

# **LNG Transport in Parry Channel:**

## **Possible environmental hazards**

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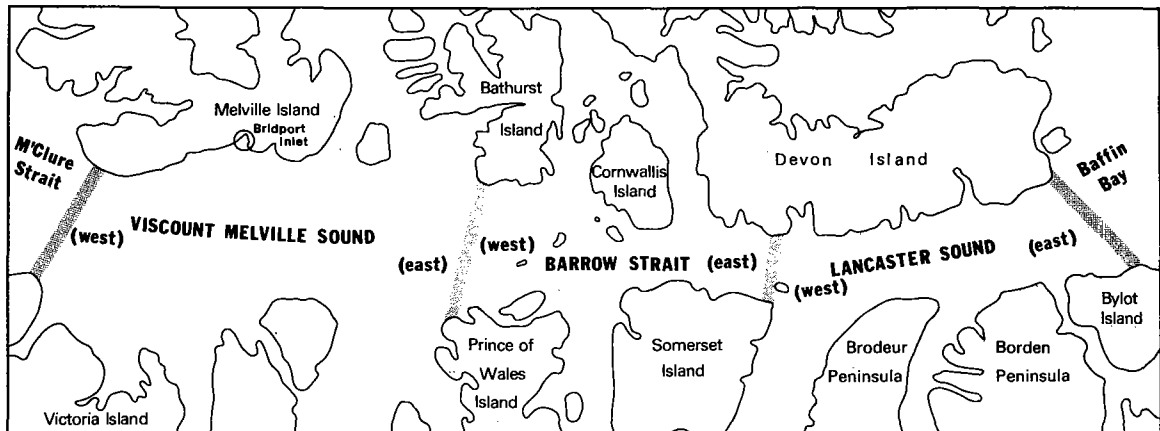
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Sounds and Straits of Parry Channel, arbitrarily delineated for the purposes of this Report.

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## 1. SUMMARY

This review is intended to direct attention to the possible effects of year-round icebreaking in Parry Channel. The Arctic Pilot Project proposed by Petro-Canada and Melville Shipping Limited is the first to incorporate a marine shipping component for liquid natural gas (LNG) through a region of complete ice cover. Consequently, it is important to scrutinize the Project's most obvious environmental implications in advance of its official Applications to the National Energy Board and Federal Environmental Assessment Review Office. We attempt to inform government scientists of various Arctic disciplines about the nature of the Project, and about major environmental concerns and outstanding data gaps.

During the normal operation of icebreaking LNG carriers, the Channel's ice cover will be physically disrupted. In addition, groundings, collisions and other accidents will result in LNG fires, explosions, vapour-clouds and diesel-oil pollution. To varying degrees, these events threaten resident and migratory Arctic wildlife. The foremost risks and unknowns are summarized as follows :

1. Incomplete bathymetry exists along the northern side of Parry Channel in such areas as South McDougall Sound, portions of Barrow Strait south of Bathurst Island, and the Keene Bank area of S Austin Channel. This inadequacy will hamper the choice of safe shipping routes through the thinnest ice in winter and spring.
2. The expanse of landfast ice could be diminished westward in Barrow Strait by routine icebreaking. This may cause a longer ice-free season and a general warming trend in E Parry Channel.
3. The icebreaker's wake through landfast ice will re-freeze quickly in winter and early spring. Ice rubble, ridges and temporary open water, characteristic of the ship's track, will probably not delay Inuit travellers seriously, nor wildlife movements such as caribou inter-island migrations. However, in May and later, new tracks will re-freeze little or not at all and the relatively thin ice of previous wakes will melt prematurely. Early break-up of landfast ice in Barrow Strait will cause open water and moving ice conditions. These situations will curb or prohibit travel across Barrow Strait.
4. Migrant seabirds, polar bears and other marine wildlife may encounter a significant shift in their feeding habitat if the landfast ice-edge is forced to stabilize further west than usual. This shift could be serious to seabirds and sea mammals which depend critically on the Channel's ice-edge for foraging - for example, near colonies or summer retreats, in spring and early summer.
5. Small numbers of early migrant white whales and narwhal may risk fatal entrapment in the icebreaker's wake - assuming a compulsion of these animals to explore any access, even though dangerous and refreezing, into landfast ice.

6. A regular disruption of landfast ice in Barrow Strait and E Viscount Melville Sound by spring icebreaking could threaten an unknown number of breeding ringed seals and newly-born pups. Crushing, wetting or abandonment of pups could result from the passage of icebreakers through whelping locales.
7. If a ship collision or grounding occurs, gas explosions, fires and drifting vapour-clouds from the LNG cargo could produce serious wildlife hazards within a few tens of kilometres of the accident site. The noise and physical presence of the 150,000 hp icebreakers are potentially disruptive to seabirds and marine mammals. For these reasons, icebreaking LNG carriers should not pass close to critical wildlife locales, such as seabird nesting colonies, polar bear denning areas and coastal summer retreats, walrus haulouts, and white whale calving embayments. If possible, ship refits should be scheduled annually for the spring, especially in April and May, in order to minimize the icebreaking threat to pupping seals.
8. Landfast ice-edges, offshore leads and coastal bays - many of which are important wildlife locales - could be seriously polluted by a diesel spill of 10,000 or so tonnes from a damaged LNG carrier. Reduced evaporation in conditions of freezing air temperature, cold water, sea ice and snow cover increases the risk to some wildlife populations significantly, especially to seal pups and seabirds.
9. Over the 30-year period required to exploit Sverdrup Basin gasfields, possible long-term cooling trends in climate could inhibit winter icebreaking in E Parry Chanel. Even a slight temperature decline could result in heavier concentrations of multi-year ice, and more sea-ice cover than expected. This may necessitate the employment of higher Ice-Class LNG carriers, or may even force the cessation of winter and spring icebreaking operations.

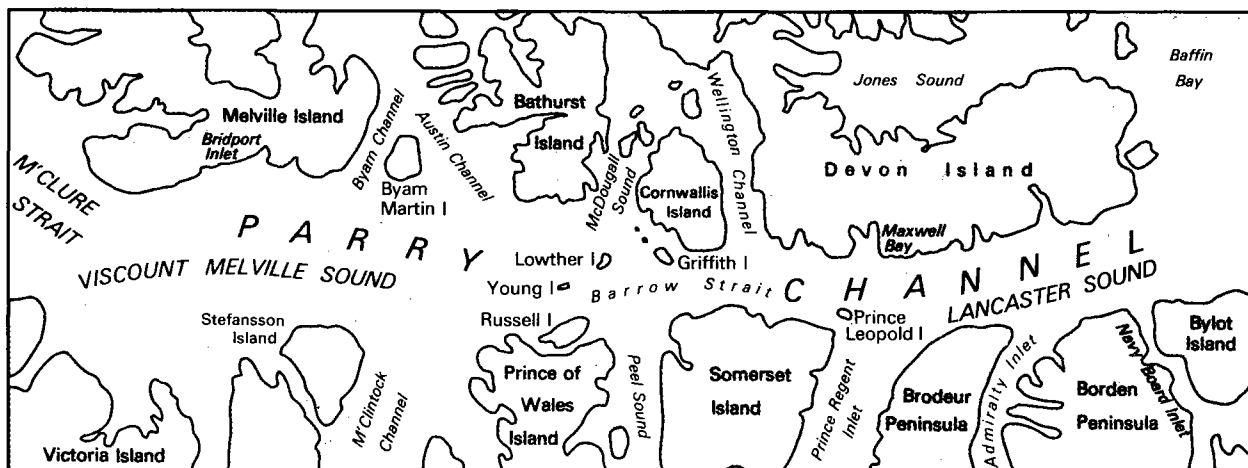


Figure 1. Parry Channel place names.

## 2. INTRODUCTION

In 1819, Lt. W. E. Parry set out for Lancaster Sound from the East in the ships, *Hecla* and *Griper*, convinced that the Sound would prove to be the entrance to the Northwest Passage<sup>1</sup>, now called Parry Channel. Before mid-September, he had explored as far west as Melville Island, and overwintered in Winter Harbour just west of Bridport Inlet (Figure 1). Today, 159 years later, year-round marine traffic is proposed for Parry Channel for the first time - from Bridport Inlet eastward - using icebreaking ships carrying liquid natural gas (LNG). This proposal was announced by Petro-Canada (a Canadian Crown Corporation) and its partners\* in 1977. It is known as the Arctic Pilot Project. The National Energy Board (NEB) has not officially reviewed the Arctic Pilot Project. However, the Federal Environmental Assessment Review Office (FEARO) expects to receive an Environmental Impact Statement (EIS) from Petro-Canada in early 1979. NEB and FEARO reviews are likely also in 1979. Meanwhile, Petro-Canada and Melville Shipping Limited are continuing the design of the marine LNG delivery system (Arctic Petro-Carriers Project).

The Arctic Pilot Project stimulated the Study Board of the Arctic Islands Pipeline Program\*\* to request a review of the Parry Channel section of the marine route. The objectives of the review were twofold : first of all, to succinctly review the major characteristics of the Project for the benefit of the Study Board and Government scientists; and, second, to alert the Study Board to potential hazards and major unknowns which are insufficiently addressed in environmental studies available to Petro-Canada. Consequently, this report (not a surrogate EIS) describes :

- The Arctic Pilot Project and its implications for the future,
- Hazards and constraints to icebreaking LNG carriers in Parry Channel,
- Threats to the Parry Channel environment, and
- Some remedial measures to reduce these threats.

\* Petro-Canada with Alberta Gas Trunk Line manages the Project. Panarctic Oil Limited operates the gas-fields. For the marine route, Melville Shipping Limited is the major partner with participants : Federal Commerce & Navigation Ltd., Upper Lakes Shipping Ltd., and Canada Steamship Lines (1975) Ltd.

\*\* Department of Fisheries and the Environment component of the Environmental/Social Program, Northern Pipelines of the Government of Canada.

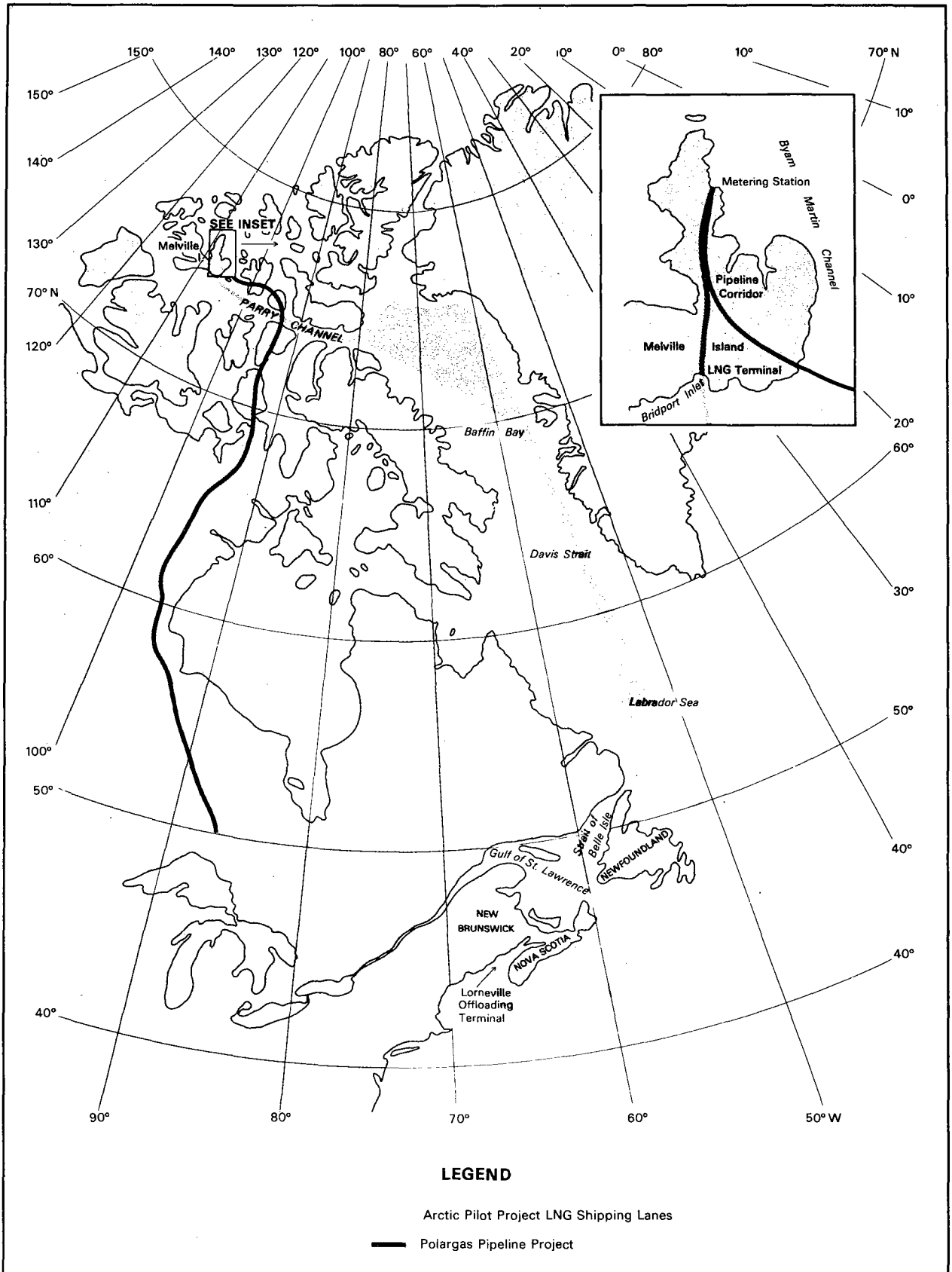


Figure 2. Routes proposed for the Arctic Pilot Project<sup>4</sup> and the Polar Gas Pipeline Project.

There are two competing proposals for delivery of Melville Island gas to southern markets: the Polar Gas Project - a purely pipeline system - and the Arctic Pilot Project - a combined pipeline and icebreaking LNG carrier system (Figure 2). The Arctic Pilot Project entails delivery of gas from the Drake Point Field (Figure 3). Both projects propose pipelines to transport gas southward on Sabine Peninsula.

The Sverdrup Basin has currently marketable gas reserves of 16 trillion scf (TCF)<sup>\*\*\*</sup>, projected to increase to 30 TCF within 4 years<sup>2</sup>. This compares with Alberta's 66 TCF of produced and recoverable reserves (1977).

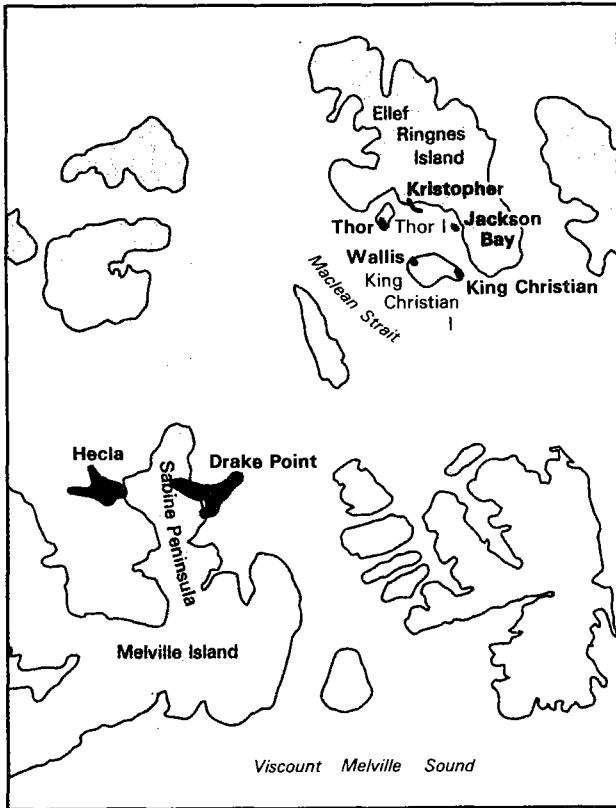


Figure 3  
Gas-fields with  
proven reserves  
in the Sverdrup  
Basin<sup>2</sup>.

