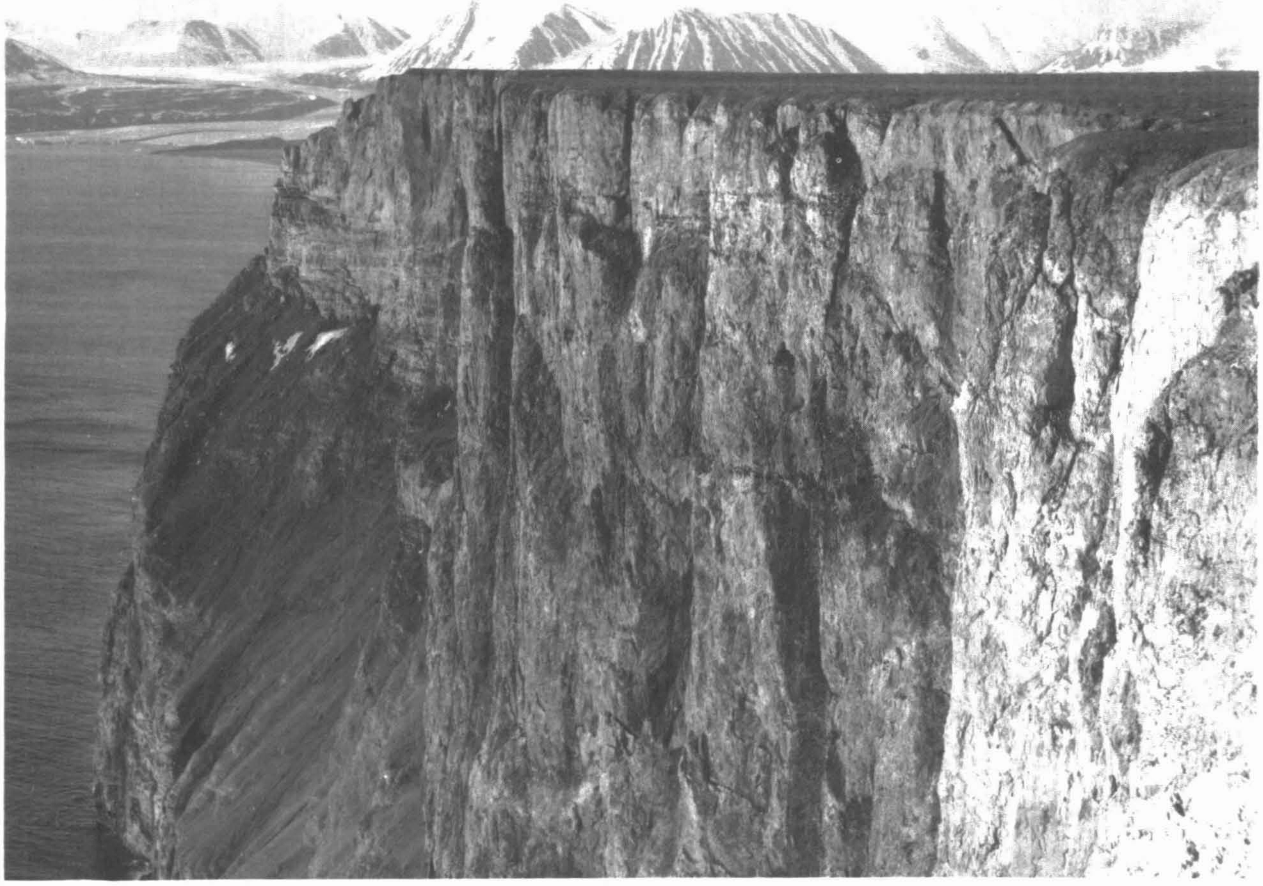
* **Note:** Tables 8.1 to 8.5 are based on References 8.8, 8.9, 8.12, 8.13 and 8.15

of 240 birds/km^2, two to three times more dense than elsewhere in eastern Lancaster Sound. Closer to the colony, densities reached 1,600 birds/km^2 or more[8.8]. Although the nesting ledges and the chicks are well protected from oil-spills, the adults foraging in summer waters are extremely vulnerable. Their diving or swimming habits when feeding and resting, and their general unawareness of the oil-threat ensures death from feather-fouling and chilling. Survival of the entire Cape Hay colony of Thick-billed Murres and, to a lesser degree, Black-legged Kittiwakes is seriously endangered.

