The Effects of Vessel Traffic in the Arctic on Marine Mammals and Recommendations for Future Research

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June 1983

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1186

…ment of Canada
…es and Oceans
Gouvernement du Canada
Pêches et Océans

Canadian Technical Report of Fisheries and Aquatic Sciences

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THE EFFECTS OF VESSEL TRAFFIC IN THE ARCTIC ON MARINE MAMMALS AND RECOMMENDATIONS FOR FUTURE RESEARCH

A Report Commissioned by
The Arctic Research Directors Committee
of the
Department of Fisheries and Oceans

and prepared by

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Cat. No. Fs 97-6/1186 ISSN 0706-6457

Correct citation for this publication:

Mansfield A.W. 1983. The effects of vessel traffic in the arctic on marine mammals and recommendations for future research. Can. Tech. Rep. Fish. Aquat. Sci. 1186: x + 97 p.

PREFACE

The Arctic Offshore Development Committee (ARCOD) of the Department of Fisheries and Oceans asked the Arctic Research Directors Committee (ARDC) for advice on the effects of vessel traffic in the Arctic on marine mammals. ARDC convened a working group, chaired by Dr. Arthur Mansfield. In the event, Dr. Mansfield prepared the report himself, but he received helpful advice and comments from J. Terhune, University of New Brunswick; R. I. Verrall, Defence Research Establishment, Pacific; L. J. Leggat, Defence Research Establishment, Atlantic; P. F. Brodie, Department of Fisheries and Oceans, Bedford Institute of Oceanography, and J. Percy, Department of Fisheries and Oceans, Arctic Biological Station.

As a guide to the form of report desired, the Arctic Research Directors posed four questions to which answers were requested. It was of course recognized that the answers would be incomplete, but the Arctic Research Directors desired to have the best information and judgements available in the light of present scientific knowledge. The questions were:

1. What is the scale and frequency of vessel traffic expected from the development and exploitation of mineral and hydrocarbon resources in the arctic in the foreseeable future (considered to be the year 2000)?

2. What are the most likely effects of this increased traffic on the marine biota (especially marine mammals)?

3. What is the likelihood of such effects causing changes in the behaviour and productivity of the marine biota, and how could this be distinguished from natural variability?

4. What kinds of research will need to be undertaken to answer the more important problems implied in the above questions?

It should be noted that the answers provided to questions 2 and 3 concern marine mammals only. Polar bears and birds are not discussed as they are properly the concern of the Department of the Environment and will be subject to a report by that department if deemed necessary. Fish and plankton and other components of the marine biota have been ignored because not enough is known, or likely to be known in the next few years, about their ecology and behaviour and how they would be affected by vessel traffic, a view also expressed by Smiley and Milne (1979) in their assessment of possible environmental hazards involved in the transportation of liquified natural gas in Parry Channel. The concern with marine mammals alone is considered justified in view of their primary importance to the Inuit economy and their high profile in any discussions on northern problems.

The report was drafted by Dr. Mansfield, submitted for criticism to various specialists named above, and finally accepted, after further amendments, by the Arctic Research Directors Committee of DFO. The committee thanks Dr. Mansfield for his work, and his advisors for their assistance, and is confident that the report will be useful to DFO and other organizations in the formulation of policies regarding the exploitation of resources in Arctic marine environments.

K. H. Mann

Chairman, Arctic Research Directors Committee

June 1983

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ABSTRACT

Mansfield, A.W. 1983. The effects of vessel traffic in the arctic on marine mammals and recommendations for future research. Can. Tech. Rep. Fish. Aquat. Sci. 1186: x + 97 p.

The proposed development of arctic offshore hydrocarbon resources will lead to a marked increase in vessel traffic, particularly in the southeastern Beaufort Sea and in the Northwest Passage from Amundsen Gulf to Davis Strait. This increase is best exemplified by the projected use of supertankers, which will cause unprecedented levels of disturbance from their year-round icebreaking activities and by the very high levels of sound produced underwater, principally by propeller cavitation.

The possible effects of such disturbance on the marine mammals that occur along the proposed tanker route are discussed, and recommendations are made for appropriate scientific research that will help to predict the outcome of such interactions.

Keywords: arctic, marine mammals, behaviour, acoustics, underwater sound, hydrocarbon (oil and gas) development, ships (supertankers), icebreaking.

RESUME

Mansfield, A.W. 1983. The effects of vessel traffic in the arctic on marine mammals and recommendations for future research. Can. Tech. Rep. Fish. Aquat. Sci. 1186: x + 97 p.

La réalisation des projets d'exploitation des ressources pétrolifères au large des côtes arctiques occasionnera une augmentation prononcée du trafic maritime, en particulier dans la partie sud-est de la mer de Beaufort et dans le Passage du nord-ouest, du golfe d'Amundsen jusqu'au détroit de Davis. Cet accroissement est illustré de manière exemplaire par l'utilisation projetée de superpétroliers. Leur activité de brise-glaces à longueur d'année et les niveaux très élevés de sons produits sous l'eau, principalement par la cavitation reliée à l'action des hélices, provoqueront des perturbations atteignant un niveau sans précédent.