Most accessible in the Sverdrup Basin are Panarctic's Hecla (3.5 TCF) and Drake Point (4.8 TCF) fields, encompassing areas on and offshore of Sabine Peninsula, Melville Island.

It is unlikely that the Arctic Pilot Project and the Polar Gas Project will be simultaneously approved by the NEB. (The Polar Gas Project's EIS was submitted to FEARO in early 1978). Our concern is the prospect of the Arctic Pilot Project and its use, year round, of large icebreakers throughout Archieplago waters. The question is asked whether or not there are adequate environmental studies to highlight short and long hazards - both to the year-round operation of such vessels in Parry Channel and to the physical and biological environment.

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<sup>\*\*\*</sup> One trillion =  $1 \times 10^{12}$ ; scf = standard cubic foot (60°F, 1 atm.).

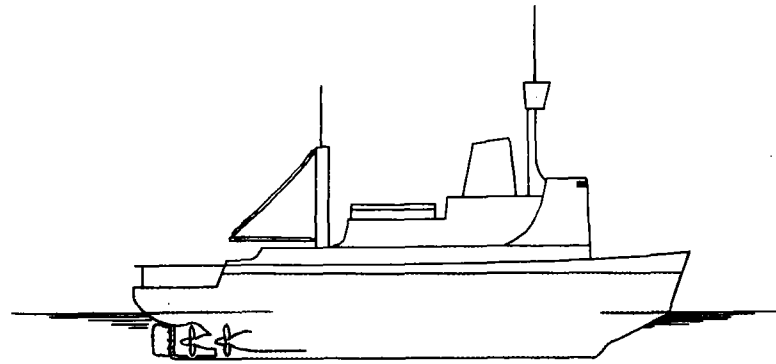
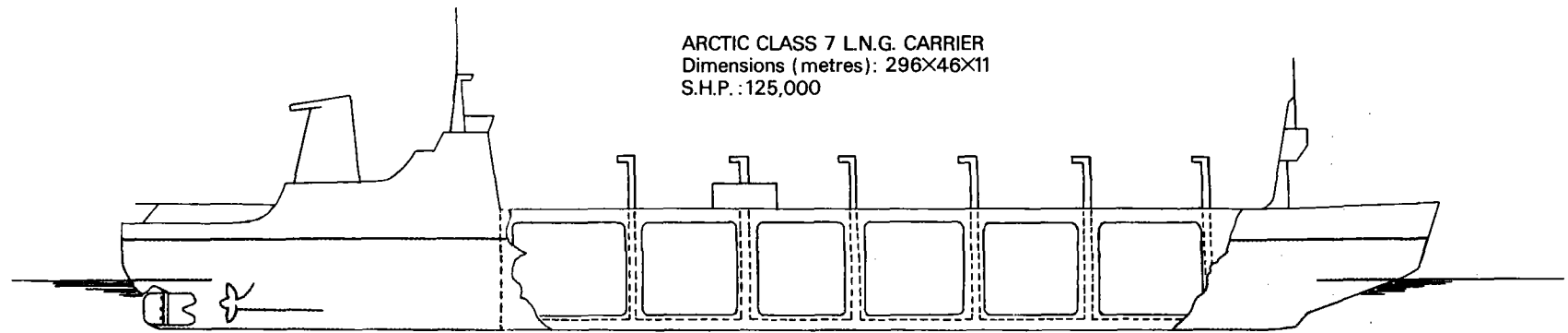


Figure 4. Size comparison of a proposed LNG carrier<sup>4</sup> and the Canadian Coast Guard Icebreaker, *Louis St. Laurent*.

### 3. ARCTIC PILOT PROJECT

#### 3.1 Components

The Arctic Pilot Project includes the following components :

- Gas-gathering pipelines from onshore and, initially, one offshore well in the Drake Point gas-field;
- Gas treatment plant on Sabine Peninsula;
- Transmission pipeline south from Sabine Peninsula to Bridport Inlet;
- Liquid Natural Gas-plant at Bridport Inlet;
- LNG-carrier dock and loading facility at Bridport Inlet;
- The marine route, year round, in Parry Channel into Baffin Bay;
- The marine route to southern markets through Baffin Bay, Davis Strait and the Labrador Sea to an eastern Canadian port;
- Re-gasification plant.

#### 3.2 Gas Delivery Rate

This 'pilot' project is designed to test the technical and economic feasibility of transporting Arctic Islands natural gas to eastern North America. The Project expects to deliver an average  $7.07 \times 10^6 \text{ m}^3 \text{ API}^* / \text{d}$  (equal to  $250 \times 10^6 \text{ scf/d}$ ) through a gas pipeline south across Melville Island and then by icebreaking liquid natural gas (LNG) carriers through Parry Channel, Baffin Bay, Davis Strait and south. This gas supply, expected to equal 3% of Canada's needs in 1980<sup>3</sup>, is valued at \$275 million per year.

Two Arctic Class 7 LNG vessels\*\* (Figure 4) are required to ply the marine route, each carrying  $140,000 \text{ m}^3$  ( $4.4 \times 10^6 \text{ ft}^3$ ) of LNG (each  $\text{m}^3$  of LNG is the result of compressing  $600 \text{ m}^3$  API of gas). The Project is designed to tap, and exhaust the Drake Point Field in about 50 years - given its known reserves of 4.8 TCF.

#### 3.3 Energy Efficiency.

Assuming delivery to the Montreal region of Canada, the overall energy efficiency of the Arctic Pilot Project is about 78% compared to 90% for the Polar Gas Project<sup>2</sup>. The Melville Island pipeline requires no compressor stations since Drake Point wellhead pressures are sufficient to force the gas through the 56 cm diameter, 160 km long pipeline to Bridport Inlet. About 9% of the gas (equivalent to a power of 285 Mw) is consumed in liquefaction operations at Bridport Inlet. Most of this energy is wasted as heat, although about 100 Mw may be harnessed to suppress winter ice-growth at the LNG loading dock in Bridport Inlet. Energy efficiency of LNG carriers may attain 90%.

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\* API - American Petroleum Institute standard atmosphere (101.325 kPa) and reference temperature (15°C).

\*\* MOT ice classes<sup>2</sup>. Class 7 assumes that the design will enable the vessel to advance through 7 ft-thick sea ice. It is also a classification permitting partial or year-round entry to geographical regions in the Canadian Arctic.

Boil-off (vaporization) of 0.1 to 0.25% of the LNG cargo, per day, is burned for the ship's propulsion. Some LNG is carried to keep containers chilled on the return journey, north. In total, up to 6% of the gas cargo is consumed in a 23 day round trip. Other losses of energy are in regasification (2%) and in pipeline transport to Montreal area markets (2.7%).

### 3.4 Properties of LNG.

Drake Point gas is 97% methane (CH<sub>4</sub>), with traces of nitrogen, carbon dioxide, ethane and propane. The liquefaction plant at Bridport Inlet would clean and refrigerate the gas which, at atmospheric pressure, liquefies at -161.5°C. Its volume is then 1/600th of the original gas volume at atmospheric pressure or about 1/10th the volume of high-pressure pipeline gas. The density of methane is 0.415 when liquid at -164°C; it freezes at -183.2°C. Its flash-point is 538°C (1000°F), at atmospheric pressure. In the gas phase at -161.5°C, its boil-off density is about 45% greater than ambient air density. As methane warms to -114°C, its density equals that of air. At 0°C and 760 mm pressure, the densities of methane and air are  $0.717 \times 10^{-3}$  and  $1.29 \times 10^{-3}$ , respectively. Hence, vaporized methane dissipates rapidly upwards when it warms to arctic winter or summer temperatures. Methane is an asphyxiant, although it is non-toxic and relatively non-reactive, except by burning.

### 3.5 Carrier Characteristics.

An Arctic Ice Class 7 LNG carrier resembles the shape and size of a conventional LNG cargo-carrier. However, there are major differences - a double hull to withstand the ramming and racking of icebreaking, and four times the propulsion power. Other design characteristics are as follows :

- Arctic Ice Class 7, capable of continuous forward progress in 2 metre-thick ice
- Dimensions : 296 m long, 46 m beam, 11 m draft
- Displacement : 145,000 tonnes
- LNG cargo : 125,000 to 140,000 m<sup>3</sup> of LNG (weighing 52,000 to 58,000 tonnes)
- Speed : 22 kts maximum in open water, 16 kts cruising
- Cargo containers : 6 prismatic tanks
- Shaft HP : 150,000
- Crew : 45
- Fuels : Diesel and natural gas from boil-off. (Diesel fuel-tanks carry up to 15,000 tonnes of diesel fuel)
- Lubricating oils : 550 tonnes
- Waste Disposal : Sewage treatment and holding tanks entirely

### 3.6 Carrier Operation.

The total one-way marine voyage from Melville Island to an eastern Canadian port (yet to be determined) is about 4,800 kilometres (3,000 nautical miles). Round-trips are expected to average 23 days, with 14 trips annually for each of 2 vessels. After loading is complete from

the LNG storage-barges at Bridport Inlet, gas from boil-off supplements diesel fuel for propulsion. The gas boil-off is regulated by varying the allowable pressure build-up in the LNG containers. Agitation of LNG by the vibrations of icebreaking and heavy seas generates more boil-off gas - possibly more than required for propulsion. This excess is either vented clear of the superstructure or used to fire boilers from which the steam is vented. The latter option would be chosen near southern terminals when propulsion power requirements are low, and air pollution standards are enforced.

LNG icebreaking vessels will be ballasted with sea-water when breaking ice through Parry Channel, then de-ballasted in open water to reduce draft for more economical operation. When dead-heading to Melville Island, the vessels will ballast with Atlantic water for the whole route. Some LNG will remain in the six cargo tanks to provide en route fuel and to maintain cool tanks prior to loading at Bridport Inlet. Excess sea-water ballast will be emptied into Bridport Inlet at loading.

Projected cruising speeds in *worst* winter conditions are 20 kts from the southern terminal to near Disko Island off Greenland, at 70°N. Speeds slow in ice to 10 kts off Cape Sherard, S.E. Devon Island, then further reduce to 4.5 kts near Maxwell Bay (89°W) in western Lancaster Sound. From here, the speed averages 2 to 2.5 kts in landfast ice to Bridport Inlet. Travel times are 4, 3 and 6 days on each leg, respectively, or 13 days total.

### 3.7 The Future.

To exploit the full potential of the Drake Point Field will require more than two icebreaking, LNG vessels. If the Hecla Field off western Sabine Peninsula is tapped, an additional two or more LNG carriers may ply Parry Channel, year-round. Other gas-fields in the area of south Ellef Ringnes Island will eventually be produced, possibly using sub-sea pipelines which 'island-hop' to a more eastern port in Parry Channel. Potential reserves for the Sverdrup Basin<sup>2</sup> could reach 100 TCF in the next 25 years. Assuming only half of this is delivered by LNG carriers of the size contemplated for the Arctic Pilot Project, and assuming field depletion in a period of 30 years, eighteen carriers are required. With round-trips averaging 23 days, an LNG carrier would pass by Cornwallis Island every 15 hours, on average, in the future.

Large icebreaking cargo carriers of Arctic Pilot Project-size are unbuilt and untested. If the Project is successful, icebreaking oil-tankers to exploit the Cameron Island oilfield, and icebreaking ore-carriers to export Strathcona Sound lead and zinc will inevitably follow.

Soon, petroleum exploration in the Arctic Archipelago may be assisted by the 'Arctic Locomotive', a huge Class 10 icebreaker proposed by Dome Petroleum. Although it remains an unfunded concept, the prospect of extensive and frequent icebreaking forays into the thus-far-untouched, winter landscape of the Archipelago is imminent.

#### 4. ACCIDENTS

In addition to normal, year-round operations of icebreaking LNG vessels, accidental spills of LNG, diesel fuel and lubricating oils cannot be ignored as environmental threats. Some emergencies also necessitate complete off-loading of LNG to other carriers, or the venting of it to the atmosphere along the proposed route. Gas from LNG spills can explode or burn at source over a liquid pool, or downwind as a dissipating vapour cloud. (The gas is flammable when 5 to 15% of it is mixed with air). Designs of icebreaking, LNG carriers depict insulated, LNG containers separate from the main hull - the foremost container 50 m from the bow. Most of the diesel fuel is stored between the LNG containers and the ship's hull or bulkheads.

The best engineering cannot prevent human error or completely account for equipment failure, particularly in a pioneering project where no comparable experience is available. There is always the probability of accidents occurring in Parry Channel, as follows :

- The LNG vessel collides with an iceberg, an ore-carrier, a drillship or drilling platform (offshore drilling is proposed in Lancaster Sound). One of six LNG containers and some fuel-tanks are fractured, spilling 23,000 m<sup>3</sup> of LNG and 2,000 tonnes of diesel fuel.
- The LNG vessel is rammed broadside by an icebreaker, drillship or ice-strengthened supply vessel. Two LNG containers are ruptured, together with some fuel-tanks, spilling 46,000 m<sup>3</sup> of LNG and 4,000 tonnes of diesel fuel.
- The LNG vessel grounds bow-first or broadside on land or on a submerged iceberg shelf, rupturing all six LNG containers and most fuel tanks, spilling 140,000 m<sup>3</sup> of LNG and 10,000 tonnes of diesel fuel.

In the worst case, the LNG carrier will be completely destroyed in an explosion or fire. Most of its diesel fuel may be incinerated at the same time. In fact, the authors assume that, in any ship-to-ship collision which may only breach one or two LNG containers on impact, the result will be an explosion and fire involving all containers, and the destruction of both ships. In this class of accident, the 6-container explosion or fire is assumed to be most probable. This conclusion is at variance with assumptions of the Arctic Pilot Project<sup>4</sup>, where fire and explosion-related accidents are only considered probable for up to two ruptured LNG containers. Table 1 summarizes the downwind hazard ranges listed in reference 4, but also includes hazard ranges for 6-container fires and explosions on water (estimated using a simple power law based on one and two-container hazard ranges).

Table 1 shows that the upper bound hazard-ranges is about 16 km. This corresponds to estimates of range for the edge of the fire and blast damage to structures. Radiation damage could be experienced at shorter ranges. Presumably, if a loaded LNG carrier travelled at the centre-line of a shipping lane 32 km wide, all life and structures outside this lane would survive a 6-container LNG disaster.

TABLE 1. Rapid LNG spill at 28,000 m <sup>3</sup> per container	Hazard range (km)					
	Fire hazard			Explosion hazards		
	Edge of fire		Blast damage to houses (0.1 bar)		Radiation damage To people in open*	
	Esti- mate	Upper bound	Esti- mate	Upper bound	Estimate	Estimate
1 container on ice	3.0	4.8	5.2	6.9	5.0	4.3
2 containers on ice	3.8	7.4	6.6	8.7	6.4	5.8
1 container on water	3.4	8.5	5.7	8.5	6.1	5.6
2 containers on water	4.4	10.6	7.2	10.6	7.9	7.5
6 containers on water	6.5	16.3	11.0	16.3	11.7	11.0

\* 5,000 watts/m<sup>2</sup>; the power flux at which an immobile person experiences extreme pain on unprotected skin within 20 seconds' exposure time.

\*\* 31,500 watts/m<sup>2</sup>; the power flux for spontaneous ignition of cotton and other combustibles.