A continuous belt of landfast ice is anchored to most beaches and the cliffs of Bylot Island for eight months of the year. This effectively excludes oil from contacting the shores. The seaward edge of this landfast ice will concentrate floating oil, especially from early May to mid-July. We predict that the persistent ice-edge across the north mouth of Navy Board Inlet will be a site of heavy oil accumulation. Wildlife also accumulates at this ice-edge. Polar Bears, Ringed Seals, Narwhals, White Whales, Walruses, Harp Seals, Black Guillemots, Oldsquaws and Thick-billed Murres migrate and feed at these edges. Survey



Cape Hay Murre Colony, Bylot Island (photo: D. Nettleship)



Cape Hay Murre Colony, Bylot Island (photo: D. Nettleship)

Nesting Thick-billed Murres at Cape Hay, Bylot Island (photo: D. Nettleship) biologists, in 1976, reported that 26 to 47% of White Whales, Narwhals, Walruses and Harp Seals preferred coasts with landfast ice from May to August[8.9]. About 1,300 Narwhals congregated along the north Navy Board Inlet ice-edge on July 22, 1976[8.12]. Moulting Ringed Seals are attracted to ice-edges, probably accounting for high concentrations of Polar Bears in Navy Board Inlet. The Inlet's slow rotting ice is one of the last places where bears can hunt before open water forces a retreat to land.

During 1976 seabird surveys of eastern Lancaster Sound, almost 60% of Thick-billed Murres were sighted in coastal landfast ice habitat. This clumped distribution is prevalent along north Bylot Island, often within a hundred metres of the ice-edge itself. Johnson et al (1976a)[8.9] report:

> "... when Murres were most numerous and most heavily concentrated at the fast-ice edge near Cape Hay (16 to 24 May), large amounts of pan-ice were packed against the ice-edge adjacent to the colony. On those dates, Murres were heavily concentrated in the very few cracks and leads that were present."

Oil-pollution of such local critical habitat would inflict heavy mortality on alcids.

When ice conditions permit migrating seabirds and whales a choice between offshore and coastal routes, many continue to hug the shores. About 40% of all Narwhals travelling in or out of the Sound in 1976 passed within several hundred metres of the Bylot Island and north Baffin Island coasts[8.9]. At times, this migration was intense along this coastal corridor; 2,728 Narwhals and 4,062 Harp Seals swam past Cape Hay between July 13 and 15, 1976[8.13].

The potential oil-pollution hazard extends south into Eclipse Sound. Narwhals, White Whales, Ringed Seals and seabirds migrate through or reside in these waters, but it is not known to what extent and in what numbers. The stable landfast ice of Navy Board Inlet and Eclipse Sound offers prime winter and spring habitat for feeding, breeding and moulting Ringed Seals. The Inuit of Pond Inlet can endorse this fact; their seal hunts focus here each year. In spring, Narwhals are hunted along coastal ice-edges, melt ponds and cracks in the Sound's landfast ice. Trapping of Arctic Foxes provides a small community cash income in most years. Both these species are of local importance, providing food and cash income.

Oil spreading in Eclipse Sound may alter travel and feeding patterns of these marine mammals, at least until pollution is flushed out or immobilized on shores. In turn, disruption of local hunting patterns of Pond Inlet Inuit is possible.

Of concern to wildlife preservation and hunters is the threat to the uniquely large population of Great Snow Geese on southwest Bylot Island and other coastal locales along Navy Board Inlet. Moderate to light oiling of beaches, river deltas and shallow marine bays may foul thousands of fall staging geese and their young. Traditional staging sites, if any, have not been defined; the proportion of the population exhibiting marine habits is uncertain.

Inuit of Pond Inlet sometimes fish, mostly for Arctic Char, during hunting expeditions into Navy Board Inlet and Eclipse Sound. There is no information about these coastal fish stocks. Their vulnerability to oil in river deltas and bays is unknown but probably low.

The shores of north Bylot Island are known summer retreats for Polar Bears. Here their vulnerability to oil is at least two-fold: (1) direct fouling of females, cubs and sub-adult males, and (2) scavenging of oiled bird-carcasses littering shores[8.12]. There is no past experience or evidence upon which to speculate concerning behavioural responses of Polar Bears to floating or stranded oil - either on land or sea ice. The toxicity of ingested oils is not known nor the chilling effects from matted fur. Although impact predictions are impossible without such information, the threat remains.

8.2.3 South Devon Island

Coasts of south Devon Island, including Cape Warrender, Dundas Harbour and Croker Bay are potentially oil-polluted when intermittent strong south or west winds interact with west-flowing surface currents along the Sound's north margin (Figures 5.9 and 5.12). This possibility exists for five or less months of the year, between May and September, and in conditions of partial or complete open-water. As elsewhere in Lancaster Sound, coastal landfast ice will shield most shores from oil, except during July through mid-October. The seaward ice-edges will receive the brunt of oiling, and will concentrate floating oil. During the summer, Croker Bay and Dundas Harbour provide quiet, protected embayments where oil will accumulate.