Le présent rapport examine l'impact éventuel d'une telle perturbation sur les mammifères marins vivant dans les régions avoisinantes du trajet qu'emprunteront les superpétroliers. En plus, on y retrouve des recommandations formulées en vue d'initier des recherches scientifiques susceptibles d'aider à prédire les conséquences de telles interactions.

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1. INTRODUCTION

The continuing search for non-renewable resources such as base metals and hydrocarbons in the Canadian arctic, and the impending development of several major projects to exploit them have important implications for the Department of Fisheries and Oceans (DFO), which has responsibility for managing aquatic living resources.

The preparation of the Green Paper on Lancaster Sound (Dirschl 1982) presented an initial opportunity for DFO to provide a public statement on issues considered to be of importance to the Department's management responsibilities. A further opportunity to provide a policy statement was presented by recent hearings of the Special Committee of the Senate on the Northern Pipeline which concerned itself primarily with offshore transportation, particularly that involved with the Arctic Pilot Project and hydrocarbon development in the Beaufort Sea. The latest opportunity to present a departmental position paper has been afforded by recent publication of the seven volume environmental impact statement for hydrocarbon development in the Beaufort Sea - Mackenzie delta region (Dome Petroleum Limited, Esso Resources Canada Limited and Gulf Canada Resources Inc. 1982), now currently under review by the Beaufort Sea Environmental Assessment Panel.

The need for suitable Departmental statements to cover the above activities, and to provide input to such bodies as the Environmental Advisory Committee on Arctic Marine Transportation and future regional Land Use Planning boards, led to the request for a review of scientific evidence on the effects of vessel traffic in the arctic on marine mammals, as described in the preface. The present paper attempts to fulfil the latter requirement and follows the format adopted by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) in addressing the oil and fisheries issue on the east coast (Longhurst 1982).

2. SCALE AND FREQUENCY OF VESSEL TRAFFIC

As noted in the introduction, Lancaster Sound is linked to the Beaufort Sea (and indeed to the North Slope of Alaska; see Tikkoo 1980) as part of a projected Northwest Passage transportation route for the movement of oil and liquefied natural gas (LNG) to North American east coast and possibly European markets. Although the mining of base metals such as lead and zinc is occurring in the Lancaster Sound region, and the mining of iron ore will undoubtedly be undertaken when market conditions are right, the major volume of traffic will be involved with the movement of liquid hydrocarbons. Since much information is available about this phase of arctic marine transportation, it can be used as an appropriate example for discussion.

2.1 Transportation of LNG

A measure of the development in vessel transportation that is likely to occur is afforded by the Arctic Pilot Project. The APP was conceived in 1976 as a means of producing and processing approximately 7×10^6 m^3/day of natural gas from fields located on northern Sabine Peninsula, Melville Island, and transporting it by a 160 km pipeline to a liquefaction plant at Bridport Inlet on southern Melville Island. From there, two tankers with icebreaking capabilities would transport LNG through Lancaster Sound to an east coast port, with a round trip time of about 14 days in summer and 36 days in winter (Miller 1981).

The unique feature of the vessels involved in the Arctic Pilot Project will be their ability to operate all year round in ice covered waters. In order to move an anticipated cargo of about 140 000 m^3 LNG, the tankers will be very large, measuring 371 m in overall length, with a draft in ice of 13 m (Miller 1981). As originally designed, the tankers were to be equipped with engines capable of producing a maximum power output of 134 MW, or about 180 000 shaft horsepower (Miller *ibid.*), enabling them to move through ice 7 ft (2.1

m) thick at a speed of 4 knots (i.e. Arctic Ice Class 7 rating, as defined in the Arctic Shipping Pollution Prevention Regulations; see Dey 1981).

In their revised configuration, the LNG tankers will produce a maximum power output of 150 000 shaft horsepower (about 112 MW), but their more efficient design (see section 3.2.3) will enable them to proceed steadily through ice 10 ft (3.0 m) thick at a speed of 6 knots (Arctic Pilot Project 1982). By comparison, the specially ice-strengthened but otherwise conventional super-tanker 'Manhattan,' which was the first vessel of its class to sail through the Northwest Passage, had a maximum power output of 43 000 shaft horsepower, or 32 MW (Dome Petroleum Limited 1982), while the largest super-tankers afloat, the 'Batillus' class of 559 000 tonnes capacity, operate at a power output of 48.5 MW (Dome Petroleum Limited et al. 1982, Vol. 2, Table 6.3-1).

The Arctic Pilot Project is designed to test the technical and economic feasibility of transporting LNG from one gas field in the Arctic Islands to eastern North America, and is therefore of comparatively small scale. To exploit the full potential of the gas reserves in Sverdrup Basin would require many more vessels. Smiley and Milne (1979) estimate that 18 LNG tankers would be required, assuming that half of the possible reserves of 100 trillion cubic feet would be delivered in a period of 30 years. At this scale of development an LNG tanker would pass by Cornwallis Island about every 9-24 hours on average, depending on the season.

Transportation of LNG from the Beaufort Sea via the Northwest Passage will depend primarily upon market demand, full scale production being unlikely before 1992. If this method of transportation is preferred over transportation via the proposed Dempster Lateral gas pipeline, six LNG tankers would be required by 1992 with as many as 16 operating by the year 2000 (Dome Petroleum Limited 1981). These ships will be similar in size to the APP tankers but will apparently operate on a lesser power of 105 MW (Dome Petroleum Limited et al. 1982, Vol. 2, 6.3).