Only in extreme emergencies is LNG transferred to another LNG carrier, or jettisoned. These operations are dangerous. Controlled jettisoning requires 8 to 12 hours for an entire cargo, and is attempted only in a remote location, with persistent, steady breezes to ensure against sweeping the vapour-cloud over the ship. Ship-to-ship transfer of LNG requires side-by-side berthing and, again, consistent breezes to carry away boil-off gas.

Barring fire or explosion, a collision or grounding of sufficient violence to rupture an LNG container would result in a major fuel-spill of, perhaps, one-third of the carrier's 15,000 tonne diesel fuel capacity. The pour-point of No. 2 fuel oil is -40°C; it evaporates readily if spread thinly on the sea. This evaporation is slowed by cold arctic water and air temperatures, or when pooled in sea-ice and sponged-up in snow. For example, a slush avalanche destroyed a tank-farm at Deception Bay (W Hudson Bay)<sup>5</sup> in June, 1970, when snow-covered ice still covered the Bay. An estimated 1,600 tonnes of diesel fuel poured on to the ice. After 10 days, about 8 tonnes had evaporated since the evaporation rate was reduced an estimated 75% by snow and cold. Diesel fuel is highly toxic and, in addition to LNG, should be considered as a potential environmental hazard.

## 5. ICE AND LNG ICEBREAKERS IN PARRY CHANNEL.

Sea-ice in Parry Channel is a focus concern of the Arctic Pilot Project. Sea-ice is a barrier to the passage of LNG carriers; ice forms an inter-island bridge for migrant land mammals and Inuit hunters. Sea-ice is the winter residence of seals and, in turn, a dinner-table for polar bears and foxes. Will cuts and scars made by LNG carriers in the sea-ice mantle alter ice break-up patterns or wildlife distribution? Will the ice climate change during the decades of resource extraction? Questions such as these cannot be answered adequately. However, the following descriptions of the Parry Channel ice climate and possible effects on the ice by year-round icebreaking vessels may not only assuage old concerns but possibly generate new ones.

### 5.1 Ice Drift and Surface Circulation.

Archipelago ice drifts generally south and east, when it is not landfast in winter (Figure 5). The drift follows the pattern of water movement such that the Archipelago acts as a "drain" to the frigid surface waters in the Arctic Ocean. This water moves eastward over the 130 m deep Barrow Sill, north of Somerset Island, and southward over the 146 m deep sill in Wellington Channel. Parry Channel surface water exits mainly south through Prince Regent Inlet, and east through Lancaster Sound into Baffin Bay. Lancaster Sound deepens toward Baffin Bay; this allows Baffin Bay water from the West Greenland Current to underflow and then mix with the Arctic surface water. The heat input from the water originating from Baffin Bay's more moderate climate, causes thinner ice and more persistent open water in summer throughout eastern Parry Channel.

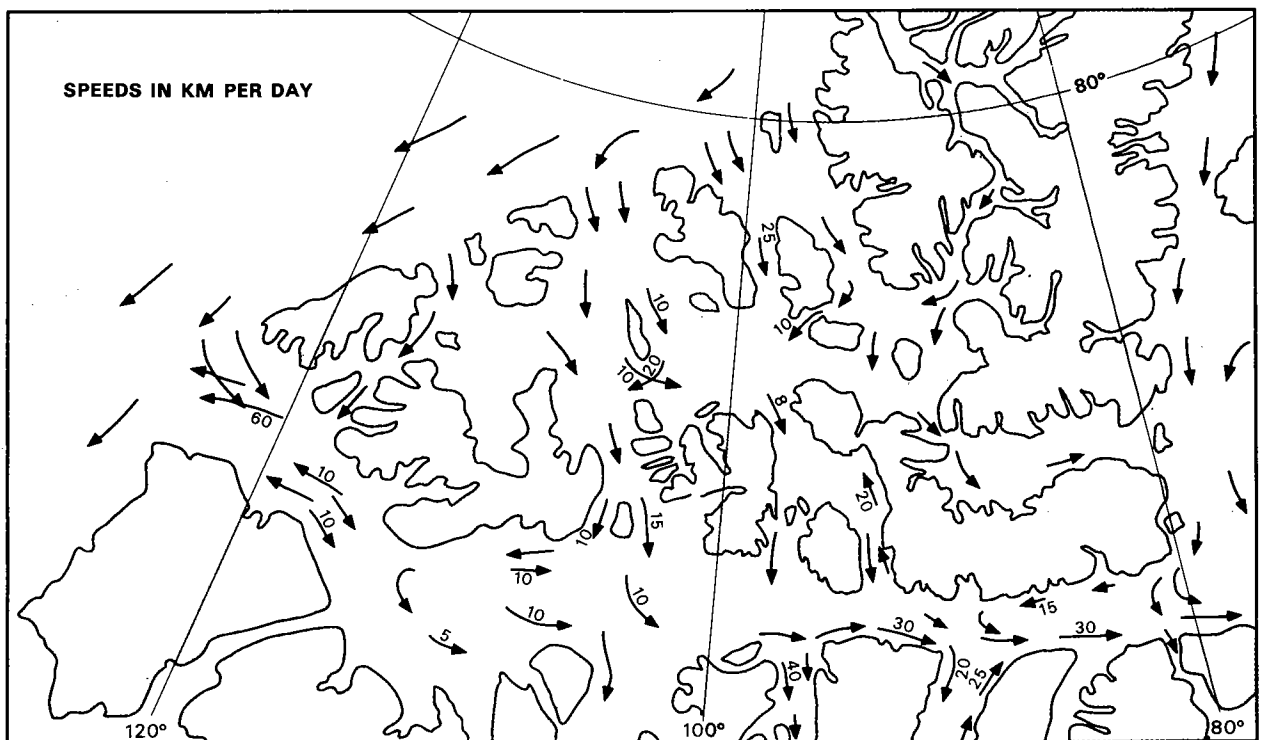


Figure 5. Generalized surface water movements : a composite of drifts from Black<sup>6</sup>, Verrill *et al*<sup>7</sup> and Marko<sup>8</sup>.

The generalized surface water circulation differs from summer to winter, and from one summer to the next (Figure 5)<sup>6,7,8</sup>. For example, multi-year pack ice can drift into M'Clure Strait from the Arctic Ocean, or be cleared out in summer. In Lancaster Sound, the westward surface water-flow along S Devon Island is evident in summer but not evident in winter. The most important oceanographic features to icebreakers are (1) the southward drift of Arctic Ocean pack ice into the Archipelago and (2) the eastward or westward drift of multi-year ice in M'Clure Strait which congests or clears Parry Channel. These summer characteristics effectively set the stage for winter icebreaking.

## 5.2 Winter Ice Cover.

The most difficult period for icebreaking is mid-April to late May, the time of maximum ice thickness in the landfast ice of Parry Channel. Multi-year ice is comprised of second-year\* and older ice, and perennial or polar ice. In mid-April, its *mean* thickness is about 3.6 m; 90 per cent of multi-year ice (primarily second-year ice) is over 2.3 m thick, and 10% is over 4.5 m thick<sup>9</sup>. In comparison, first-year ice is about 2.2 m thick at this time. A Class 7 icebreaker will not be capable of steady progress through multi-year ice, *even with 200,000 shaft HP*, and will attempt to avoid regions of multi-year ice<sup>10</sup>. Where avoidance is impossible, ramming is necessary, with severe economic penalties in fuel usage and delivery schedules. Once a channel is initially broken in landfast ice, it could be reused up to six times or until it clogged with rebroken new ice (this proves true from Finnish icebreaking experience<sup>10</sup>). A new route would then be broken.

Winter patterns of multi-year and first-year ice vary greatly from year to year, as seen in Lindsay's Ice Atlas<sup>11</sup> (Figure 6). Except for Lancaster Sound, Parry Channel is covered by 10/10ths landfast ice in winter and spring. The time of freeze-up\*\* varies from late September in Viscount Melville Sound, to mid-October in Lancaster Sound. Ice movement in Viscount Melville Sound diminishes, and then ceases by the end of December<sup>12</sup>. Later, as early as mid-January in some years, a fast ice-edge forms at various locations in Parry Channel<sup>8</sup> (Figures 6 and 7).

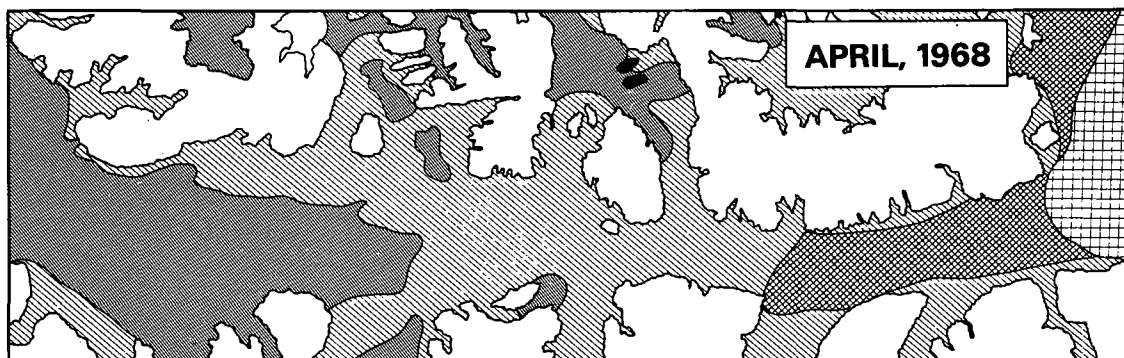
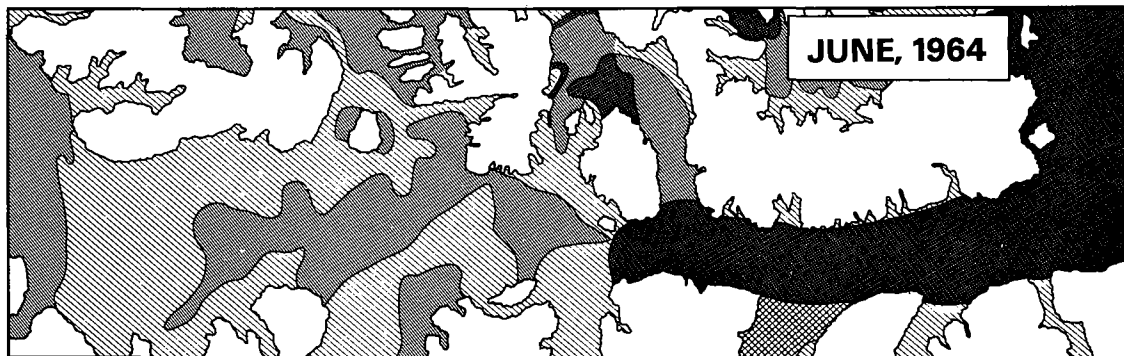
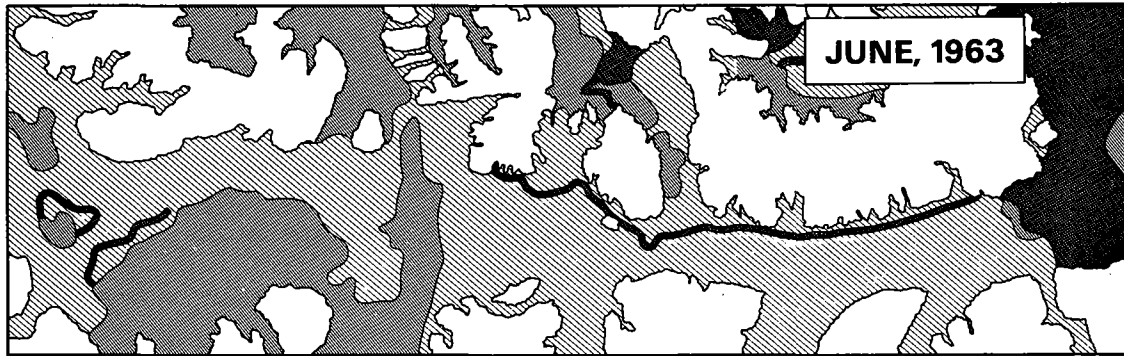
Multi-year ice in E Viscount Melville Sound, and other eastern waters of Parry Channel, originates in the Sverdrup Basin and the Arctic Ocean. West of the Resolute area, there are sufficient degree-days of freezing to enable first-year ice to survive the summer's melt. Consequently, there exist numerous ridges of weathered, multi-year ice, having formed several years previously and well to the north. On the other hand, extensive, but low-ridged first-year ice occurs amongst multi-year floes and within first-year icefields.

Undoubtedly, the captain of an Arctic Class 7 LNG carrier will do his utmost to avoid multi-year ice, and manoeuvre through nearby first-year ice, assuming there is a minimum of 1 to 2 kilometres of forward visibility<sup>9</sup>. He must seek routes of thinnest ice, which will vary

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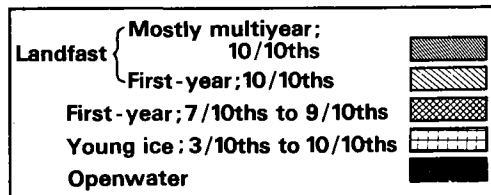
\* Second-year ice is included to simplify ice descriptions; multi-year ice usually includes third-year and older ice.

\*\* Freeze-up is loosely defined as the date when the multi-year ice is relatively stationary and new ice is consistently present in formerly open water.



**Winter patterns of ice  
in Parry Channel**

**Figure 6.**



from year to year. Clearly, an Arctic Class 7, or any other icebreaker currently conceived, cannot progress without ramming through most multi-year ice in Parry Channel. The mean thickness of multi-year ice is about 3.6 m; individual floes, with thicknesses of up to 6 m at their minimum thickness in September<sup>13</sup>, are reported in Parry Channel.

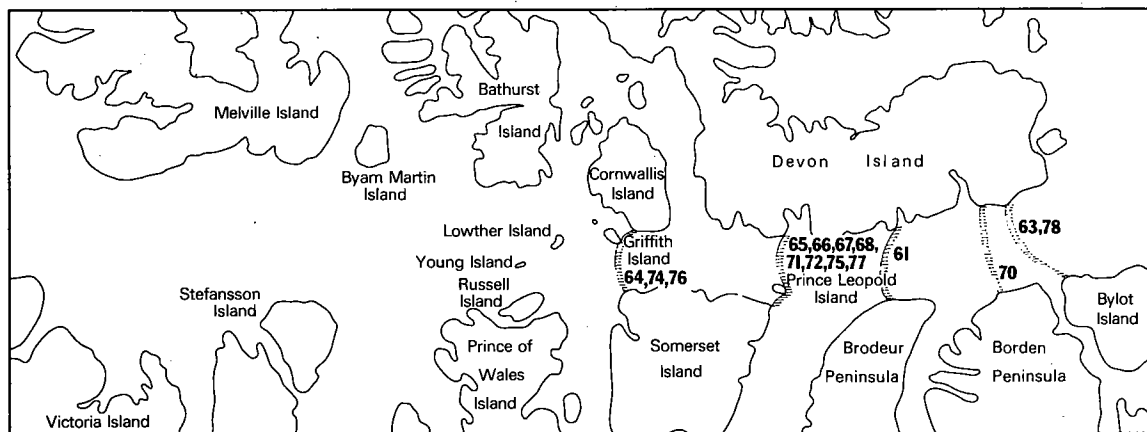


Figure 7. Locations of ice-edges in late winter of various years<sup>8</sup>.