Table 8.3 summarizes the approximate abundance of birds and mammals which feed, breed or travel along this stretch of the south Devon coast. Croker Bay is an important location where seals, Polar Bears, Walruses, and whales concentrate. In essence, Croker Bay is to south Devon Island what Navy Board Inlet is to north Baffin Island (Section 8.2.2). Two reasons for such high wildlife activity in Croker Bay are the presence of landfast ice until mid-August or later, and the proximity of a major migration corridor for marine mammals. Ringed Seals seek out the Bay's fast-ice to breed, feed and moult. In turn, Polar Bears hunt seals here. For example, densities of 2.5 seals/km² along the Croker Bay ice-edge were the highest recorded anywhere in eastern Lancaster Sound in 1976; about 30% of all Polar Bears frequented this same ice-edge from mid-June to mid-August[8.9]. Any oil "boomed" against this and other coastal ice-edges poses a serious hazard to these residents and, to a lesser degree, to large numbers of passing White Whales and Narwhals. In spring, up to ten times more White Whales travel along the south Devon Island coast than along the north Baffin route. The Dundas Harbour vicinity proved the best place to spot White Whales (12 whales/km²) in July, 1976[8.9].

In early summer, Croker Bay continues to attract late migrants. Of all Walruses recorded between June and September, 1976, 40% were found in the Croker Bay

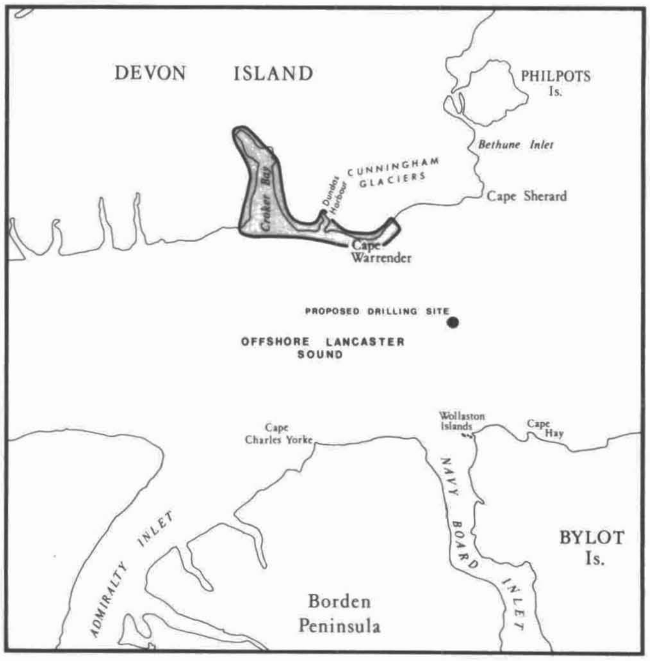


Table 8.3 *

SOUTH DEVON ISLAND
(Croker Bay, Dundas Harbour, Cape Warrender)

Major Wildlife Value or Use	Species	Approx. numbers or Density	Dates	Habitat Preferences
Known maternity denning area	Polar bears	Possibly 10's	October to early April	Coastal lowlands around Croker Bay
Principal migration route	White whales	1,000's (up to 50-250 beluga/km^2)	mid-March to late July	S. Devon Island flaw-lead, landfast ice-edge near Dundas Harbour, Croker Bay and Cape Warrender
	White whales	100's to 1,000's (up to 20-50 beluga/km^2)	mid-September to mid-October	Shallow waters of Croker Bay and near Dundas Harbour
	Narwhals	100's to 1,000's (up to 20-50 narwhals/km^2)	late April to early July	(Similar to white whales in Spring)
	Walrus	10's to 100's (up to 4 walrus/km^2)	late April to early July	S. Devon Island flaw-lead, coastal landfast ice-edges, with nearby pan ice-edge across Croker Bay
	King eiders	1,000's (up to 340 eiders/km^2)	early May to early June	Coastal waters free of landfast ice near Cape Warrender
	Fulmars	1,000's (up to 78 fulmars/km^2)	early May	Landfast ice-edge near Cape Warrender
	Guillemots	1,000's (20-50 guillemots/km^2)	May	Shorelines and ice-edges along entire coasts
Minor Migration route	Narwhals	1,000's (up to 5-10 narwhals/km^2)	late September to mid-October	(Similar to white whales in Fall)
	Murres	1,000's (up to 50 murres/km^2)	late May and June	Ice-edge of Croker Bay
Known Summer retreat	Polar bears	10's	July to September	Persistent landfast ice in Croker Bay and Dundas Harbour
Major Feeding area	Fulmars	10,000's (up to 775 fulmars/km^2)	late June to mid-September	Coastal waters and landfast ice-edges, especially in Croker Bay
	Kittiwakes	10,000's (up to 320 kittiwakes/km^2)	mid-August to late September	Ice-free coastal waters along entire shore
	Glaucous Gulls	1,000's (up to 26 gulls/km^2)	early June to mid-September	Ice-infested coastal waters of Dundas Harbour and Croker Bay
Important nesting and brood-rearing area	Eiders	100's to 1,000's	early June to late September	Breeding sites on raised beaches and ponds along shores of Croker Bay
	Guillemots	100's to 1,000's	early June to late August	Coastal waters near colonies at Dundas Harbour and Cape Warrender
Summer Feeding area and/or haul-out site	Bearded seals	10's (less than 1 seal/km^2)	July to September	Shallow waters of Croker Bay and Dundas Harbour
	Walrus	10's to 100's (up to 2.5 walrus/km^2)	late July to September	Shallow waters of Croker Bay and Dundas Harbour
	Harp seals	100's (up to 12 seals/km^2)	July to September	Ice-edge and shallow waters of Croker Bay and Dundas Harbour

* **Note:** Tables 8.1 to 8.5 are based on References 8.8, 8.9, 8.12, 8.13 and 8.15

region of eastern Lancaster Sound, and herds of 6 to 20 were common. Likewise, many hundreds of summering Harp Seals congregated here, up to 58 seals/km^2 by September[8.9]. These benthic-feeding species may feed heavily on marine invertebrates and fishes in the Bay's shallow waters and this could explain their attraction to this area.