Transportation of LNG from the North Slope of Alaska through the Northwest Passage to east coast markets is also seen as a possibility by at least one firm of tanker operators, and has resulted in a proposal to build from 4 to 20 Arctic Ice Class 10 vessels of 125 000 or 165 000 m^3 capacity to transport the equivalent of up to 2 billion cubic feet of natural gas per day (Tikkoo 1980).

2.2 Transportation of Oil

One of the two major scenarios for energy production in the Beaufort Sea (Dome Petroleum Limited 1981) reveals a closely linked network of harbours, drilling/production islands, Arctic Production and Loading Atolls (APLAs), and a fleet of oil and possibly LNG tankers. The oil tankers will be vessels of 300 000 tonnes displacement, measuring 390 m in length and capable of carrying 200 000 tonnes of oil. They have been designed to an Arctic Ice Class 10 rating with a full power output of 112 MW (150 000 shaft horsepower), which should allow them to break through level ice up to 3 m thick at a speed of 6 knots. Based on the assumption that approval will be given for transportation of oil by tankers rather than by pipeline, 11 vessels will be needed for the first production phase from 1986 to 1991, and an additional 15 by the year 2000, bringing the total fleet to 26 oil tankers and production up to 1.25 million barrels per day (Dome Petroleum Limited 1981).

Transportation of oil from the Prudhoe Bay area of northern Alaska through the Northwest Passage to a trans-shipment terminal in Newfoundland has been proposed (Tikkoo 1980) and would require up to 24 icebreaking tankers of Arctic Ice Class 10 rating. Projected size of these vessels would be 350 000 tonnes displacement with a shaft horsepower of 280 000 (≈209 MW). Such power is equalled only by U.S. Navy aircraft carriers of the Enterprise class, which are currently the most powerful ships afloat (Dome Petroleum Limited et al. 1982; Vol. 2, Table 6.3-1).

If all these projected vessel operations for transporting oil and LNG were put into effect, then 104 super-tankers would be required. These would make the round trip to our east coast port in about 20 days in summer and 48 days in winter (these figures are based on the round trip times for the APP tankers operating from Bridport Inlet; see Miller 1981). Assuming that the vessels were regularly spaced during their voyages, this would mean that a tanker would pass any point on the route about every 2.3 to 5.5 hours, depending on the season.

2.3 Transportation of Other Commodities

According to a recent presentation by the Department of Transport to the hearings of the Special Committee of the Senate on the Northern Pipeline (Senate of Canada 1982), predicted vessel transits in the arctic in 1995 will be: 74 grain ships, 69 mineral ships, 208 supply ships, and 546 oil and gas tankers. Not all of these vessels will ply the Northwest Passage.

3. EFFECTS OF VESSEL TRAFFIC ON MARINE MAMMALS

Vessel traffic will affect marine mammals in two ways: by physically impinging on individuals, both in open water and while breaking ice, and by interfering with their sound production and hearing (see reviews by Busnel and Fish 1980, Herman 1980 and Norris 1969).

3.1 Direct Physical Effects

Very large tankers, with their combination of extreme size and speed in open water, can present a serious hazard for marine mammals in their path, particularly the slower moving baleen whales. An example of the level of mortality to be expected from collisions between ships and whales is shown in a study carried out in southern California during a period of nearly six years, from 1975 to August 1980 (Patten, Samaras and McIntyre 1980). In that time 14 collisions were recorded, 12 involving the slow moving gray whale Eschrichtius robustus. Eight deaths were attributed to these collisions, six of them gray whales. During the period 1975 to 1979, eleven strandings of gray whales were also recorded, two of which were caused by collisions.

It would be difficult to extrapolate from these figures, which represent an unknown proportion of the collisions of a fairly abundant species along a busy coast, to the situation in northern Canada where the population of the only large arctic whale, the bowhead, numbers several thousand in the Beaufort Sea (Breiwick, Mitchell and Chapman 1981) and only a few hundred in Baffin Bay and Lancaster Sound (Davis and Koski 1981); but occasional collisions might be expected. It is unlikely that these would be confined to debilitated or moribund animals, since evidence from the California study (Patten et al. ibid) suggests that most whales involved in collisions are normally healthy animals.

The LNG tankers could also exert detrimental effects on animals inhabiting close pack ice or fast ice. The species that would be most frequently encountered in the ice by tankers is the ubiquitous ringed seal Pusa (Phoca) hispida. During winter and spring, adults of both sexes are found scattered beneath the fast ice and more stable fields of offshore ice, in which they maintain breathing holes. Where snow drifts collect in hummocky ice and along pressure ridges, lairs are excavated in the snow above the breathing holes for resting and for protection from predators. In March or April the adult female gives birth to its whitecoated pup and nurses it for 6 to 8 weeks (McLaren 1958, Smith and Hammill 1981, Smith and Stirling 1975).

The quality of ice and snow cover is a primary determinant of ringed seal distribution, first year ice being chosen almost exclusively for occupation (Smith, Hay, Taylor and Greendale 1979; Smith and Hammill 1980a, b). In spite of the marked seasonal changes that occur in the distribution of first and multi-year ice in an area such as Parry

Channel (see Smiley and Milne 1979), it is possible to use available data on seal distribution to make some estimate of the physical damage likely to be caused by the passage of a supertanker.