### 5.3 The Icebreaker's Wake in Ice.

The configuration of the broken-ice path left behind an LNG carrier depends on the icebreaker's speed of advance. In turn, this speed is dictated by the resistance of breaking ice, the gravity forces due to turning and submerging ice, and the inertial forces dependent on the ship's speed. For the proposed 150,000 HP icebreaker, its speed of advance could reach 4.1 m/sec (8 kts) through 2 m thick, first-year ice. However, there are many uncertainties in this calculated performance (Figure 8), such as pressure ridges, poor visibility and multi-year floes. The predictions also show speed capabilities of 6 m/sec (12 kts) in 1.5 m-thick ice, reducing to 1 m/sec (2 kts) in 2.75 m thick ice. Ramming is necessary in ice 2.9 m thick. Assuming an icebreaker with triple screws of equal power, the loss of one screw would still permit continuous breaking of 2 m thick ice at a predicted speed of 2.5 m/sec (5 kts).

Some energy expended at high speeds (6 to 8 kts) likely thrusts broken ice well abeam of the ship's bow. As a result, ridges of broken ice, welded by the cold, are left on either side of the path. At slower speeds, a large fraction of the broken ice is merely pumped by the screws behind the vessel, where it partly refills the path. Smaller ridges are formed by up-ended ice and shards unable to float back into the vessel's wake. High-speed passage through thin ice leaves extensive open water; slower runs in thicker ice leave little open water.

The freedom of over-ice travel which requires crossing the aging wake of an LNG carrier depends primarily on air temperature. The growth of sea-ice<sup>14</sup>, under zero snow thickness, starting from open water, is given by  $h = 1.53 (\Sigma\theta)^{0.59}$ , where  $h$  = cms of ice and  $\Sigma\theta$  is the sum of the negative degree-days of air temperature below 0°C. Average air

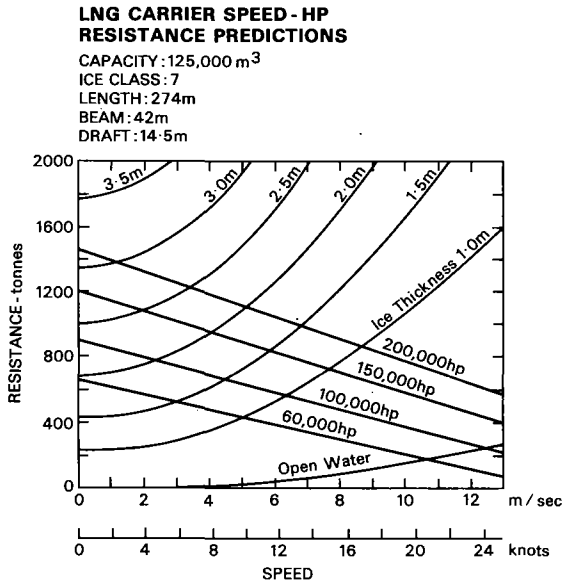


Figure 8.

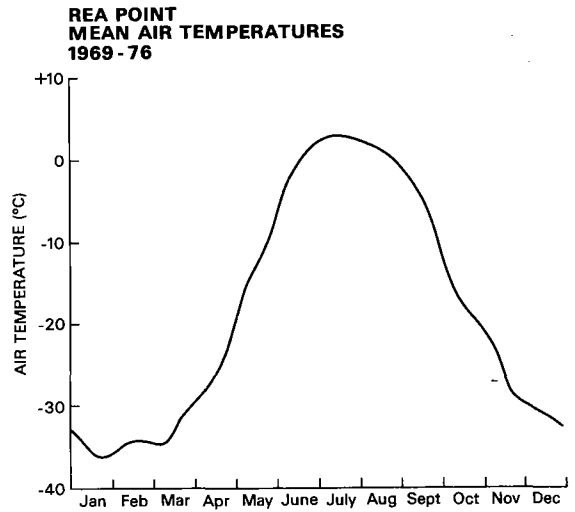


Figure 9.

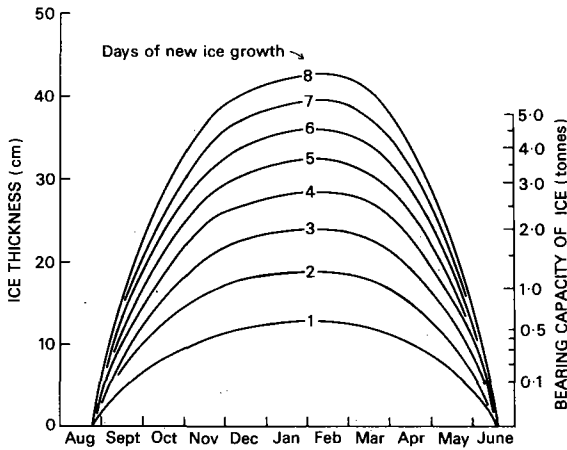


Figure 10.

New ice growth (cm) from open water vs time of year based on Rea Point air temperatures (Figure 9). Bearing capacity of the new ice (tonnes) is also shown.

temperatures in 1969 to 1976 for Rea Point, Melville Island, are plotted in Figure 9. (Resolute Bay's temperatures are slightly higher). From this curve, it is extrapolated that no *new* ice will grow, on average, between 18 June and 14 August. In fact, the low albedo of the open pools in June absorbs the sun's heat and accelerates local melting; elsewhere, the ice remains continuous.

Based on temperatures from Figure 9, new ice-growth is plotted at different times of year in Figure 10. Each curve predicts the growth of ice from open water as a function of the number of days of re-freezing up to 8 days, where 8 days is the assumed time-lapse before the path is re-broken by a returning LNG carrier.

Of interest is the ice thickness required to carry safely the moving weight of a man, a caribou, a laden dog-sled, a snowmobile and, possibly, a light tracked-vehicle.

Generally, the bearing capacity of ice is expressed in the form  $P = Ah^2$ , where  $P$  is the load,  $h$  is the ice thickness and  $A$  is a constant<sup>15</sup>. A conservative value of  $A$  is  $3.52 \times 10^{-3}$  for  $P$  in tonnes (t) and  $h$  in cm (sea ice even more than lake ice is subject to strength variations dependent on its salinity, rate of growth and temperature<sup>16</sup>). The safe ice thicknesses corresponding to the assumed loads are given in Table 2.

Weight-bearing capacities of ice are plotted on the right-hand ordinate of Figure 10. For example, it is predicted that, on or near 1 May, nearly two days are required before the ice is again thick enough (11.9 cm) to move safely across the LNG-carrier's refrozen wake with a 0.5 t load.

Moving load	Assumed weight (tonnes)	Safe ice thickness (cm)
Man	0.10	5.3
Caribou	0.15	6.5
Dog-sled	0.30	9.2
Snowmobile	0.50	11.9
Tracked vehicle	1.00	16.9

However, one must realize that the new, thin ice in the LNG carrier's wake is the *first* to melt away in the springtime - far sooner than the surrounding first-year ice. Figure 11 shows this rapid decay for new ice of thicknesses 25, 50, and 100 cm compared with first-year ice grown during the whole of an average winter\*. Note that 50 cm-thick ice melts to a thickness of 25 cm nearly two months earlier than full-term, first-year ice.

\* Using Bilello's formula<sup>14</sup> :  $h = 0.55 \Sigma \theta$  cm where  $\Sigma \theta$  is the accumulated °C days above an air temperature of -1.8°C.

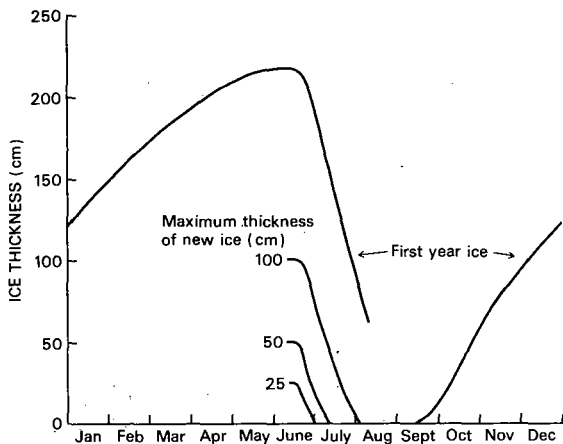


Figure 11. Growth and decay of first-year ice vs time of year. Also shown is the decay vs time of new ice of maximum thicknesses 100 cm, 50 cm & 25 cm. (Calculated from Rea Point air temperatures, Figure 9).

In average years, the first-year ice south of Melville Island does not fully melt in the short summer; the expected growth is 217 cm, whereas the summer's ablation is only 143 cm (Figure 11). The extensive summer open water often depends, therefore, on the eastward drift of ice in Parry Channel.

The path cut through landfast ice closes or widens, depending on whether the ice-sheet is under compression or tension. It is unknown whether or not an LNG carrier will be slowed by ice-pressure, or how much its path may widen if the field is under tension. We assume that, even with a high wind stress on the icefield, there is likely to be little convergence or divergence, unless some areas of the landfast ice are not truly landfast. For example, if an E-W path is broken through ice which is landfast to the south but not to the north, this risks ice-pressure under N winds, or path-spreading under S winds. This situation is likely in Parry Channel during the first half of winter.

#### 5.4 Routing through Ice.

LNG carriers will travel in open water or thinnest ice in order to minimize costs, yet must avoid hitting sea-bottom, icebergs and fragments of shelf-ice. Most icebergs sweep southward in Parry Channel, in concave westward arcs<sup>17</sup> across eastern Lancaster Sound. These icebergs originate from West Greenland glaciers, although some smaller icebergs and bergy bits calve from glacier-tongues of the Devon Island Ice Cap. A few icebergs float westward in summer along the south coast of Devon Island, and then curve southward into the eastern drift in Lancaster Sound. In some years, icebergs drift as far west as Lowther Island, west of Resolute Bay. No data exist for seasonal changes of iceberg distribution in eastern Parry Channel. In winter, ice-drift is eastward across the whole of Lancaster Sound, and iceberg numbers are expected to diminish from fall into winter. The highest iceberg hazard to navigation exists in E Parry Channel.

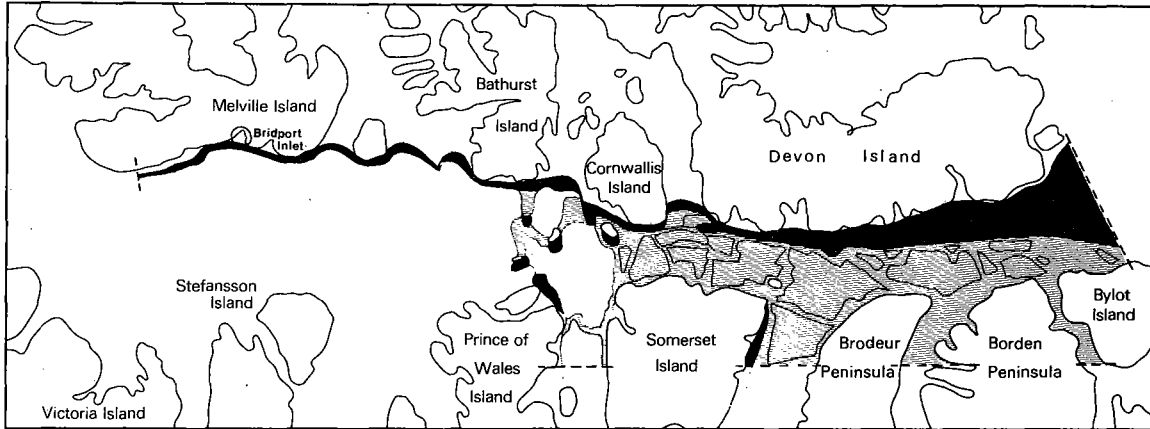


Figure 12. An example of the ice cover in early winter sketched from Nov. 2, 1972, NOAA infrared imagery. Dark shading indicates open water or thin grey ice, lighter shading indicates young ice and 'white' is thicker landfast ice (in Parry Channel).

Shelf-ice, 50 m or more in thickness, calves from the Ward Hunt Ice-shelf of N Ellesmere Island and, in some years, enters the Archipelago. The last major break in 1961 to 1962 provided a source of ice-islands for the Arctic Ocean, and some fragments drifted into the Archipelago through various channels (see Maps 1-1963 and 1-1964 of Lindsay's Ice Atlas<sup>11</sup>). For example, in the spring of 1964, numerous ice-island fragments were sighted along the south coast of Melville Island. Like icebergs, these ice chunks are relatively few throughout most of Parry Channel and, although hazardous, do not significantly complicate LNG carrier travel through thinnest ice. However, it is difficult to identify them; they look like rough, polar floes but, on average, have 4.4 m more freeboard than a typical, 7 m-thick polar floe.

Where is the thinnest ice in Parry Channel? The answer lies in monitoring freeze-up patterns. Figure 12, sketched from a NOAA satellite infrared image of November 20, 1975, shows thin ice (or open water) along the entire north margin of Parry Channel. Channels north of Parry Channel have southward-drifting ice which becomes landfast in early winter, prior to freeze-up to the south. This staggered freeze-up produces an almost continuous lead along the south coasts of Cornwallis, Bathurst and Devon Islands, including the Keene Bank shoal at the southern end of Austin Channel. This lead-system repeats itself, with some differences, each winter<sup>8</sup>. By early January, all ice movement ceases in W Parry Channel. However, easterly drift continues in E Parry Channel from a stable landfast ice-edge which forms across Parry Channel between mid-January and early April<sup>18</sup> (Figure 7). Its position, most frequently, lies between Prince Leopold Island and Maxwell Bay, at the longitude of NE Somerset Island. In other years, the ice-edge stabilizes at the longitudes of NW Somerset Island, Sargent Point on Brodeur Peninsula, Cape Charles Yorke on Borden Peninsula or Cape Warrender near SE Devon Island.

With the cessation of ice drift in W Parry Channel by early January, first-year ice remains undisturbed and grows thinnest near the north boundary of the now-frozen E-W lead. Evidently, this lead provides a path through fields of multi-year ice that often drifts south earlier in the fall. Based on degree-days of cooling from 1 January, the maximum ice-growth in the E-W lead-system is an estimated 167 cm compared to a full season's first-year ice thickness of 217 cm (Figure 11).

Satellite imagery is a useful tool for predetermining thinnest ice in winter. The route must also account for safe bathymetry, bearing in mind the vessel's draft of 11 m and those regions sparsely or poorly sounded, such as southern McDougall Sound, south of Bathurst Island, and the Keene Bank area in southern Austin Channel.

## 6. CLIMATE AND LNG ICEBREAKERS IN PARRY CHANNEL

Will icebreaking by LNG carriers alter the ice-cover and, ultimately, the local climate of Parry Channel? This is a possibility, related to the position of the fast ice-edge which forms across E Parry Channel in late winter (Figure 7). Evidence from the winters of 1975-76 and 1976-77 suggest that the ice-edge stabilizes further west when ice drifts quickly eastward and prevents new ice from freezing *in situ*. The easterly ice-drift, averaged monthly, in Lancaster Sound was about twice as fast in the winter of 1975-76 compared to 1976-77; the ice-edges were located at the longitudes of NW and NE Somerset Island, respectively<sup>18</sup>. This leads to speculation that ice-edges could form more easterly still, but only if ice-drift is very slow. Whether the ice-drift results from west winds or surface currents, or both, is unknown. Once ice-edges have formed, they have an arch-shape, in plan, and often persist until mid-July.

In late winter, icebreaking at 8-day intervals could conceivably force ice-edge formation to retreat westward. For example, an ice-edge which might otherwise become anchored between Prince Leopold Island and Maxwell Bay could stabilize north of NW Somerset Island, or bridge Lowther, Young and Russell Islands further west. Likewise, in the springtime, an existing ice-edge could be weakened by icebreaker penetration, analogous to pulling the keystone from an arch. Break-up would be earlier than expected.