Although there are no known major seabird colonies between Cape Warrender and Croker Bay, this stretch of coastline attracts hundreds of thousands of marine birds. The summer's overall density averaged from 90 to 120 birds/km^2 in 1976, with peak densities of 780 birds/km^2 in early August[8.8]. Some species, such as eiders are May migrants en route to better nesting tundra of the Central Arctic. Northern Fulmars and, to a lesser extent, Black-legged Kittiwakes and Black Guillemots forage in these waters throughout the summer and fall. Any persisting ice-edges and coastal shallow water are generally preferred habitats.

8.2.4 Southeast Devon Island

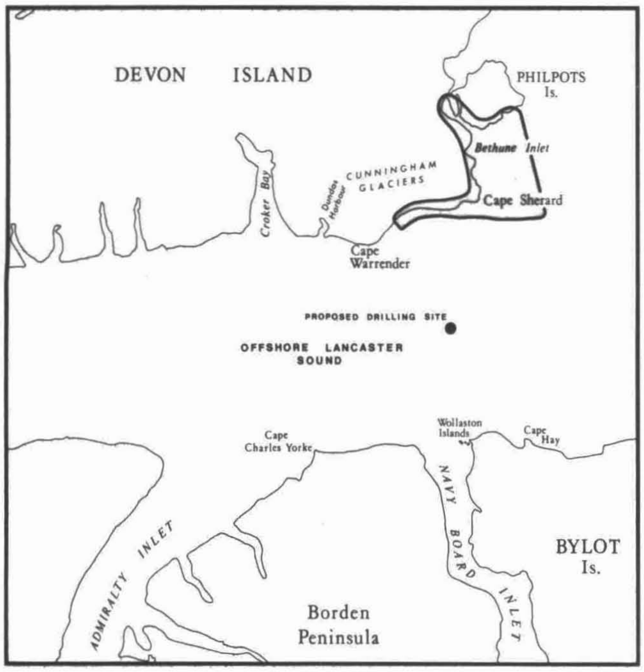
Although the Cape Sherard-Philpots Island region is outside the predicted realms of moderate and heavy oil pollution (Figure 5.8), this locale probably deserves mention. Vagaries of the Arctic's currents, winds and ice ensure that coastal waters and beaches adjacent to those mentioned in sections 8.21 and 8.23 are not completely "safe" from oiling especially in the open-water season.

The Devon ice-cap is an immense physical feature of southeast Devon Island. Its glacier fronts enter the Sound in Bethune Inlet, and between capes Warrender and Sherard. Glacial run-off, shallow waters and strong currents from Baffin Bay make this corner of Devon Island a dynamic, productive marine area which attracts hundreds of thousands of feeding seabirds. Table 8.4 briefly summarizes these and other important wildlife uses from March to October. The highest densities of Northern Fulmars (about 1,300 birds/km^2, in flocks of 500 to 2000) anywhere in

Table 8.4 * SOUTHEAST DEVON ISLAND
(Philpots Island, Bethune Inlet, Cape Sherard, Cunningham Glaciers)