The authors of the "Integrated Route Analysis" (Arctic Pilot Project 1981) have calculated that a maximum of about 1% of the ringed seal pups born in Parry Channel each year will risk being destroyed by the two proposed LNG tankers. Based on the observed densities of ringed seal birth lairs in Barrow Strait and the average extent of suitable fast ice for breeding in Lancaster Sound (Smith et al. 1979), this would represent between 65 and 530 pups. By comparison the recorded catch of ringed seals at Resolute, the only settlement involved in hunting in Barrow Strait, averaged 376 during the period 1962-1972 (Smith and Taylor 1977). The situation described is the most pessimistic since it is based on the assumption (1) that all pups less than 6 weeks old, occupying birth lairs in the path of the ship and up to one ship's width to each side, will be killed; (2) that 8 ship passages will occur during the nursing period; (3) that each ship passage will follow a different track; and (4) that available data accurately reflect the widespread low-density distribution of birth lairs.

It would be difficult to extrapolate this estimate to the situation where a hundred tankers or more might be plying the same route, but it could hardly be doubted that pup mortality would then be very high. However, even if it were high enough to reduce production of pups almost completely in the offshore ice of Parry Channel, it would have a much less drastic effect on overall pup production in this general region of the eastern arctic since an estimated 73% of pups are born in the inshore bays and inter-island channels (Smith et al. 1979).

The only species known to concentrate in offshore ice is the hooded seal *Cystophora cristata*, which forms a whelping patch in March just within the edge of the pack ice in Davis Strait, between latitudes 62°

and 64°N (Sergeant 1974, 1976a). This whelping patch, which varies in location from year to year depending on weather and ice conditions, was estimated to number between 34 000 and 42 000 animals in 1978 and 1977 respectively (MacLaren Marex 1979). Physical damage could be inflicted on the more concentrated parts of this whelping patch if a tanker were unable to avoid moving through them, though the looseness of the ice and the relative precocity of the newborn 'bluebacks' might enable most to escape.

Several other species are known to frequent the moving offshore pack ice, especially in southern Baffin Bay and Davis Strait in winter. The white whale *Delphinapterus leucas* and the bowhead whale *Balaenamysticetus* appear to prefer the looser ice, up to 75% cover, while the walrus *Odobenus rosmarus* and the narwhal *Monodon monoceros* are found in the closer pack. The two latter species occur in ice of up to 99% cover, but it is the narwhal in particular that inhabits the closest ice in the centre of Baffin Bay and Davis Strait, the walrus preferring the ice above the shallow offshore banks along the west coast of Greenland (McLaren and Davis 1981). Both species are widely scattered throughout their preferred areas and it is assumed that few would occur in the intended track of a tanker.

3.2 Effects of Noise

Ship noise could affect marine mammals in two ways: it could cause high levels of disturbance, which might result in detrimental changes in behaviour, and it could increase the ambient noise level to the point where vocalizations were masked, and communication and echolocation were interfered with. Both seals and whales use relatively low frequencies when vocalizing, which makes their inter-communications particularly prone to masking by the peak noise levels produced by the ships at these frequencies.

Since sound is so important to marine mammals, it is necessary to consider present levels of underwater noise and the changes to be expected with the introduction of icebreaking tankers. These levels can then be compared with the known hearing abilities of certain species to provide some idea of the effects that might be expected.

3.2.1 Measurement of underwater noise

The acoustic intensity of a sound wave underwater is related to the acoustic pressure (p), the velocity of sound (c), and the density of sea water (ρ) by

$$I = \frac{p^2}{\rho c} \qquad \text{(Urick 1975)}$$

Since intensity is not a directly measurable quantity, acoustic pressures are generally used when comparing sounds from different sources. Values can be measured by means of sensitive hydrophones whose voltage outputs are proportional to the pressure fluctuations.

3.2.1.1 Sound pressure level

Sound Pressure Level is the ratio between the acoustic pressure measured at the hydrophone and a reference pressure, currently one microPascal (1 μPa). Since changes in sound intensity can vary by 20 or more orders of magnitude, it is convenient to use a logarithmic scale to the base 10 to express this variation. The fundamental unit is the Bel, but the more convenient unit in general use is the decibel.

The general expression for the Sound Pressure Level in decibels is

$$\begin{aligned} SPL &= 10 \log (p/p_o)^2 \\ &= 20 \log (p/p_o) \end{aligned}$$

where p is the sound pressure measured at the hydrophone and p_o is the reference pressure of 1 μPa.

3.2.1.2 Source level

Since it is not always possible to measure acoustic pressure at a standard distance from the source of sound, it is necessary to construct a hypothetical value for source strength that will enable measurements made at a variety of distances to be compared. Source level, as usually defined, is the acoustic pressure that would be measured in an infinite body of water at a distance of one metre from the source of sound, considered as a point. The complete specification of source level includes the reference distance, thus:

dB re 1 μPa at 1 metre (Ross 1976)

3.2.1.3 Spectrum level

When dealing with single-frequency tonal components of underwater sound, spectrum level refers to the total acoustic pressure of the received signal. The situation is not so simple when dealing with broadband sources such as propeller cavitation noise since the measured level is then a function of filter width. However, if the distribution of energy in the measured band is relatively uniform, it is possible to calculate a value for the spectrum level equivalent to that produced by an ideal filter 1 Hz in width at the effective centre frequency of the band (Ross 1976). When calculated in this way, spectrum levels are conventionally expressed in the form

dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$,

or dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 metre if they are source levels.