Two extremes can be visualized. The first is stabilization of the fast-ice edge far to the east in Lancaster Sound, presumably in conditions of little easterly stress from surface currents tending to clear the Sound. The second is ice-edge stabilization far to the west, in Barrow Strait - a possible result of vigorous surface currents moving newly-formed ice continually eastward. An LNG carrier penetrating an ice-edge during its formation could go unnoticed in the first case; in the second, icebreaking could delay its formation, or make it retreat still further west in Barrow Strait. If such extremes of surface currents persist until ice-edge break up - usually in the first week of July - then an LNG carrier will not affect break up when Lancaster Sound is covered with landfast ice. The ship could, however, precipitate earlier-than-ever clearing to the west of Barrow Strait by smashing an ice-edge already stressed by easterly currents. The actual outcome probably lies somewhere between these extremes.

On average, year-round icebreaking could result in earlier break up of Parry Channel, followed by extensive clearing to the west. This would greatly increase the solar heat input, particularly after mid-June when sea-ice no longer grows. Since the albedo of open water (0.1) is a factor of 7 lower than that of sea-ice (0.7), 90% of the incident solar radiation would be absorbed over most of the region, instead of only 30% for a complete ice-cover. Again, the prediction is, on average, an earlier clearing of sea-ice and warmer summers. Another possibility is that the extreme situations, described above, will be accentuated, making an early break up and clearing of Lancaster Sound and Barrow Strait even earlier but leaving, unaffected, a Lancaster Sound choked with landfast ice.

Other than NOAA satellite observations of ice-drift and inferred surface currents, there are no year-round water current measurements available to illuminate their influence on the eastward extent of landfast ice in Parry Channel at winter's end.

### 6.1 Long-term Climate Trends.

The proposed Arctic Pilot Project is a test-bed for the delivery of natural gas from the High Arctic. Although engineers and economists consider seasonal and yearly changes of ice-cover in LNG ship design and routing, little thought is devoted to climate *trends* which could facilitate or frustrate the passage of LNG carriers over the 20 or more years required to deplete Archipelago gas-fields.

In the northern hemisphere, atmospheric cooling has, in fact, proceeded since the 1950's<sup>19</sup>. However, the growth and advection of sea-ice also depends on water masses flowing beneath. Excess ice growth induced by a cooler atmosphere is sometimes countered by oceanic heat flux. In addition, water circulation in the Arctic Archipelago is induced by external water mass movements. For example, in Lancaster Sound, warm Baffin Bay water intrudes westward under Arctic surface waters. As depths shoal toward the Barrow Sill, surface waters are forced eastward and mixed with the warmer Baffin Bay water. The resulting eastward current is slightly warmed which slows new ice-growth, and moves ice eastward. Perhaps the location of the ice-edge in E Parry Channel is largely dependent on this variable flow of Baffin Bay water which intrudes deep into Lancaster Sound. (Other examples of the influence of oceanic heat and its advection are the persistent winter polynyas; one of these provides lake-like open water in winter, north of Cornwallis Island.)

The sensitivity of sea-ice thickness to oceanic heat is illustrated by a recent thermodynamic model of sea-ice<sup>20</sup>. Using accepted values of Arctic Ocean snow cover, atmospheric and oceanic heat fluxes, the equilibrium thickness stabilizes at 3.17 m when growth ceases, and 2.71 m at the end of melt. Entire removal of the ocean heat flux increases the maximum thickness to 5.6 m; this is the thickness of old floes frequently encountered in the Archipelago<sup>13,21</sup>. This implies that, in parts of the Archipelago, the near-zero oceanic heat flux and small year-to-year ice drift allows ice to grow to this thickness. Another implication is that climatic cooling could increase ice concentrations in summer, such that a higher percentage of very thick ice would remain in Parry Channel.

The following scenario is possible, assuming 150,000 HP LNG carriers capable of speeds of 2 m/sec (4 kts) in 2.5 m-thick first-year ice (Figure 8). Progress at lower speeds may be uneconomic in W Parry Channel, the most difficult part of the whole route. Based on Rea Point mean air temperatures (Figure 9), first-year ice grows to a thickness of over 2 m during winter and spring. However, during summer, there is insufficient heating to melt this ice *in situ*. The existence of open water thus depends on south and east advection of this ice from Parry Channel (see drift trends in Figure 5). Assuming a future decrease of 2°C in year-round air temperatures, first-year ice would grow to 2.3 m thick, of which only 1.1 m would melt in summer. If this residual ice does not drift out of W Parry Channel, second-year ice grows during the following winter. The 2°C temperature-drop may also diminish ice advection in summer and reduce E-W lead formation along N Parry Channel in early winter. The LNG carrier would be forced to advance in the ramming mode to Melville Island throughout late winter, and possibly cease operations from early February to late June.

The year-round dynamics of water masses in the Archipelago are poorly known and cannot be used as credible support for the above speculations.

## 7. ECOLOGICAL SIGNIFICANCE OF PARRY CHANNEL.

Due to early ice break-up and clearing, E Parry Channel is accessible to migrating animals by April or May of most years. By comparison, Jones Sound, 150 km to the North, is ice-covered for at least two or three months longer than Lancaster Sound. Another alternative route, Hudson Strait, lies over 1,500 km south of Parry Channel and clears of ice by August of most years; however, ice conditions quickly worsen to the northwest in Foxe Basin and the Gulf of Boothia.

Early break-up and relatively high food production are eastern Parry Channel's major attractions for marine wildlife. White whales, narwhal, bowhead whales, ringed and bearded seals, harp seals, walrus, polar bears and seabirds depend on this Channel to varying degrees for feeding and breeding. The Channel also provides early access to more remote but preferred wildlife destinations, such as Creswell Bay and Cunningham Inlet on Somerset Island, Crozier Strait and Admiralty Inlet. Eastern Parry Channel, comprising Lancaster Sound and Barrow Strait, ranks high in North American and, possibly, world-wide ecological significance, bordering on the unique for some species. The following generalizations tend to support this ranking :

- Over one-half of Canada's northern fulmars, a relative of the shearwater and albatross, nest and feed in Parry Channel, and comprise an estimated 150,000 breeding pairs.
- Roughly one-quarter, or 424,000 breeding pairs, of eastern Canada's thick-billed murrelets nest or feed in Parry Channel. They are the Arctic's ecological counterpart of the Antarctic's penguins.

- About 50%, or 96,000 to 112,000 breeding pairs of North America's black-legged kittiwakes, a tern-like gull, nest or feed in Parry Channel.
- At least 1,500,000 dovekies, and possibly many more, feed briefly in eastern Parry Channel in the spring of some years. These birds are a small relative of the murre.
- About one-third, or 10,000 of North America's white whales (beluga) migrate and feed in Parry Channel.
- Over 85%, or 20,000 to 30,000 of North America's narwhal feed and, in part, breed in Parry Channel.
- Bowhead whales, also called Greenland 'Right' whales once used Parry Channel as a summer nursery and, today, still feed in these waters, although their population is much reduced and endangered.
- In some years, over 130,000 harp seals oversummer and feed in Parry Channel.
- An unknown number - probably hundreds of thousands - of ringed seals, and hundreds of polar bears are year-round residents of Parry Channel.

While the numbers of animals are impressive, the key to the maintenance of these large populations, and even the survival of birds, mammals or any living thing is the *availability* of breeding and feeding areas. Without the protection of such habitats, populations of seabirds, seals, bears or fishes cannot eventually recover from heavy man-made or natural mortality. This is basic to the concept of critical areas. Stirling *et al.*<sup>22</sup>, and Nettleship and Gaston<sup>23</sup> emphasize that our attempt only to preserve the maximum number of individual seals, polar bears, thick-billed murres or other Arctic fauna is futile *if* irreparable damage is done to key feeding and breeding locales. In the following discussion of seabirds and marine mammal biology, we attempt to identify these known or suspected critical habitats. The Arctic Pilot Project is a unique venture, employing icebreakers in regions of stable, landfast ice during the winter. However, strict adherence to particular routes and optimum timing of passage can probably avoid most critical habitats, and thus reduce impacts on wildlife. However, environmental threats of year-round LNG transport in Parry Channel are difficult to predict. Never has the Channel's solid fast-ice been scarred by artificial linear leads parallel to the coastline in winter and spring. Resident wildlife, such as hunting polar bears, scavenging white foxes or breeding ringed seals, have not yet encountered a 150,000 HP, 300 metre-long icebreaker proceeding at 3 knots through their sea-ice habitat. How will pregnant, denning polar bears or suckling seal-pups respond to the noise and physical presence of a nearby-passing ship? No-one knows.

To further complicate impact predictions, the Arctic marine environment is, itself, unpredictable. Plant and animal populations undergo radical changes in size and distribution from season to season, and year to year. Critical habitats for foraging and breeding can shift tens, or even hundreds of kilometres. These changes depend, to a large degree, on varying sea conditions. For example, the rugged multi-year ice of Barrow Strait is probably poor breeding habitat for ringed seals<sup>24</sup>, yet the year-to-year

distribution of this ice-type is extremely variable (Figures 6 and 7) - a function of freeze-up patterns, surface currents, and so on. The successful choice of birth-lair sites by pregnant seals must reflect the conditions characteristic of each winter. Similar geographic choices will be made when marine routes of least ice resistance are prescribed for LNG carriers. Given such variance, the prediction of mortality to newborn seal pups, for example, cannot be based realistically on 'atlas-scale' generalizations of ice conditions, site-specific data of seal distribution in one or two selected winters, nor on the assurances of a fixed shipping corridor chosen from historic satellite imagery interpretations. The Arctic Pilot Project will require real-time information about Parry Channel's physical features and wildlife dependants, especially during ice-covered and ice-infested periods.

There are some research needs which would clarify the impact of year-round icebreaking in Parry Channel. These focus on the dependence of wildlife populations upon special features of their physical environment. One example is the value of ice-edges in and near Parry Channel to migrant seabirds and mammals; another is the importance of different ice-types to breeding ringed seals in fast ice areas of Barrow Strait and Viscount Melville Sound. These unknowns cloud our understanding of the Project's potential impact, and hinder the choice of passage-routes and timing.

Discussions to follow centre on data deficiencies concerning biological features most seriously at risk from normal operations and accidents of icebreaking LNG carriers. Only common species of seabirds and sea mammals are considered; lower life forms, such as fishes, planktonic invertebrates, benthic and under-ice organisms are not judged to be seriously-threatened populations. Even so, their availability as prey for higher life-forms could be reduced if major ice features, such as ice-edges, are disrupted by icebreakers.

Biological reviews and literature surveys are available for most waters of Parry Channel. The interested reader is referred to the documents listed below for more detailed species-accounts at different geographic locales.

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Sefton, J. and G. Miller, 1978. The Arctic Islands Pipeline Route : a Bibliography of unpublished Department of Fisheries and the Environment Reports; Environmental/Social Program, Northern Pipeline Report No. A1-12. 154 pp.

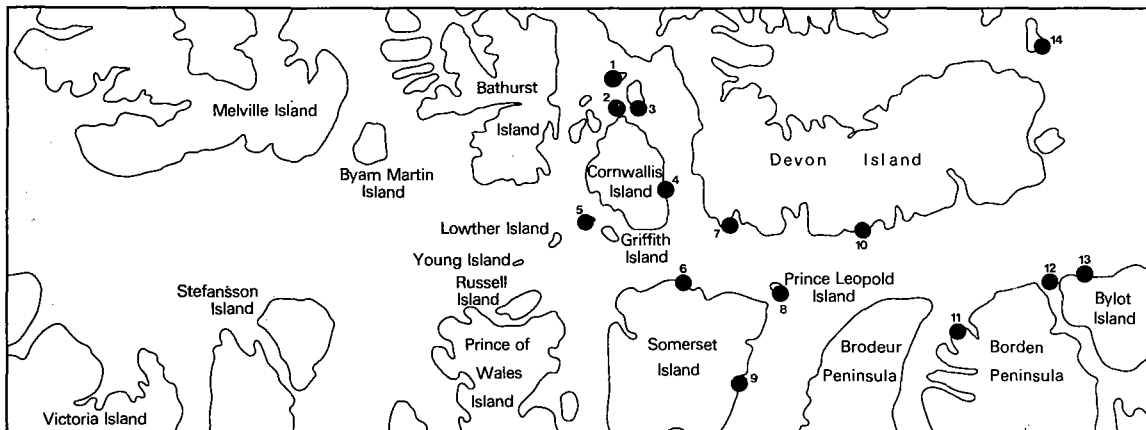


Figure 13. Locations of Major Seabird Colonies in or near Parry Channel.

TABLE 3. Major Seabird Colonies of Four Common Species in or near Parry Channel				
Locale (shown in map above).	Northern fulmars	Black-legged kittiwakes	Thick-billed murre	Black Guillemots
	Estimated number of Breeding Pairs*			
1. Dundas Island	--	100	--	--
2. Houston Stewart Island	--	500	--	--
3. Washington Point, Baillie Hamilton Island	--	3,000	--	--
4. Separation Point, East Cornwallis Island	--	125	--	--
5. Brown Island	--	1,000	--	--
6. North Somerset Island	--	100	--	--
7. Cape Liddon, South Devon Is.	20,000	--	--	--
8. Prince Leopold Island	62,000	29,000	86,000	2,000
9. Batty Bay, East Somerset Is.	--	125	--	--
10. Hobhouse Inlet, South Devon Is.	10,000	--	--	--
11. Baillarge Bay, North Baffin Is.	60,000	--	--	--
12. Wollaston Island	1,000	--	--	--
13. Cape Hay, North Bylot Island	--	50,000	145,000	--
14. Colburg Island	up to 5,000	50,000	200,000	--

\* With the exception of Prince Leopold Island, these numbers are provisional estimates by Dr. D. N. Nettleship, Canadian Wildlife Service, Dartmouth, N.S. (October, 1978). The results of ongoing study and analysis may warrant the revision of the estimates for Cape Hay and Colburg Island.

## 8. WILDLIFE AND LNG ICEBREAKERS IN PARRY CHANNEL.

### 8.1 Seabirds.

As many as two or three million seabirds migrate, nest or feed in Parry Channel during the open water season from April to October, representing over one-half of Canada's population of eastern Arctic seabirds. Northern fulmars, thick-billed murres, black-legged kittiwakes, black guillemots and eiders probably comprise the bulk of the migrants, If dovekies are included, the total numbers of seabirds may almost double. Although dovekies do not breed in Arctic Canada, they feed briefly at the entrance of Lancaster Sound en route to Greenland nesting-cliffs in spring<sup>25</sup>.

Major seabird nesting locales are known throughout Parry Channel, especially for colonial species, such as murres, kittiwakes and fulmars (Figure 13). Most colonies border the sea, and often the nesting ledges are situated on near-vertical, shoreline cliffs. The two largest colonies within Parry Channel are situated on N Bylot Island (Cape Hay), and Prince Leopold Island. Together with nearby colonies on S Devon Island (Hobhouse Inlet and Cape Liddon), N Baffin Island (Baillarge Bay), distant Colburg Island and E Bylot Island (Cape Graham Moore), these are the breeding sites of 50 to 60% of Canada's fulmars, and over 25% of Canada's thick-billed murres. Because of their proximity to the sea, these colonies are highly vulnerable to man's disruption by marine traffic.