Major Wildlife Value or Use	Species	Approx. numbers or Density	Dates	Habitat Preferences
Suspected maternity denning area	Polar bears	Unknown - possibly 10's	October to early April	Maternity dens in snowbanks of coastal tundra of S.E. Devon Is.
Spring concentration area	Polar bears	10's	March, April & May	Landfast ice edge between Bethune Inlet & Cape Sherard
Principal Migration route	White Whales	1,000's (up to 20-50 whales/km^2)	mid-March to late June	Edge of landfast ice near Cape Sherard and Bethune Inlet (South Devon Island flaw-lead used by earlier westward migrants).
	White whales	1,000's (up to 50-250 whales/km^2)	mid-September to mid-October	Shallow coastal waters in Bethune Inlet and along Cape Sherard
	Narwhals	1,000's (20-50 narwhals/km^2, near Cape Sherard)	late April to mid-July	(Similar to White Whales in Spring)
	Walrus	10's	late April to early July	Shallow ice-infested waters near rocky islands and peninsulas
	Eiders	10,000's (up to 130 eiders/km^2)	mid-May to mid-June	Coastal ice-edges west of Cape Sherard
	Fulmars	1,000's (25-75 fulmars/km^2)	early May	(As above).
	Oldsquaw	1;000's (20-50 oldsquaw/km^2)	early June to late July	(As above)
Minor Migration	Narwhals	100's to 1,000's (up to 5-10 narwhals/km^2)	late September to early October	Shallow coastal waters near Cape Sherard and Cunningham Glaciers
	Guillemots	1,000's (up to 10-20 guillemots/ km^2)	May	Edge of landfast ice, near Cape Sherard
Major Feeding area	Fulmars	10,000's (up to 1300 fulmars/km^2)	late July to mid-	Coastal waters of Cape Sherard
	Kitiwakes	1,000's (up to 275 kittiwakes/km^2)	late August and September	Coastal waters along entire S.E. Devon Island Coast
	Ivory Gulls	10's (up to 1.5 gulls/km^2)	late June to late September	Landfast ice-edges and glacier fronts in Bethune Inlet
	Arctic terns	100's (up to 7.5 terns/km^2)	mid-June to late September	Shorelines and coastal waters of Bethune Inlet and Cape Sherard
Minor Summering area	Harp Seals	100's	July	Coastal waters along ice-edges or near pan-ice
Known Summer retreat	Polar bears	10's	July to September	Coastal lowlands; sometimes glaciers
Summer Haul-out site	Walrus	100's (less than 1 walrus/km^2)	July to September	Shore of S.E. Philpots Island
Important Nesting & Brood-rearing area	Eiders	100's	early July to late September	Coastal waters west of Cape Sherard; nesting on adjacent coastal plain
	Glaucous Gulls	1,000's (up to 71 gulls/km^2)	early July to mid-September	Coastal waters of 5-25% pan-ice cover near glacier fronts
Moulting area	Eiders	100's	early August to mid-September	Protected bay near Cunningham Glaciers

* **Note:** Tables 8.1 to 8.5 are based on References 8.8, 8.9, 8.12, 8.13 and 8.15



eastern Lancaster Sound were recorded along an 18 km stretch of coastline just west of Cape Sherard in September 1976[8.8]. Nettleship (1974a)[8.14] estimated that 100,000 Fulmars feed here – probably non-breeders or commuters from four of six major Fulmar colonies known in the Canadian Arctic. Southeast Devon Island also ranked first in densities of feeding Ivory Gulls and Arctic Terns, and migrating and breeding Eiders in 1976[8.8].

Polar Bears converge on the continuous belt of landfast ice between Philpots Island and Cape Sherard in June and July. For example, about 60% of bears (27 out of 46) recorded along the south Devon Island coast, from Croker Bay to Bethune Inlet, were sighted here[8.9].

Southeast Devon Island falls within a major migration corridor for most White Whales which travel in and out of Lancaster Sound. About 2,500 whales were gathered in Bethune Inlet on 19 September, 1976[8.9]. Although southeast Devon Island supports no major seabird colonies, nor harbours any large populations of over-summering marine mammals, oil pollution, if destined for this locale, poses the most serious threat to feeding Northern Fulmars and other seabirds. Massive kills are expected.

Table 8.5 *

NORTH BAFFIN ISLAND
(North Borden Peninsula; northern portion of Admiralty Inlet)

Major Wildlife Value or Use	Species	Approx. numbers or Density	Dates	Habitat Preferences
Known or suspected maternity denning area	Polar bears	10's	October to early April	North coast of Borden Peninsula
Spring concentration area	Polar bears	10's	March, April and May	Coastal landfast ice and ice-edge along N. Borden Peninsula and in Admiralty Inlet
Important breeding and moulting area	Ringed seals	1,000's	early May to late July	Coastal landfast ice along North Borden Peninsula; landfast ice of Admiralty Inlet
Principal migration route	Eiders	1,000's (up to 260 eiders/km^2)	mid-May to mid-August	Coastal landfast ice-edge and shallow waters along North Borden Peninsula
	Narwhals	1,000's (up to 5-10 narwhals/km^2)	early May to late July	Along land-fast ice of North Borden Peninsula; ice-edge of Admiralty Inlet
	Narwhals	1,000's (up to 5-10 narwhals/km^2)	late September to early October	Coastal waters along North Borden Peninsula
	Oldsquaw	1,000's (up to 150 oldsquaw/km^2)	mid-May to mid-July	Shallow coastal waters along North Borden Peninsula (in bays and near river-mouths)
Minor migration route	White whales	100's (10-20 beluga/km^2, late May to mid-June)	late May to mid-June	Coastal landfast ice-edge of North Borden Peninsula
Known summer retreats	Polar bears	10's	July, August and September	North coast of Borden Peninsula and N.E. coast of Brodeur Peninsula
Important summering area	Narwhals	1,000's	July and August	Landfast ice-edges and coasts of Admiralty Inlet
Important Feeding area	Guillemots	100's to 1,000's (up to 20-50 guillemots/km^2)	early June to mid-August	Coastal ice-edges and shallow waters along North Borden Peninsula
Major Feeding area	Kittiwakes	1,000's (up to 220 kittiwakes/km^2)	early June to late September	Landfast ice-edge and shallow coastal waters
	Fulmars	10,000's (up to 230 fulmars/km^2)	late May to late September	(Similar to above)
Minor Moulting route	Oldsquaw	100's to 1,000's	July to mid-September	Coastal waters of North Borden Peninsula