To be rigorous, one should express spectrum levels as intensities rather than pressures. This is done in some texts, where they appear in the form

dB//1 $\mu Pa^2/Hz$

or dB//(1 $\mu Pa \times$ metre)^2/Hz,

both referred to 1 metre if they are source levels.

These terms are essentially interchangeable with the terms based on acoustic pressures.

3.2.1.4 Comparison of underwater noise levels with airborne noise.

As a means of mentally interpreting underwater noise levels, it is useful to consider a number of noises commonly experienced by humans

(Table 1). A healthy human ear can detect a minimum intensity of 10^{-12} watts per square metre in air and in water. Because of the difference in impedance (ρc) between air and water (1 to 3560; Kinsler and Frey 1962), the pressure required to produce $10^{-12} W/m^2$ of acoustic intensity in water will be about 60 times greater than that required in air.

$$I_{water}/I_{air} = \frac{(p^2/\rho c)water}{(p^2/\rho c)air} = 1 \text{ (for this example)}$$

$$p^2_{water} = \frac{p^2 air\ (\rho c) water}{(\rho c) air}$$

$$p_{water} = 59.7 \times p_{air}$$

$$SPL_{water} = SPL_{air} + 35.5 \text{ dB}$$

The threshold of hearing for humans in air, usually expressed as 0 dB re 20 μPa, will therefore be equivalent to 35.5 dB re 20 μPa in water, or 61.5 dB re 1 μPa. (For the above explanation, I thank L. J. Leggatt, Defence Research Establishment Atlantic, and J. M. Terhune, University of New Brunswick.)

3.2.2 Ambient noise levels

There are many sources of background noise in the sea, but most prevailing noise arises from pressure fluctuations induced by turbulence in shallow water, oceanic ship traffic, and surface bubbles and spray caused by wind and precipitation (Fig. 1). The ship traffic makes a significant contribution at frequencies below 200 Hz. Where a surface ice cover is present, wind induced noise is much reduced or absent and sound levels are generally much lower (Payne 1964). Even lower levels occur in the high Arctic where little ship traffic is encountered (Milne and Ganton 1964, Milne 1967). However in areas such as Baffin Bay where there is much ice movement, even in summer, noise levels can be surprisingly high (Fig. 2). Loud bursts of noise are also very likely, as exemplified by the noise of a rolling iceberg (115 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$, measured at a range of about 200 m -- Leggat, Merklinger and Kennedy 1981), and that of an actively forming pressure ridge (136 dB re 1 μPa/Hz$^{\frac{1}{2}}$ at 1 m -- Buck and Greene 1979, as reported in Arctic Pilot Project 1981).

3.2.3 Ship noise levels

When breaking ice the LNG tankers will undoubtedly increase noise from that source substantially, but probably no more than the noise levels already recorded for natural ice ridging (Buck and Greene 1979). It is assumed that marine mammals would not be seriously disturbed by this level of sound. More important is the level of sound produced by the vessel itself. Originally the tankers were to be powered by gas turbines providing a final electric drive to three fixed pitch propellers, 8 m in diameter (Miller 1981), but the revised design incorporates a mechanical drive to twin controllable pitch propellers enclosed in Kort nozzles. Each propeller will have four blades, 9.2 m in diameter, with a full-power rating of 75 000 shaft horsepower (56 MW) at 80 revolutions per minute (Arctic Pilot Project 1982). The maximum power output of 112 MW will enable the ships to move at a speed of 22 knots in open water and 6 knots when breaking fast ice 3 m in thickness (Dome Petroleum Limited et al. 1982, Vol. 2, 6.3). Although the propulsion machinery will produce a lot of noise, it will be masked by the noise produced by cavitation from the propeller blades and discrete tones produced by the frequency of rotation of the propeller blades. According to Ross (1981) about 80-85% of the noise power radiated into the water comes from propeller cavitation.

The spectrum of underwater noise radiated from the ship can be approximated by two straight lines. At low frequencies the spectrum is assumed to be flat, but at frequencies higher than the peak frequency, the spectrum decreases at a rate of 6 dB per octave (i.e. for every doubling of frequency) up to 10 kHz. Plots of the continuous source level spectra for four operating conditions of the modified design of tanker have been taken from the revised Integrated Route Analysis (Arctic Pilot Project 1982), and are shown in Figure 3. When compared with the estimated noise levels for the earlier tanker design (Leggat et al. 1981), it is evident that the new ship design will result in lower source levels at all frequencies.

Discrete tones produced by the frequency of rotation of the propeller blades are expected to reach levels of 200 dB and 178 dB re 1 μPa at 1 m in the full power mode in ice and at half power in open water respectively, but they will be confined to a narrow band at the fundamental frequency of 5.3 Hz, and its next two harmonics (Arctic Pilot Project 1982), and are therefore of lesser concern than the broad band spectrum of other sounds.