More difficult to delineate in Parry Channel are the important seabird *feeding* locales. Marine distribution of seabirds is largely dictated by ice conditions and weather, especially in spring and early summer. Since ice conditions vary dramatically, seasonally and annually, (section 5), seabirds must respond with flexible diets and feeding patterns. Consequently, most feeding sites in Parry Channel are preferred, rather than fixed. One preferred locale is the area of coastal waters near the corner of SE Devon Island which often attracts thousands of feeding fulmars in August. In 1976, densities of 1,357 birds/km<sup>2</sup> and flocks of 2,000 birds were recorded here<sup>25</sup>. If these birds are foraging to feed their young, they travel over 150 km from the nearest colony. Other examples of somewhat traditional feeding areas are along the fast-ice edges across Navy Board Inlet, Wellington Channel and Parry Channel. For example, Alliston *et al*<sup>26</sup> reported high densities of 723 and 1,210 murres/km<sup>2</sup> along the Wellington Channel and Barrow Strait ice-edges, respectively, in June. Other surveys by Bradstreet and Finley<sup>27</sup> revealed that the Barrow Strait ice-edge attracts areal densities six times greater for fulmars, three hundred and forty-two times greater for eiders and nine times greater for murres and guillemots than are found in nearby open waters. Marine birds also concentrate at the Navy Board Inlet ice-edge. In June, 1976, over 700 fulmars/km<sup>2</sup> were recorded here<sup>25</sup>. These dense seabird concentrations usually persist until the fast ice disappears in mid-July. Why are these ice-edge habitats so popular for foraging birds? Guesses are that under-ice organisms are easy prey to diving birds, or that calmer waters near the ice increase the

conspicuousness of plankton to surface-feeding birds. For whatever the reasons, the ice-edges across Barrow Strait, and other channels, inlets and bays, appear to be important feeding areas for fulmars, murre and guillemots until the fast ice clears from Parry Channel. To quote Nettleship and Gaston<sup>23</sup>, "Because the position of the ice-edge is likely to be unpredictable, the position of the most crucial feeding area during the period prior to the hatching of chicks in late July probably alters substantially from year to year." This observation complicates generalized predictions of threats from year-round LNG transport.

There exists a potential hazard to seabird colonies at Cape Hay, Hobhouse Inlet, Cape Liddon, Prince Leopold Island and Browne Island unless the LNG carriers are routed away during the egg-laying and chick-rearing periods. Seabird colonies should be given the same consideration as centres of population. The same strict measures and criteria of "safe distance" should apply. If LNG carriers pass close to these colonies, possibly within 1 or 2 km, the vessel's noise and physical presence could initiate a hasty and confused mass exodus of brooding birds from the nesting cliffs. Eggs and young chicks would be dislodged, accidentally, into the water. Unprotected eggs and chicks would fall prey to glaucous gulls and other aerial predators. The ship's noise may also cause fulmar, kittiwake and murre chicks to fledge prematurely. The resultant cumulative mortality to the colony's brood could be significant. Another, though less probable threat as a result of the vessel's normal operations is the "boil-off" of natural gas near the seabird colonies - to which birds would be extremely sensitive. In fact, birds are often biological indicators of very low concentrations of toxic gases, such as methane and ethane. With light onshore winds and under temperature inversion, vapours from a nearby-passing LNG carrier could kill instantly large numbers of nesting seabirds and chicks. To minimize such threats of noise and air pollution, LNG carriers should travel well offshore in Parry Channel from April to October, thus avoiding seabird-colony locales, and most coastal feeding areas.

An offshore travel route would also reduce the gravity of shipping accidents. If an LNG carrier grounded, collided with another ship, exploded or caught fire, up to 10,000 tonnes of diesel fuel, and about 500 tonnes of lubricating oils would pollute the sea (section 4). A 10,000-tonne diesel oilspill is a relatively large amount of pollutant if compared with oilspills from the *Arrow* in Chedabucto Bay and the *Ocean Eagle* off Puerto Rico, where about 16,000 and 12,000 tonnes of oil was spilled, respectively. Contamination of ice and open water by diesel oil is a serious potential hazard to dovekies and murre migrating in offshore cracks and leads, to fulmars and kittiwakes feeding along the seaward edge of landfast ice near their breeding colonies or foraging grounds, and to all seabirds swimming through oil-slicks. The impact of an arctic diesel spill would be somewhat lessened if the pollution remained offshore, away from coastal ice-edges and coastal waters near colonies.



Coastal Cliffs of the Cape Hay Seabird Colony on North Bylot Island. (Photograph by D. N. Nettleship).

In the event of an emergency jettisoning of the LNG cargo, or an explosion, fire or vapour-cloud following a collision or grounding, seabird colonies and feeding concentrations could be seriously endangered if located within 16 km of a worst case mishap (Table 1). Although of low probability, the threat from such an accident can be minimized by the distant offshore routing of LNG carriers when seabirds are in attendance at their colonies. However, careful routing cannot avoid the Barrow Strait ice-edge where seabirds concentrate.

In offshore open waters, normal operations of LNG carriers are probably of no consequence to seabird populations. Flocks of swimming seabirds are expected to swim, dive or fly away in advance of the vessel's approach. The ship's noise and physical presence is temporary - a matter of tens of minutes. The powerful propeller-wash of the ship will tend to mix the surface waters, exposing plankton prey, and overturn ice, dislodging under-ice invertebrates and fish. This disruption could increase local food availability and benefit surface-feeding birds, such as fulmars and kittiwakes. In late fall, winter and early spring,

it is unlikely that any significant hazard exists to seabirds during the passage of an LNG carrier through Parry Channel. Few seabirds can survive over winter in the near-complete ice cover of Parry Channel. Most eastern Arctic seabirds fly to distant Davis Strait, Labrador Sea and North Atlantic waters, especially along West Greenland, and stay there from November to April.

It is possible that year-round icebreaking in Parry Channel could result in a longer ice-free season and a general warming of marine waters during the summer (see section 5). Seabirds and other migrant wildlife may benefit by this man-made alternation. Reduced sea-ice cover may favour their preferred travel patterns and feeding habits. Warmer water temperatures may also stimulate plankton growth in the Sound's marine environment and, in turn, enhance food availability to seabirds, whales and seals. This assumes, however, that any enhanced food production occurs at a time and place when birds and mammals could profit. A shift of three or four weeks, earlier or later, in peak plankton growth or availability could have severe repercussions for nesting and brooding seabirds. Longer ice-free seasons may restrict the habits and movements of polar bears and seals which rely on floating icefields for food and rest offshore. Our understanding of feeding and breeding cycles for most marine plants and animals is poor, including their dependence on factors such as ice cover and water temperature. Since this state of data inadequacy also pertains to the basic oceanographic prediction of warmer water, detailed discussion of its ecological significance is not attempted here.

## 8.2 Ringed Seals.

Ringed seals, the most common sea-mammal of Parry Channel, are year-round residents. They are also widely distributed offshore and coastally, but prefer certain ice habitats for breeding. These biological facts make ringed seals one of the most vulnerable mammals to the Arctic Pilot Project. Undoubtedly, LNG carriers will encounter more ringed seals, per kilometre of travel, than any other mammal species. For this reason, careful consideration needs to be given to critical aspects of the seal's biology, such as pupping.

Most seal research<sup>24,28,29,30</sup> in Parry Channel has focused on Barrow Strait and the Viscount Melville and Peel Sound regions, where gas pipeline crossings envisioned by Polar Gas Limited probably overlap seal pupping areas. Findings indicate, however, that most juvenile and adolescent seals overwinter in the unstable ice further east in Lancaster Sound<sup>3</sup>. In Barrow Strait, 1975 spring aerial surveys<sup>24,30</sup> showed that the density of ringed seals was about 0.53 to 0.69 seals/km<sup>2</sup> in *coastal* ice. Highest mean densities (up to 3 or 4 seals/km<sup>2</sup>) were concentrated near Prince of Wales and Russell Islands, in Aston Bay (Somerset Island) and at the mouth of Peel Sound. These data are summarized in Table 4 (Density discrepancies between the findings of Smith and Finley are, in part, a function of different survey coverages and timing, but may also reflect the "patchiness" of seal distribution and abundance).

TABLE 4. Compared Densities of Ringed Seals Hauled-out on Coastal Sea-ice of Parry Channel region in Spring, 1975 (summarized from Smith *et al*<sup>24</sup>).

Locale	Area surveyed (km <sup>2</sup> )	Total number of seals	Mean density seals/km <sup>2</sup> <sup>a</sup>	Mean density seals/km <sup>2</sup> <sup>b</sup>
1. South Devon Island (excluding Maxwell Bay)	145.2	63	0.44	0.58
2. North Somerset Island (excluding Aston Bay)	248.9	248	1.00	0.63
3. South Cornwallis Island	352.6	138	0.39	0.72
4. McDougall Sound	757.0	320	0.42	0.84
5. South Bathurst Island and Austin Channel (excluding de la Beche Bay)	570.4	158	0.28	0.62
6. Byam Martin Island and East Melville Is.	414.8	33	0.08	0.74
7. North Prince of Wales Island and Russell Island	539.2	417	0.77	0.79
8. Peel Sound	1,161.4	1,181	1.02	0.91
9. Aston Bay, NW Somerset Island	165.9	522	3.15	4.69
10. Maxwell Bay, SW Devon Island	165.9	34	0.20	0.39
11. de la Beche Bay, SW Bathurst Island	41.5	17	0.41	1.35
	4,562.8	3,131	0.69	0.53

a. Smith *et al*<sup>24</sup>  
 b. Finley<sup>30</sup>

These Barrow Strait data can be compared with those of Lancaster Sound where Johnson *et al*<sup>31</sup> recorded a lower mean density of 0.21 seals/km<sup>2</sup> in the Sound's nearshore, moving pack-ice (1.0 to 1.4 km from the ice-edge or shore), during early June, 1975. However, a limited survey of coastal fast ice revealed a mean 0.40 seals/km<sup>2</sup>, whereas some flights near Croker Bay and Navy Board Inlet recorded up to 2.5 seals/km<sup>2</sup>.

Mean, areal densities *offshore* are observed to be somewhat similar to those on coastal sea ice. Averaged over eastern Parry Channel areas, the mean offshore density was 0.56 to 0.88 seals/km<sup>2</sup>, respectively<sup>24,31</sup>. However, seasonal and annual survey bias is suspected to vary these observed concentrations.

Parry Channel's fast ice is considered as critical habitat for breeding ringed seals. Pregnant seals preferentially select the relatively flat, stable, first-year ice of Barrow Strait where there is only minor ridging and little multi-year ice. Alternatively, they choose areas at the edge of a field of more extensive rough ice<sup>24</sup>. During fall freeze-up, they are attracted to the last remnants of open water, and locate breathing holes in freezing leads and cracks. If suitably placed, these breathing holes can eventually serve as underwater entrances to pupping lairs or haul-out lairs buried beneath protecting, drifted snow. These birth-lairs are as essential to the seals' survival and reproduction as cliff colonies are to murrees and kittiwakes. Here, in relative warmth and safety, newborn seal-pups can suckle and grow until their white, insulating fur is shed and replaced by subcutaneous blubber. This critical period of whelping lasts one or two months.

Unlike seabird colonies, concentrations of birth-lairs cannot be depicted by tiny black dots on a chart. With the exception of a few protected locales, such as Aston Bay, varying ice conditions cause seals to shift their pupping grounds, sometimes tens or hundreds of kilometres. Only the broad stroke of a brush across a chart of Barrow Strait can realistically represent the patchiness of important breeding areas. Nevertheless, the following generalizations, based on limited surveys of one or two winters, provide some clues to the locales of recurring whelping areas for ringed seals.

In late April and May, 1976, high areal densities of pupping seals were reported in four locations - at the mouth of Peel Sound, in nearby Aston Bay, north of Prince of Wales Island, and around Lowther and Russell Islands<sup>24</sup>. The density of subnivean (snow-covered) birth-lairs varied from 0.38 to 3.09/km<sup>2</sup>. If haul-out lairs are included, these densities increase to 0.84 to 16.52/km<sup>2</sup> (Table 5). In addition, good to excellent breeding habitat also existed in Byam and Austin Channels.

Locale	Area surveyed (km <sup>2</sup> )	No. of birth-lairs	No. of male lairs	No. of haulout lairs	No. of breathing holes	Density, lairs/km <sup>2</sup>
Austin Channel	13.04	5	2	3	1	0.84
NE Russell Is.	1.51	1	0	0	18	16.52
E. Lowther Is.	9.31	7	0	6	7	2.15
12 miles E of Lowther Is.	1.94	6	0	8	9	11.86
N Griffith Is.	4.48	3	0	5	5	2.90

These density figures are based on sparse field data. The search areas were often small - sometimes less than 2 km<sup>2</sup> - and the complex nature of sea ice prevented accurate extrapolation. It remains speculative that the rough, heavily-pressured portion of the fast ice in Barrow Strait is poor breeding habitat for ringed seals. No searches have been made here because of difficult over-ice travel and limitations of present ground-search techniques.

Other indirect evidence supports the existence of important pupping areas along the coast of west Bathurst Island (de la Beche Bay), in central Barrow Strait between Prince of Wales and Lowther Islands, and near Russell Island. Here, in 1976, Smith *et al*<sup>24</sup> found large numbers of excavated seal-lairs and partially eaten pup carcasses - both signs of polar bear predation.

For ringed seals, the most obvious and probably the most serious threat from icebreaking LNG carriers is the crushing and wetting of newborn pups, hidden within the snow and ice. During March and April, icebreaking in the fast ice of Barrow Strait could kill all young seals incapable of escaping from the ship's path. Pup abandonment by nursing females is also possible as a result of the ship's noise and its physical presence. The range of influence beyond the ship's icebroken path is unknown.

Existing studies of seal breeding areas are inadequate to define or predict those shipping routes least damaging through Barrow Strait and Viscount Melville Sound. The year-to-year variability of offshore ice-types and concentrations necessitates further investigation of the seals' association with and dependence on different ice habitats. Availability of food cannot be ignored as a factor controlling their winter distribution.

The impact of LNG icebreakers could worsen if pregnant seals are attracted to the ships' broken ice paths during fall freeze-up. The icebreaker tracks may offer, temporarily, the advantages of naturally-occurring leads and cracks. However, re-use of this ice-broken corridor for three or four successive ship-passages could force seals to vacate the area to nearby, poor breeding habitat. For those that remain, the disruption could hinder their successful construction of lairs or, later, increase the risk of pup mortality.

Current knowledge seems to indicate that both seals and icebreakers will seek out similar winter and spring "habitat" - the relatively smooth, stable fast ice with a minimum of thick, multi-year ice. Fall freeze-up patterns may dictate the seals' distribution over the winter and spring months. If this is the case, detailed aerial ice reconnaissance of Barrow Strait and Viscount Melville Sound is necessary, together with a better knowledge of seal/ice relationships. This would permit more credible extrapolation of birth-lair densities and delineation of critical breeding locales. Ultimately, ice reconnaissance alone, in any particular year, may provide a means of estimating ringed seal abundance with respect to chosen carrier routes. Scheduling of the vessels' annual refits could be arranged to coincide with the seals' most vulnerable months of March and April. Reduced traffic would reduce pup mortality.

Aside from pups, adult and juvenile ringed seals are not unduly threatened by LNG carriers. In open water or complete ice-cover, seals can dive or swim away from the vessel's path, in advance of its approach. Seals may even benefit by the creation of artificial leads and cracks left in the wake of the icebreaker, since they often seem to prefer hauling-out along open cracks instead of beside breathing holes<sup>24</sup>. Explosions, fire or vapour-clouds, in the event of a shipping accident, are localized and of short duration, threatening only a small segment of the seal population. Diesel oil pollution of ice and water can be more serious if the seals are newborn or in poor health, and if exposure is prolonged<sup>32</sup>.