* **Note:** Tables 8.1 to 8.5 are based on References 8.8, 8.9, 8.12, 8.13 and 8.15

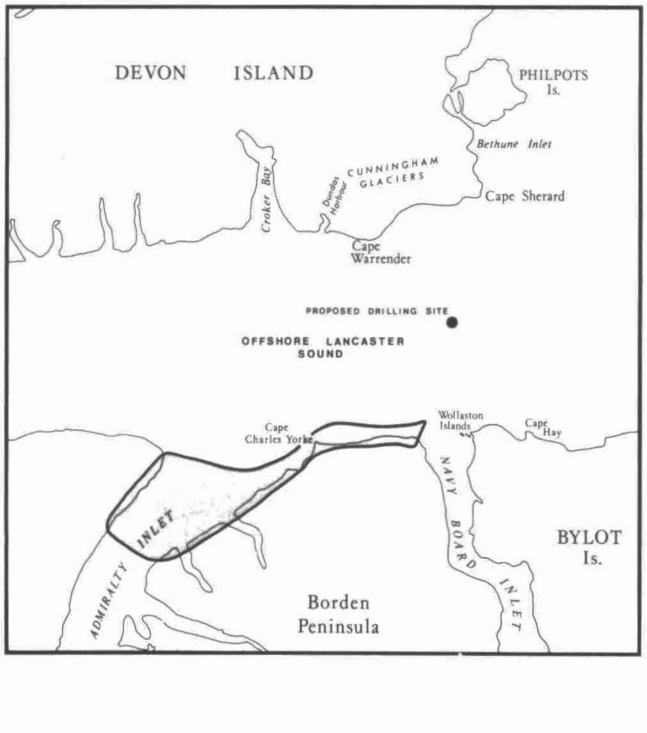
8.2.5 North Baffin Island

North Borden Peninsula, Capes Joy and Charles Yorke and northern Admiralty Inlet fall outside predicted trajectories of oil slicks from the blowout (Figures 5.9 and 5.12). However, statistical predictions do not guarantee that oil will not pollute coastal waters and shorelines of north Baffin Island. Strong, persistent NE winds in September could counter prevailing currents and drive oil slicks beyond the southwest bounds of predicted oil pollution.

This stretch of coastline is probably a less vulnerable habitat to wildlife populations than most other locales of eastern Lancaster Sound. However, Narwhals, Polar Bears and seabirds seasonally inhabiting coastal waters and shores could be threatened (Table 8.5). The density of birds was relatively low (about 75 birds/km^2) from May to September 1976, but, at times, reached 350 birds/km^2. These densities are at least three times less than those recorded in Navy Board Inlet, only 50 km away[8.8]. Probably most of these birds are (1) migrating Eiders and Oldsquaws bound for westerly nesting tundra; (2) feeding Northern Fulmars from, perhaps, the Baillarge Bay breeding colony, or (3) post-nesting Black-legged Kittiwakes from Cape Hay. The open, unnamed bay, between capes Joy and Charles Yorke, attracts many of these birds[8.8].

As elsewhere in the Sound, popular spring and early summer habitat are marine waters immediately adjacent to landfast ice. Densities of 260 Eiders/km^2 (May 6 to 20, 1076) and 4.5 Narwhals/km^2 (June 6 to 7, 1976) were recorded at ice-edges near Cape Charles Yorke[8.8, 8.9]. About 1,600 Narwhals were concentrated in the cracks and leads of the ice-edge at the mouth of Admiralty Inlet on 22 July, 1976[8.12]. Polar Bears use Borden Peninsula and Admiralty Inlet for spring seal-hunting or summer confinement. The coast near Cape Charles Yorke supports one of, possible, six critical summer retreats[8.15].

In the event of a blowout, oil accumulated on north Baffin Island shores and ice-edges, especially across Admiralty Inlet, would add significantly to the overall kill of seabirds, such as Northern Fulmar, Eiders and Black-legged Kittiwakes, and pose a threat of unknown significance to migrating Narwhals and resident Polar Bears.



8.3 Major Damage and Predicted Impacts on Marine Life

8.3.1 Damage and Impacts from Oil Pollution

In the event of offshore exploratory drilling in eastern Lancaster Sound, the possibility of an oilwell blowout cannot be ignored. This tempts us to predict concerning the acute and long-term impacts of such large-scale pollution on the Sound's marine life, sometimes regardless of the strength of the data base. This makes the task of environmental assessment difficult and controversial. Dr. Jon Percy of Fisheries and Marine Service states:

> "Even in temperate waters where intensive research has provided a solid information base, it is still impossible to predict the precise ecological effects of an anticipated oil-spill. Even after a spill has occurred, it has proven difficult to assess the overall environmental impact. Given the dearth of information about Arctic marine ecosystems, any attempt at detailed impact prediction, at present, can only be considered an exercise in futility.[8.16]"

Based on such rationale, we make no attempt in this report to exhaustively list and discuss interactions between oil and *all* marine life. Instead, our focus centres on "high profile" organisms such as seabirds, since without a doubt, certain species of Eastern Arctic seabirds are extremely vulnerable and susceptible to oil polution.