An important point to note is that the tankers will not be operating at full power the whole year round. About half the time will be spent in open water, much of that cruising at 17 knots at 40 percent power.Under these operating conditions the peak sound level will be decreased to 165 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m (Arctic Pilot Project ibid.). Since propeller cavitation noise levels are very dependent on blade size and speed, it is quite possible that conventional ships, when operating at full power, can make as much noise as, or even more noise than, a very large ship travelling at the same speed. According to Brown (1982) source levels estimated from data obtained for the Canadian icebreaker 'Louis S. St. Laurent,' a vessel of 14 000 tons and power output of 24 000 shaft horsepower, are greater than the source level estimates for the LNG tanker operating in open water at a similar speed (Fig. 4). At least two other conventional icebreakers currently in operation appear to be capable of making almost as much underwater noise at full speed in open water as the LNG tanker.

Some sounds have been recorded of smaller work boats attending drilling sites in open water. Ford (1977) estimated peak sound pressure levels of two tugs, each pushing a full barge, to be 164 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m, while Fraker, Green and Würsig (1981) estimated a possible range of 144-167 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m for the supply ship 'Canmar Supplier VIII.' Unfortunately no details of the propulsion systems of these vessels were given.

3.2.4 Sound propagation

Underwater sound radiating from a vessel will be attenuated by spreading, absorption by sea water, absorption by and reflection from the bottom, and reflection from the undersurface of ice. Initially,sound radiates spherically from the source; that is, the decrease in intensity is proportional to the square of the distance. This loss of sound energy can be expressed as:

$$L = 20 \log r \text{ dB}$$

where r is the distance in metres (Albers 1960).

The loss from spherical spreading for a few ranges is as follows:

Range (metres)	Loss in decibels
1	0
10	20
100	40
1000	60
10000	80

It can also be shown from the above equation that the loss fromspherical spreading is equal to 6 dB per distance doubled.

In arctic waters, the stability of the surface layer acts as a channel to confine the vertical extent of the expanding sound wave, resulting in so-called cylindrical spreading. Under these conditions, propagation losses are proportional to the linear distance; that is, 3 dB per doubling of distance. Cylindrical spreading also occurs in deep water, especially at lower frequencies (Greene 1981, Leggat et al. 1981, U.S. Naval Oceanographic Office 1965). Losses of sound from absorption by seawater are low, especially at low frequencies, but increase rapidly at higher frequencies (Figs. 6 and 7); values, according to Thorp (1965), are 0.08 dB/km at 1 kHz and 0.35 dB/km at 5 kHz.

In shallow water scattering losses by reflection from the water surface or the smooth underside of annual shore-fast ice are also low at low frequencies but may be significant at high frequencies, especially where the surface has been roughened by much ridging and rafting (Verrall 1981). Such losses are often higher than would be expected from spherical spreading as a result of the upward refraction of sound caused by the increase in speed of sound with depth, and repeated scattering at the ice surface (R. I. Verrall *in litt.*).

In the deeper water of Baffin Bay, sound will interact appreciably less with the surface, and the effect of ice roughness will be weakened. Generally, sound propagation losses were found to be low in Baffin Bay (Leggat et al. 1981), which probably accounts for the high noise levels observed (Fig. 2). Over the deeper central part of the bay, losses were about equal to the lowest losses recorded in the North Atlantic, the pronounced sound channel producing cylindrical spreading after approximately the first kilometre.

Increased propagation losses occur when sound, particularly at the lower frequencies, enters shallow water (about 200 m) and interacts with the bottom. Leggat et al. (1981) observed an additional maximum loss of 25 dB at 63 Hz when sound from a source 150 nautical miles away in Baffin Bay moved into the coastal area of NW Greenland. This observation has significance for those marine mammals which frequent inshore waters in summer.

The most recent method of estimating sound propagation losses for the proposed LNG tanker route is described in the revised version of the Integrated Route Analysis (Arctic Pilot Project 1982). A general purpose sonar model (GENERIC) developed by the U.S. Navy has been used, with some modifications, to predict transmission losses for the LNG tankers during summer and winter for a number of different conditions. The results show good agreement between the model and the predictions of Leggat et al. (1981) when the source of sound and receiver are at similar depths. When both source and receiver are nearer the surface, sound losses can be increased substantially by interference between the direct and surface-reflected sound, especially at the lower frequencies. This is the so-called Lloyd mirror, or image-interference, effect (Urick 1975).

3.2.5 Marine mammal hearing abilities and vocalizations

The underwater hearing abilities of only a few marine mammals have been measured (Johnson 1966; Schusterman, Balliet and Nixon 1972; Terhune and Ronald 1975a). Single animals isolated in small tanks are trained to respond to sound signals of various intensities over a wide range of frequencies. Results are used to plot underwater audiograms, as shown in Figure 5. The discrete separations of maximum sensitivity, optimum frequency and upper hearing limits depicted in the figure suggest that it may be reasonable to talk in terms of otariid, phocid and odontocete underwater hearing abilities (Terhune 1981). Certainly the audiogram of the white whale (White, Norris, Ljungblad, Baron and di Sciara 1978) fits this general picture. Unfortunately, but understandably, no audiogram is available for any baleen whale because all common species are too large for tank experiments.