### 8.3 Bearded Seals.

Bearded seals are less common than ringed seals in Parry Channel. As predominantly bottom feeders, they often inhabit shallow-water coastal areas. The peak pupping period is around late April, although breeding activity can extend from mid-March to mid-May. The pups are large and precocious, swimming soon after birth. They nurse for only two or so weeks, and do not require the protection of a lair<sup>22</sup>. Their coastal habits and low abundance tend to lessen the potential threat of winter passage by icebreakers. The behavioural response of bearded seals to approaching icebreakers is assumed to be similar to that of ringed seals, that is, avoidance by swimming or diving away, and a temporary disruption of feeding or resting. The reaction of nursing females is unknown.

### 8.4 Polar Bears

Polar bears are thought to occur in relatively discrete sub-populations of up to 15 or so in Arctic Canada. Based on bear tag-and-recapture studies, Inuit hunter kills and aerial survey sightings, polar bears in Parry Channel are probably members of one such population group<sup>33</sup>. They are most common on the frozen channels of Barrow Strait, W Lancaster Sound and N Prince Regent Inlet; their population-size is not known. Observed patterns of travel and abundance indicate a seasonal fidelity of polar bears to certain feeding locales, such as the Barrow Strait ice-edge (depending on its geographic position), the Wellington Channel ice-edge and numerous SW Devon Island bays. In this region, Stirling *et al*<sup>34</sup> report that the majority of bear recaptures in winter and early spring were less than 150 km from where the bears were originally tagged, after an intervening period of one or more years. However, some bears travel the much-further 300 to 800 km distances to NE Baffin Island and Greenland<sup>12</sup>.

During 8,300 miles (13,280 km) of aerial surveys in offshore and coastal Barrow Strait, Finley<sup>30</sup> observed an average of one bear in 125 miles, in June, 1975. Thirty-one per cent of the total 68 sightings occurred along the E Barrow Strait ice-edge which was anchored, temporarily, near Prince Leopold Island. Here, as many as one bear in 4 miles was observed. Later, from late June to late August (the period of open water), these offshore concentrations declined to about one bear in 250 miles averaged over 15,800 survey miles (24,280 km); most bears had moved to coastal feeding locales. A similar abundance was recorded in E Lancaster Sound, from 2 May to 28 September<sup>31</sup>.

In mid-June, when the Sound's offshore icefield had cleared, most bears had retreated to landfast ice along S Devon and N Baffin Islands.

Sea ice ultimately controls the life-style and habits of polar bears, making elusive our rigid definition of areas critical for winter feeding. Polar bear survival is linked to their principal prey, the ringed seal. Hunting success depends on the seals' availability and, more importantly, their vulnerability to the bears' hunting tactics. Often, ice-roughness and snow-cover are important factors when bears successfully stalk seals at

offshore breathing holes and cracks, or search for seal-pups in subnivean lairs.

Good feeding habitat for polar bears is probably patchy and wide-spread throughout Barrow Strait and Lancaster Sound, and depends on ice conditions. (This can be said for seals as well). In spring, bears tend to concentrate in the coastal ice regions along SE Devon Island, off the mouths of Navy Board and Admiralty Inlets, in Prince Regent Inlet, and especially along SW Devon Island, such as Maxwell and Radstock Bays<sup>33,34</sup>. When offshore ice finally drifts away and melts in Parry Channel, polar bears are forced to retreat to the solid footing of land, or persistent landfast ice - ideally, also, where ringed seals congregate, such as in Radstock and Maxwell Bays.

Suitable breeding (denning) habitat for polar bears probably exists on all coastal lands bordering Parry Channel. This is corroborated by Stirling *et al*<sup>34</sup> and Schweinsburg *et al*<sup>33</sup> who report that maternity dens are sparsely scattered along the Channel's coastline. However, some locales appear more important than others, such as on NW Somerset Island, N Prince of Wales Island, SW Devon Island, SE Bathurst Island, W Cornwallis Island and N Bylot Island (Figure 14). Most bears construct maternity dens within a few kilometres of the sea. The reader is cautioned that the locations of dens are probably underestimated due to limitations of survey techniques and coverage.

Noise and the physical presence of LNG icebreakers, during winter, will probably cause only minor or negligible disruption to feeding and travelling polar bears in Parry Channel. However, bears are more sensitive to disruptions when larger numbers converge from open water at coastal summer feeding areas and sanctuaries. For this reason, Radstock and Maxwell Bays (SW Devon Island), Croker Bay and Dundas Harbour (SE Devon Island) and N Navy Board Inlet should be circumnavigated, as far as possible, by shipping traffic in July, August and September. Denning polar bears are probably particularly sensitive to high levels of noise from LNG carriers. Bears may den almost anywhere in Parry Channel, in a widely scattered manner, along the shores of S Devon, N Baffin and other islands bordering the Channel. Stirling *et al*<sup>34</sup> suggest that land-based, industrial activities should be avoided within 10 km of the coasts where known or suspected denning occurs between 1 October and 30 April. In their words, "Widespread disturbance along protracted areas of coastline (where denning occurs) . . . could cause premature abandonment, and increased mortality of cubs-of-the-year to a significant portion of a local group of bears." Icebreakers travelling close to shore may fit into this category of disturbance. At present, denning sites are poorly mapped, and the vessel's noise levels (and their effects) unquantified. It seems prudent, therefore, to assume an extra safety margin, well exceeding 10 km . . . when establishing the winter's shipping route.

If year-round LNG traffic causes the Barrow Strait ice-edge to stabilize, each spring, near Griffith Island or even further west at Lowther Island, polar bears will probably exhibit different travel and feeding patterns. This does, in fact, occur during year-to-year natural variance in this major, oceanographic feature. For example, in mid-June, 1974, the Barrow Strait

ice-edge persisted for weeks at the longitude of Griffith Island. Aerial surveys of marine mammals revealed that, under these ice conditions, polar bears chose to concentrate in peripheral, coastal areas, such as N Somerset Island and Wellington Channel; few bears prowled the ice-edge itself<sup>30</sup>. A year later, on the same date, this recurring ice-edge settled in its most usual position across E Barrow Strait and anchored to Prince Leopold Island. At this time, most bears concentrated along the ice-edge itself<sup>30</sup>. The reasons for, and ecological significance of this apparently contrasting dispersal of bears are unknown. Biologists speculate that, although polar bears are attracted to the ice-edge for feeding and travel, they prefer to remain close to SE Devon Island and particularly to Radstock Bay, which is an important, almost obligatory locale for summer hunting and refuge. There are, as yet, no satisfactory answers to the question, "What are the repercussions on polar bears if the good seal-hunting of the Barrow Strait ice-edge consistently retreats 150 km westward of SE Devon Island as a result of icebreaker intrusions?"

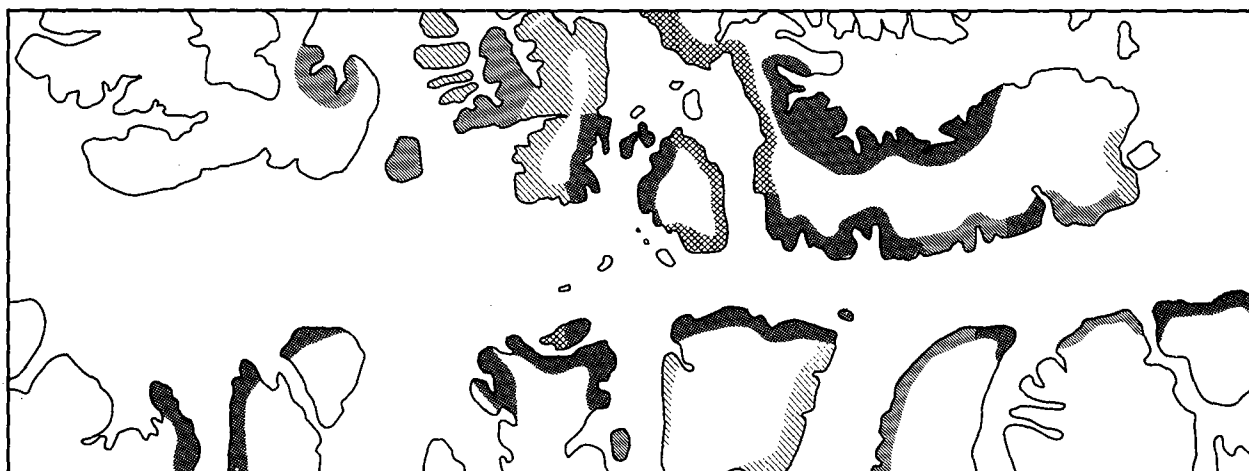
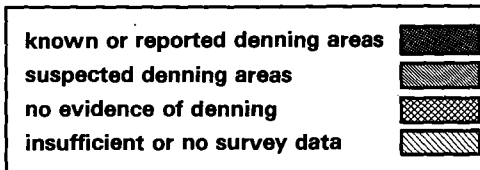


Figure 14. Maternity Denning Areas of Polar Bears in the Parry Channel region (from Stirling *et al*<sup>34</sup> and Schweinsburg *et al*<sup>33</sup>).



#### MIGRATORY SEA MAMMALS.

At spring break-up or shortly after, seven species of sea mammals migrate into Parry Channel and depart again before the Sound re-freezes. These include narwhal, white whales (beluga), bowhead whales, harp seals, walrus, hooded seals and killer whales. The two latter species are uncommon, and not addressed in this report. All marine mammals enter Parry Channel from the east, converging at Lancaster Sound after swimming through Baffin Bay. The majority of whales and migratory seals do not travel westward of W Barrow Strait, even if ice conditions permit. The relatively rich waters of Lancaster Sound appear attractive to every feeding mammal, even though just in passing for some species. Inlets, fjords and estuarine bays, in or adjacent to Parry Channel, are important breeding grounds for white whales, bowhead whales and, probably, narwhal.

## 8.5 Whales.

For about five months each summer, 10,000 or so white whales inhabit W Lancaster Sound, Barrow Strait, Peel Sound, Prince Regent Inlet, Franklin Strait and Wellington Channel. Their westward, spring migration is progressive over a period of 3 or 4 months. Low numbers of the earliest migrants wend their way as small herds through leads and cracks in the Channel's sea-ice, sometimes using, if present, the somewhat persistent flaw lead along S Devon Island. Summer feeding and, possibly, calving occur along or close to coastal E Barrow Strait, at such critical locales as Garnier Bay, Cunningham Inlet, Elwin Bay and Creswell Bay (Somerset Island), and Maxwell and Radstock Bays (SW Devon Island). In summer, more than 25% of an assumed population of 10,000 white whales congregate in the shallow waters of Cunningham Inlet; a further 35% congregate in Creswell Bay<sup>30,35</sup>.

Fall migration is eastward-abrupt and intense. In the one-month period from mid-September to mid-October, 1976, the bulk of white whales (belugas) departed through the open water of E Lancaster Sound and dispersed into Baffin Bay. At times, there were herds of 1,600 animals or more, and most swam close to the S Devon Island coast<sup>31,36</sup>.

Narwhal, a close but larger cousin of the white whale, have very different habits and habitat requirements. An estimated 20,000 to 30,000 narwhal migrate into Parry Channel<sup>37</sup> in search of deep, cold, ice-infested fjords and inlets. Admiralty Inlet, Navy Board Inlet and Eclipse Sound are the most popular summering locales for thousands of these animals. In late June and early July - or as soon as ice permits - small numbers of narwhal press westward into Prince Regent Inlet, Barrow Strait, Wellington Channel and N Peel Sound<sup>38,39,40</sup>. Unlike beluga, narwhal do not concentrate in small coastal estuaries but disperse widely in small offshore groups. Calving may occur anywhere in Parry Channel<sup>30,39</sup>. However, local concentrations, probably for feeding, are reported along coastal ice-edges near Dundas Harbour, Navy Board Inlet and Admiralty Inlet. These animals appear to await the break-up of fast ice which excludes them from these inlets and fjords. For example, on 22 July, 1976, about 3,000 narwhal had converged along the seaward edge of the fast ice across the mouths of Admiralty and Navy Board Inlets<sup>36,41</sup>. Eastward outmigration into Baffin Bay often peaks in late September. Their patterns of travel, modified by existing ice conditions, are both coastal and offshore.

A few tens, or possibly a hundred or so bowhead whales migrate from Baffin Bay to feed in the plankton-rich waters of Lancaster Sound, and other channels<sup>31,43</sup>. Lancaster Sound was formerly known as a bowhead whale nursery, implying that calving occurred here. As evidenced by bleached bones scattered on the shores throughout Parry Channel, bowheads were formerly abundant and widespread in Lancaster Sound, Peel Sound, Prince Regent Inlet and MacDougal Sound<sup>30,40</sup>. Today, their distribution is relatively unchanged but their numbers are few - drastically reduced by the over-hunting of eighteenth Century whalers. Each year, bowhead whales delay their migration into Parry Channel, usually until the open water season in late June and July<sup>31,42</sup>. Thus, accidental entrapment by ice is not a serious threat to bowheads. Locales frequented by bowheads for feeding and breeding are unknown.

Normal operations of LNG carriers will probably create minimal disruption to the breeding of narwhal, white whales and bowhead whales, assuming that the icebreakers steer clear of embayments along N Somerset and SW Devon Islands. In most imagined open water and offshore situations, the noise of an approaching ship would serve to forewarn the whales; they can easily dive or swim away from the path of a ship. There is some evidence, however, that boat traffic can temporarily impede (for up to 3 hours) white whales from coastal travel near the Mackenzie River estuary<sup>44</sup>. The inference is that heavy marine traffic may create an artificial noise barrier to whale migration and movement. This is unlikely at the outset of the Arctic Pilot Project, but could be a threat if more ships travel closer to coastal bays where beluga feed and breed.

It is speculated that migrating narwhal and white whales could be entrapped accidentally in an icebreaker's re-freezing or closing track. In nature, both species are, at times, trapped by quickly-changing ice immediately prior to fall freeze-up. If their exit to open water is blocked by ice, they struggle all winter, sometimes fatally, to maintain a breathing hole. During spring migration into Parry Channel, white whales and narwhal exhibit a strong instinct to "push" the ice, that is, they relentlessly explore cracks or leads, or other avenues of travel into icefields. This is probably the explanation for the appearance of white whales as far west as Maxwell Bay - a distance of over 100 km into Lancaster Sound - by April, 1976<sup>36</sup>. The S Devon Island flaw lead, opening into Baffin Bay, serves as a water corridor for marine mammal in-migration in some years. In other years, this E-W lead is not present, or only intermittently so. There is concern lest an icebreaker, wending East-West through the heavy ice of Parry Channel, tempt and attract whales to follow in its broken track. The ship's track may freeze slowly and the whales may be frightened away only temporarily by the icebreaker's approach. If these early migrants were to venture into the temporary, man-made lead, pushed westward through the Parry Channel ice-edge, their entrapment is certain by re-freezing ice or closing leads. An LNG carrier, returning from Melville Island, would not arrive in time to break a fresh escape route. The numbers of whales at risk are probably low, although this depends on the timing of break-up.

Fall outmigration of whales is usually completed by October, in open water prior to freeze-up. Any artificial delay in freeze-up, caused by icebreaking in Parry Channel, is unlikely to affect whale populations.

#### 8.6 Harp Seals.

Up to 150,000 harp seals swim into E Parry Channel to oversummer and feed amongst offshore ice pans, and along coastal ice-edges<sup>42,45</sup>. This post-pupping migration from Baffin Bay and Davis Strait peaks in July - later than for most migrant sea mammals<sup>30,31</sup>. Most harp seals linger in Lancaster Sound until October; however, several thousand travel as far west as E Barrow Strait. Late July surveys in 1975 revealed a mean density of about 0.2 harp seals/km<sup>2</sup> (0.5/mi<sup>2</sup>)<sup>30</sup>. A year later, also in late July, Johnson *et al*<sup>31</sup> observed a mean density of 1 seal/km<sup>2</sup> in E Lancaster Sound. Some coastal locales were popular - for example, the waters adjacent to ice-edges across Navy Board Inlet (29 to 44 harp seals/km<sup>2</sup>), and Croker Bay (12/km<sup>2</sup>) in July.