For Polar Bears, Narwhals, White Whales, Walruses, Ringed Seals and most other Arctic marine mammals, their behavioural responses to oil in feeding and breeding, their susceptibility to oil-fouling and ingestion, and their recovery from the effects of oil can only be guessed at[8.15]. Recent experiments revealed that Ringed Seals suffer little harm from brief oil immersion or oil ingestion, except during conditions of stress and poor health[8.17].

For marine fishes, benthic invertebrates, plankton and seaweeds, environmental impact assessment enters the realm of science fiction. Relatively little is known about these "low profile" organisms, even though these are the foundation of the ecological web upon which higher forms depend. Knowledge of basic ecology and physiology of the majority of Arctic marine invertebrates is lacking, rendering impact prediction impossible. Although the extinction of the copepod or clam populations in eastern Lancaster Sound seems remote in the event of a blowout, local depletions of a critical nature are inevitable. Subsequent predator-prey reverberations throughout the food chain are possible, and moreover, their significance is not yet understood.

All marine-associated birds are at risk to oil, but most vulnerable are those which sit on the water, such as Thick-billed Murres, Dovekies, Black Guillemots, Oldsquaws and Eiders. When they dive for food, these birds often cannot avoid surfacing through oil-slicks[8.18]. Murres and other alcids usually respond by futile diving, rather than flying to escape. Oldsquaws on the wing are attracted to waters which are artificially smoothed by oil[8.19]. Surface-feeding Black-legged Kittiwakes and Northern Fulmars often fail to recognize oil unless it is thick[8.18]. Oil disrupts birds' arrangements of outer contour and down-feathers. Birds lose their waterproofing and bouyancy, or are chilled by penetrating cold water and air. Exposure, cessation of feeding, shock and depletion of body-fat eventually kills the birds. Oiled birds preen and directly ingest large quantities of oil[8.20]. Lightly-oiled, breeding birds transfer oil to eggs and chicks, drastically reducing hatching and fledging success[8.21].

Lancaster Sound, one of Arctic Canada's major migration flyways and breeding locales, supports millions of diving birds, seaducks, gulls, geese and shore-birds. An oilwell blowout in Lancaster Sound will place at greatest risk the region's populations of Murres, Dovekies, Kittiwakes and Fulmars. Oil pollution in the network of offshore leads and cracks will kill tens to hundreds of thousands of migrating Dovekies — a significant fraction of West Greenland's breeding colonies. Similarly, thousands to tens of thousands of Thick-billed Murres en route to Prince Leopold Island will die. Later, during summer, oil slicks along north Bylot Island and Navy Board Inlet will kill more tens of thousands of Thick-billed Murres foraging near their Cape Hay colony.

Then, in late summer, tens of thousands of Thick-billed Murres will die while they migrate through the Sound, and out or past its eastern exit to Baffin Bay. During this out-migration, the paths of Murres, adults and young alike, from colonies at Prince Leopold Island, Cape Hay, Coburg Island and Cape Graham Moore probably converge along the east coasts of Bylot and Baffin Island, swimming with same surface currents which could carry oil slicks. These birds are flightless at this time, and would swim and dive through the polluted waters, most being killed in the process.

The cummulative impact of such large kills on Thick-billed Murres is likely to threaten the survival of the Cape Hay colony. The other three colonies at Cape Graham Moore, Prince Leopold Island and Coburg Island will be depleted. Eventual population recovery is doubtful for the Cape Hay colony and slow, at best, for the others.

The Cape Hay colony has already suffered a significant population decline in the past two decades. Biologists speculate that birds harvested by West Greenlanders and accidentally-caught by Danish salmon fishermen have exceeded the Murres' natural reproduction. At best, oil pollution of Lancaster Sound will confound the population's present slow recovery[8.6].

Tens of thousands of Black-legged Kittiwakes and fewer Northern Fulmars, will die along the shores of Bylot Island and in Navy Board Inlet. These locales are critical feeding waters for Cape Hay Kittiwakes and also the predicted sites of heaviest pollution. This anticipated kill could be severe enough to threaten the survival of the Cape Hay Kittiwake colony, the largest in eastern North America.

Thousands of Greater Snow Geese along the coastal waters and shores of Navy Board Inlet and Eclipse Sound will be lost. However, their nesting habitat on the southwest Bylot lowlands is well protected. Recovery is ensured unless traditional fall staging and feeding marine areas are persistently oiled.