The audiograms depicted in Figure 5 represent the threshold of hearing; that is, the lowest intensity of a pure tone at a particular frequency that an animal can hear (or, more accurately, will respond to) in a quiet environment. However, since the ocean is often a noisy place, the level of ambient noise is often louder than the threshold of hearing. Therefore, for an animal to communicate with one of its kind, its signal must usually be louder than the background noise at the particular frequency. The ratio of signal strength to the level of background noise, termed the critical ratio, generally increases with increasing frequency and has been estimated to vary from about 30 to 35 dB over the frequency range from 4 to 32 kHz for the ringed seal (Terhune and Ronald 1975b), and from about 22 to 40 dB over the frequency range from 5 to 100 kHz for the bottlenose dolphin (Johnson 1968, Terhune 1981). Thus if the background level of noise is 80 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 4 kHz, the threshold of detection of a pure tone at this frequency by a ringed seal will be 110 dB re 1 μPa. It has been speculated by Payne and Webb (1971) that baleen whales with their very large brains may be able to detect others of their kind when the calls are of similar intensity to the background noise, that is at a critical ratio of 0 dB, but there is no experimental evidence to support this assumption.

An important point to note is that a particular communication signal (considered here as a pure tone) is masked by only a narrow band of frequencies, the critical band, surrounding the tone (Johnson 1968, Scharf 1970). This suggests that the predominantly low frequency noise generated by ships will not prevent detection of the high frequency signals used in echolocation, but will interfere with the lower frequency sounds used in communication, especially the vocalizations of the bowhead whale.

Seals and odontocete whales use relatively low frequencies when communicating, but not when echolocating. In the ringed seal, vocalization occurs in the 0.5 to 6 kHz range (Stirling 1973). The bearded seal *Erignathus barbatus* emits a descending song that begins at 2-3 kHz and ends at 200-300 Hz (Ray, Watkins and Burns 1969). The walrus *Odobenus rosmarus* emits a variety of rasps, clicks and bell-like tones with frequencies from 200 to 1200 Hz (Schevill, Watkins and Ray 1966). Little is known of the vocal behaviour of the hooded seal, but underwater calls of adult males in the breeding season range from 100 Hz to 6 kHz, with most energy below 1.5 kHz (Terhune and Ronald 1973). The harp seal *Pagophilus groenlandicus* (=*Phoca groenlandica*) emits calls of a communicative nature between 125 Hz and 10 kHz, most of which lie below 2 kHz, and powerful short-duration clicks with maximum energy at 32 kHz (Møhl, Terhune and Ronald 1975).

The white whale is one of the most vocal of marine mammals and has a variety of social or communicative sounds: these include whistles, yelps and growls ranging from 250 Hz to 13 kHz, with most energy above 1 kHz (Fish and Mowbray 1962, Ford 1977). The average frequency of 35 social signals was found to be 3.85 kHz, with 40% containing frequencies below 2 kHz (Ford ibid.). The other types of sounds produced by the white whale are rapid series of short duration, transient pulses of sound energy or 'clicks' which are evidently used in echolocation. The most common types of click series have relatively slow repetition rates of 30 to 80 per second. Individual clicks range from 10 to 25 kHz in band-width, with a complete series usually sweeping cyclically from 2 to 75 kHz. Such click series are most likely used for analysing targets at short distances and therefore serve an orientation function. Other click series are more rapid, usually around 250 per second, with each click covering a broad band of frequencies from 100 Hz to about 75 kHz, the peak energy centering between 38 and 47 kHz (Ford ibid.). These clicks have been termed discrimination clicks in other odontocetes and serve for close-up acoustic investigation of targets (Norris 1969).

Available information on the narwhal indicates that narrowband pulses from 500 Hz to 24 kHz and pure tone whistles from 300 Hz to 18 kHz, with most less than 10 kHz, are emitted (Ford and Fisher 1978; Watkins, Schevill and Ray 1971). Narrowband clicks at repetition rates from 4 to 370 per second also occur, with most lying between 12 and 24 kHz, but some of the slower between 500 Hz and 5 kHz (Ford and Fisher ibid.). Frequencies over 24 kHz were not recorded owing to limitations of the equipment, but they undoubtedly occur in the click series and would be used for echolocation, as in other odontocetes.

The bowhead's vocal repertoire is quite different from that of the white whale, its range of sound production, principally 20 Hz to 2 kHz, falling within the louder part of the spectrum of sound produced by the vessels. Two major types of calls have been recorded: simple moans, which are frequency modulated tones ranging from 25 to 2000 Hz, with principal energy in the 100-300Hz band (Ljungblad, Leatherwood and Dahlheim 1980; Ljungblad and Thompson 1981; Würsig, Clark, Dorsey, Fraker and Payne 1982); and complex moans which are pulsive in character, with energy in a broad band of frequencies principally from

50-600 Hz (Ljungblad et al. ibid., Ljungblad and Thompson ibid.). Calls of both kinds last from 0.4 to about 4 seconds, with repetition intervals of 1.25 to 3.7 min. (Ljungblad and Thompson ibid.). Other calls recorded are the complex moans in repetitive sequences, unique to spring migrants, which are thought to constitute a simple type of song; and the high frequency calls (to 4 kHz) heard in the fall and likened to the trumpeting of elephants, or mewing of cats. The function of these sounds is not understood (Ljungblad and Thompson ibid.).