The harp seals' distribution, whether offshore or nearshore, depends on suitable concentrations of ice pans or fast ice for hauling out. This being the case, LNG carriers could encounter harp seals almost anywhere in E Parry Channel during July, August and September. Although these seals may not have defined, customary feeding areas, the icebreakers should avoid travelling close to the Channel's north and south shores. This would minimize the disturbance caused by the vessel's noise and physical presence - especially to harp seals concentrated in Croker Bay (S Devon Island) and Navy Board Inlet. Since harp seals whelp on the pack ice of E Newfoundland and the Gulf of St. Lawrence, they have no critical breeding habitat in Parry Channel.

### 8.7 Walrus

Walrus are not abundant in Parry Channel, numbering only between 300 and 400 animals. Of these, an unknown number are year-round residents of the Arctic Archipelago, overwintering in the polynyas of Penny Strait and Queen's Channel. The remainder migrate each spring into Lancaster Sound and Barrow Strait from Baffin Bay, following the westward retreat of the ice<sup>30,31,47,48</sup>. Walrus avoid offshore waters, preferring ice-infested, shallow waters where they can dive for benthic food and clamber out on to the ice to rest. Almost anywhere along the S Devon Island coast walrus are reported to oversummer. However, certain locales, such as Croker Bay (90 km west of Lancaster Sound's entrance) are more attractive than others. Here, Johnson *et al*<sup>31</sup> observed 39% of the 296 walrus sightings in E Lancaster Sound from June 13 to August 10, 1976. This local abundance was reflected by densities of about 3 to 4 walrus/km<sup>2</sup> in July. Another congregation locality for less than 100 walrus is at Innes Point (SW Devon Island) in S Wellington Channel<sup>30,49</sup>, where the animals oversummer, or possibly continue into Crozier Strait to feed with the resident walrus. When sea-ice melts and disperses, in August of most years, walrus are forced to rest on land between feeding-dives, often at traditional island or beach sites. Some known haulouts are located in Dundas Harbour (S Devon Island), on SE Philpots Island, off E Devon Island, Wollaston Islands at the mouth of Navy Board Inlet, Innes Point and E Bathurst Island.

As suggested for harp seals, LNG icebreakers should avoid coastal, fast-ice edges and inshore waters, especially along Parry Channel's north coast in order to safeguard against frightening and disrupting walrus grouped together at important summer feeding locations. Inuit hunting pressure and boat traffic during the 1950's caused several hundred walrus to vacate, permanently, a traditional Barrow Strait haulout site near Resolute Bay<sup>50</sup>. This historic evidence emphasizes the need for caution in choosing a safe, yet environmentally-acceptable shipping route through Parry Channel.

### 8.8 Caribou

Peary Caribou feed and, to some extent, calve on most islands bordering western and central Parry Channel. Relatively large herds inhabit (or once inhabited) Bathurst, Melville, Prince Patrick and several adjacent Queen Elizabeth Islands (collectively called the Parry

Islands, and the caribou, the Parry population), and Prince of Wales/Somerset Islands (supporting the Peel population)<sup>51</sup>. The size of the Parry population, in particular, has drastically declined by almost 90% during the years 1961 to 1974 - mostly on Melville and Bathurst Islands, during the extreme winter of 1973/74. Together with Prince Patrick Island, the overall Parry population has dropped to only 2,600 from an original 24,000 or more animals reported about 17 years ago<sup>52,53</sup>. Low birth rates, poor calf survival, malnutrition, starvation, and heavy winter kills were caused by early, deep and prolonged snow and freezing rain which covered the caribou's forage.

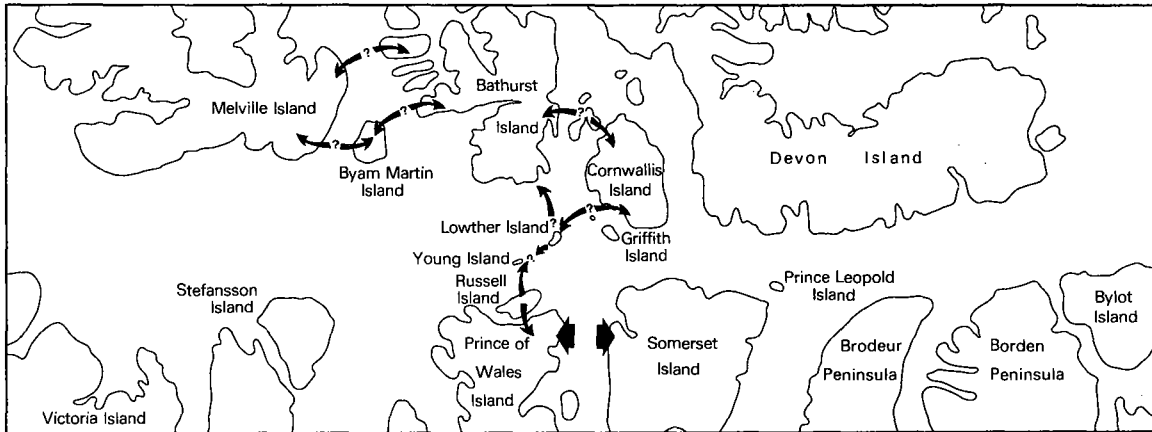


Figure 15. Inter-island movements of Peary Caribou in the Parry Channel region. (The small arrows indicate suspected intermittent movements often caused by harsh climatic conditions. The larger arrows represent known traditional migrations between seasonal ranges on Somerset and Prince of Wales Islands).

Caribou travel across sea ice from island to island, qualifying them as a "marine mammal" from the point of view of proposed winter LNG ice-breaker traffic. Each year, some caribou migrate between adjacent Arctic islands, to and from traditional calving and rutting areas or feeding locales. Such inter-island movements are documented for N Peel Strait, between Somerset and Prince of Wales Islands. Here, the majority of caribou overwinter on W Somerset Island, then cross over to Prince of Wales Island in April and May. In fall, when Peel Sound refreezes, migration is reversed<sup>54,55</sup>. Most evidence of this 'island-hopping' behaviour is indirect and is deduced from observations of caribou tracks on coastal ice, seasonal fluctuations in inter-island survey sightings and from pellet counts. Few caribou are actually sighted offshore, but this could reflect the intensity and coverage of aerial reconnaissance, to date.

Similar inter-island traffic appears to occur between Prince Patrick and Melville Islands (not shown on maps in this report)<sup>52</sup>. For example, in the short interval between aerial surveys flown in the spring and summer of 1973, caribou numbers dropped by 40% on Prince Patrick Island; the

opposite trend was observed on Melville Island<sup>56</sup>. These data demonstrate that most north-and-south-trending channels which enter Parry Channel do not pose a serious physical barrier to caribou. However, Manning<sup>57</sup> speculates that M'Clure Strait and Viscount Melville Sound are probably hazardous because of their width and the unpredictable timing of break-up and freeze-up. Barrow Strait seems to be somewhat less of an impediment to north-south migration. Islands, such as Russell, Lowther, Young, Browne, Somerville and Garrett, serve as "stepping-stones" between Prince of Wales Island and either Bathurst or Cornwallis Island. However, caribou movements across this island-chain (and the proposed path of ice-breakers) are probably intermittent, involving few animals. On 20 May, 1976, four starving caribou were sighted on Lowther Island<sup>24</sup>. Numbers of caribou (up to 20 or so animals) on Lowther and Young Islands changed quickly from week to week in the spring of 1977, also indicating limited travel in offshore Barrow Strait<sup>58</sup>. It is speculated that a future recolonization of Bathurst Island, for example, will most likely occur by caribou dispersion north from Prince of Wales Island<sup>58</sup>.

Icebreaking LNG carriers in Parry Channel will not intercept sea-ice migration paths of caribou which can be classified as traditional. The risks of noise and icebreaking, or the physical presence of the ships themselves, are probably negligible in Peel Sound and other "ice-bridge" channels of the W Queen Elizabeth Islands. However, future year-round shipping is envisioned north, into the Sverdrup Basin; here, the potential threat of disruption to migrating caribou is increased. If icebreakers were to delay the freeze-up of channels between Meville, Byam Martin, Bathurst and Cornwallis Islands, caribou could be restricted, temporarily, to summer range until late fall or early winter. In addition, premature break-up of fast ice could strand the animals on their winter range, preventing their migration to traditional calving and feeding locales.

In the spring of some years, Barrow Strait is traversed by low numbers of caribou. These may emigrate from Prince of Wales Island and other islands to Bathurst Island, or simply feed on the Strait's offshore Islands, such as Lowther and Young. It should be stressed that, although few in number, these animals could be relatively important to successful population recovery, dispersion and recolonization, especially since the current population surviving on the Parry Islands amounts to only a few thousand.

Any open water and fractured ice in the icebreaker's track is probably only a temporary obstacle to caribou crossing Barrow Strait sea-ice. In April and May, new ice will grow thick enough, in one day, to support the weight of a caribou. Caribou may, in fact, swim habitually across offshore leads which often persist in June. Small ridges and rubble ice, typical of an icebreaker's refrozen track, are likely to present no greater a barrier to caribou than do naturally-occurring pressure ridges and rough multi-year ice of Barrow Strait. Nevertheless, migrating caribou, together with breeding ringed seals, might benefit by the scheduling of LNG carrier refits in April and May.

Like caribou, small numbers of muskoxen cross frozen channels to nearby islands. However, these travels are not traditional but are, probably, infrequent, sporadic movements caused by poor or deteriorating environmental conditions.

9. TRAPPING AND HUNTING.

Many of the 200 or so native residents (1974 census) of Resolute are actively employed by a local wage-earning economy. Nevertheless, part-time hunting and trapping continues seasonally over a wide area. These hunters will, inevitably, sight LNG carriers, or at least have to cross the broken ice caused by the ships' winter passages, and are most directly affected by the proposed shipping route. Several of their popular locales for harvesting whales, seals and polar bears lie within the shipping corridor through Barrow Strait and E Viscount Melville Sound.

Hunters from Arctic Bay and Pond Inlet (N Baffin Island) kill narwhals ringed seals and polar bears along E Parry Channel's south shore, and in adjacent inlets and fjords. Although Inuit of these settlements seldom travel across Lancaster Sound, their game migrates or overwinters here. Indirectly, these people could suffer if LNG traffic disrupted marine mammal habits or altered their sea-ice habitat.

In March, or earlier, Resolute Inuit begin hunting caribou on W Somerset and Russell Islands and, to a lesser extent, E Prince of Wales Island. This hunting pattern requires extended trips across about 120 km of Barrow Strait sea ice. The collapse of caribou populations on most of the Queen Elizabeth Islands has forced hunters to abandon game areas on Bathurst and Cornwallis Islands. En route, they do not miss opportunities to shoot polar bears and ringed or bearded seals. Legally, the bear-hunting season extends from October 1 to May 31 and, since 1970, the annual quota for Resolute Bay residents has been 34 bears. Most polar bears are killed between February and May, after the coldest and darkest winter months have passed. Bear hunters travel by snow-machines throughout Barrow Strait and E Viscount Melville Sound, and as far as McDougall Sound, S Wellington Channel and N Peel Sound. However, most bears are killed at the Barrow Strait ice-edge, especially when the ice-edge stabilizes, temporarily, immediately south of Resolute village (Figure 16).

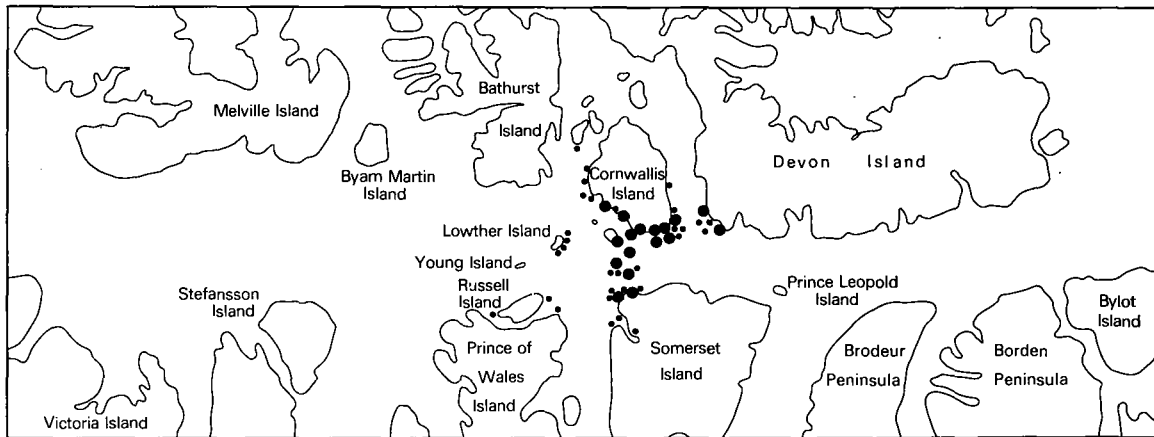


Figure 16. Known locations of Polar Bears kills by Inuit in central Parry Channel from 1968 to 1976 (from Stirling *et al*<sup>34</sup>).

The seal harvest occurs on the stable, relatively flat ice near Resolute Bay in winter and spring, but this changes as ice conditions differ. As mentioned above, many seals are killed by hunters en route to Somerset Island and Wellington Channel, but seal hunting is also popular in Allen Bay (east of Resolute Bay on S Cornwallis Island) and McDougall Sound<sup>59</sup>. Bearded seals are often shot when hauled-out on coastal sea ice in late May and June.

Inuit hunt white whales opportunistically near Resolute Bay, if herds happen to swim close to shore during their open-water migration. Walrus are hunted in certain locales in Penny Strait, around Crozier and Faring Islands, and along S Bathurst Island. Again, walrus are sometimes killed in conjunction with sealing and whaling trips in summer<sup>59</sup>.

It is unknown whether or not year-round icebreaking in Barrow Strait and E Viscount Melville Sound threatens or, in some cases, benefits Inuit hunting patterns and success. Regular and frequent icebreaker penetration east of Prince Leopold Island may result in later formation or promote earlier break-up of Parry Channel's fast ice than expected. This could cause the ice-edge to stabilize earlier and in a more western position near Griffith Island or, perhaps, even further afield, near Lowther Island. These circumstances would force hunters to seek more circuitous travel routes to Somerset Island to avoid the open water across Barrow Strait. Subsequent changes of seal and polar bear distribution and abundance may demand new hunting tactics, possibly in unusual locales.

The problem of crossing an icebreaker's path is probably not serious in early May, or earlier. The sea ice refreezes relatively quickly, in one or two days, to a thickness capable of carrying the weight of hunters and their snow-machines. Most open water patches will be temporary. However, the ice rubble left by the ship's passage may inconvenience travel by snow-machines, such that the hunters may have to search along the refrozen track for easy crossing places. In June, new icebreaker-tracks will probably not refreeze, and old tracks will probably melt early. This poses an open water obstacle.

Reactions of wildlife to winter icebreaking can only be imagined. For example, feeding seals may be attracted to the icebreaker's broken track, where thinner ice would ease their maintenance of breathing holes. On the other hand, the ship's noise may frighten breeding seals away from birth lairs and their pups. Polar bears may shift their seal-hunting patterns in response to the seals' movement, or the unusual displacement of the ice-edge itself. Ultimately, any deviation from the expected would be of concern to the Inuit hunter.

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