8.3.2 Land-base and Logistic Support

Without a detailed plan of land-based facilities and logistic requirements for proposed exploratory drilling in Lancaster Sound, potential environmental hazards cannot be addressed specifically in this Report. However, construction and normal operation of a shore support-base are potentially more damaging to Arctic terrestrial and marine life than normal offshore drilling activities (see Section 3.2). Of course, an oilwell blowout is the exception. The following discussion highlights possible wildlife threats and does not attempt to predict impacts.

If Nanisivik Mine-site is chosen as the land-base support centre of exploratory drilling, the accelerated industrial activity could pose incremental environmental hazards to the surrounding Borden Peninsula terrain and hydrology, and the shore and waters of Strathcona Sound. Mining facilities, such as an airstrip for large passenger and cargo aircraft, a marine dock for ore-carriers, and ship-loading equipment are already in place. Major improvements and modifications to these existing facilities may be required to handle increased marine and air traffic during summer drilling operations and possible year-round emergency situations. New or expanded facilities may be necessary for personnel housing, sewage and water treatment, waste incinerations, bulk storage, roads and communications.

Ship-to-shore transfer of crew, personnel and some resupplies is possible using helicopters. Strict control of air traffic (e.g. minimum altitudes and a restricted overland flight-corridor) can alleviate most disturbances to feeding and breeding seabirds, marine mammals and other wildlife. However, this 'safe corridor' concept is less feasible for marine traffic. Bulk supply vessels supported by icebreakers may be required to service the drillship(s) during normal and emergency operations in late June and early July. During this period, many tens of kilometres of landfast ice in Strathcona Sound and Admiralty Inlet will hinder marine traffic between Nanisivik and offshore Lancaster Sound. Since this region of sea-ice is the breeding, moulting or feeding habitat of Ringed Seal, Polar Bear and White Fox populations, of unknown numbers, this disturbance may or may not be significant. The ice-edge stretching across Admiralty Inlet is critical to thousands of Narwhal which probably feed here and await the approach of the Inlet's summering waters. The impact of ice-breaking vessels and supply ships on these animal concentrations, and the break-up patterns of Admiralty Inlet is unknown.

Inuit hunters from Arctic Bay, about 30 km S.W. of Nanisivik Mine, travel throughout Admiralty Inlet to shoot and trap seals, bears and whales. The Inlet's landfast ice and northern ice-edge and ice-cracks are popular hunting locales for Narwhals in June. A potential conflict exists between these Inuit resource uses and marine traffic.

In future, Croker Bay and Dundas Harbour (south Devon Island) may be considered as alternative or supplementary shore-base sites and over-wintering harbours because of their protected waters of adequate depth and close proximity to mid-Lancaster Sound. However, the potential wildlife threat of such activities is high, for the following reasons:

- Walrus haul-outs in Dundas Harbour;
- Narwhal, White Whale and seabird migration stop-overs along ice-edges and in protected waters of Croker Bay and Dundas Harbour;
- Polar Bear hunting sites and summer retreats along the ice-edge of Croker Bay;
- Ringed Seal breeding and moulting areas on the landfast ice of Croker Bay; and
- Muskoxen summering range along Croker Bay's coastal lowlands.

8.4 Major Unknowns

Important questions remain unanswered in eastern Lancaster Sound, such as "Why is Lancaster Sound so biologically rich?" or "What is the year-to-year variability in migration, feeding and breeding patterns of seabirds, whales, seals and bears?" These are not likely to be answered within the next year or two. We have no basis for speculation on the behavior of most arctic marine mammals when they confront oil in leads, along ice-edges or in coastal waters. If they should contact or ingest oil, the lethal or sublethal outcome is unknown. This data vacuum applies to most arctic plants and animals. Consequently, in ignorance of this basic ecology and oil-organism interactions, most impacts cannot be predicted. Real impacts can only be measured *after* an oilspill, if sufficient pre- and post- spill information is available. Each incident of oil pollution is unique.

Below are listed several data deficiencies which seriously hamper our immediate understanding of the oil threat in the Lancaster Sound region:

- presence or absence of major coastal benthic seaweed and invertebrate communities along north and east Bylot Island, in Navy Board Inlet and in Croker Bay;

- location, if any, of other prime feeding areas for common marine birds in Baffin Bay, along east Bylot Island, in Navy Board Inlet and Eclipse Sound;
- seabird migration patterns in fall, especially for Thick-billed Murres and Dovekies in Baffin Bay;
- abundance and distribution of summering Narwhals and other marine mammals which summer in Navy Board Inlet and Eclipse Sound;
- abundance and distribution of Ringed Seals and Arctic Foxes which breed, moult or feed in the landfast and pack ice of Lancaster Sound, Croker Bay, Navy Board Inlet, and Eclipse Sound;
- abundance and distribution of Polar Bears along north and east Bylot Island, and Navy Board Inlet in spring and summer, with emphasis on summer retreats and denning sites;
- identification of traditional haulout sites for Walruses along south Devon, north Baffin and Bylot Islands.
- coastal concentrations of Arctic Cod, Arctic Char and other marine fishes along north Bylot Island, Navy Board Inlet and Croker Bay.

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