Little information is available on the intensities of the various sounds produced by arctic seals and whales. Watkins and Schevill (1979) estimated source levels for various harp seal calls to range between 135 and 145 dB re 1 μPa at 1 m. Wood and Evans (1980) found peak overall source levels for echolocation clicks of the white whale to lie between 160 and 180 dB re 1 μPa at 1 m. Although sound intensity levels for bowhead phonations have not been published, it has been suggested that they are as intense as the sounds produced by the southern right whale (Arctic Pilot Project 1981). Cummings, Fish and Thompson (1972) estimated the source level of one type of right whale sound to be 187 dB re 1 μPa at 1 m. Preliminary analysis of sounds from bowheads within 100 m of a hydrophone array indicates that the simple moans can have intensities at least as high as 176 dB re 1 μPa at 1 m (Arctic Pilot Project ibid.).

3.2.6 Potential masking effects of vessel noise

The estimated sound pressure levels to be expected at particular frequencies at various distances from the LNG tankers are contained in a series of tables in the revised version of the Integrated Route Analysis (Arctic Pilot Project 1982, Tables 3.2.3 to 3.2.14). Certain of the values have been transcribed into graphical form in Figures 6 and 7.

The masking effects of increased levels of underwater noise on most arctic marine mammals are hard to evaluate since little is known about the intensity of sounds produced by seals and whales, the distances over which they normally communicate, and the importance of particular frequency bands in communication. In spite of these limitations it is possible to obtain a rough idea of what the effects might be on several species.

3.2.6.1 Harp seal

In this species, perhaps the best known acoustically of the pinnipeds, communicative calls range from 125 Hz to 10 kHz, most of which occur below 2 kHz (Møhl et al. 1975, Watkins and Schevill 1979). Using 1 kHz as a representative frequency, it can be seen from Figure 5 that the pure tone threshold is 78 dB re 1 μPa. At this particular frequency, a tanker travelling at 17 knots in open water would first be heard at a distance of approximately 1 km in Baffin Bay and 4 km in Lancaster Sound (Fig. 6).

The masking effects of ship noise on seal communication can be estimated by subtracting the spectrum level of the ship plus the critical ratio at the appropriate frequency from the average source level of harp seal calls (140 dB re 1 μPa at 1 m). The resulting value in decibels can then be used to calculate the effective communication distance before masking occurs. Thus in Lancaster Sound, the 1 kHz spectrum level at 1 km from a tanker travelling at 17 knots in open water will be 83 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ (Fig. 6), and the critical ratio is 23 dB (Terhune 1981). A communicative call at this frequency and distance from a tanker will be 140 - (83 + 23) = 34 dB above the ambient noise. If the communicative sounds decrease by 6 dB per doubling of distance, they will travel about 50 m before being masked by the vessel noise. Similarly the communication distances at 10, 25 and 50 km from a tanker will be about 80, 650 and 1400 m respectively. These distances would remain the same for seals both close to the surface and at 20 m depth (Arctic Pilot Project 1982, Table 3.2.10).

3.2.6.2 Ringed seal

A different situation prevails for the ringed seal, particularly during the late winter and spring months when the fast ice is at its maximum thickness and LNG tankers would require their full power to move steadily through the ice at their optimal speed. Since vocalization in this species occurs in the 0.5 to 6 kHz range (Stirling 1973), the frequency of 1 kHz can be considered as representative and will aid in comparison with the harp seal. At this frequency the pure tone threshold is 75 dB re 1 μPa and the critical ratio is about 22 dB (Terhune and Ronald 1975a, b). From Figure 7 it can be seen that a vessel approaching at full power, breaking ice, would first be heard at about 40 km in Lancaster Sound in low ambient noise conditions. No information is available on the intensities of sounds produced by the ringed seal, but if it is assumed that they are similar to those of the harp seal, then the masking effect of the ships noise can be estimated. Communication distances at 1, 10, 25 and 50 km from the ship will be about 10, 50, 80 and 180 m respectively when seals are at 20 m depth, but will be roughly doubled when near the undersurface of the ice (Arctic Pilot Project 1982, Table 3.2.10).

Without further information on the behavioural context of particular vocalizations, it would be impossible to determine the effect that such widely audible sound would have on the ringed seal population of Parry Channel.

3.2.6.3 Bearded seal

The characteristic descending call of this species is probably used by males in territorial display. Unlike the ringed seal, the bearded seal is rarely found in the fast ice, its preferred habitat being areas of pack ice in which cracks and leads are frequent. Since no acoustical experimental work has been carried out on this species, it can only be inferred that its audiogram is similar to that of other phocids (Fig. 5). During late winter and spring, when ice is at its heaviest, the bearded seal would face the same problems confronting ringed seals; that is, sound levels affecting communications at distances of about 40 km from a tanker breaking through ice at full power.

3.2.6.4 Walrus

Like the bearded seal, the walrus is found in pack ice with frequent leads and cracks. Nothing is known of its auditory sensitivity, though one might expect it to be akin to that of its close relative, the sea lion, shown in Figure 5.

3.2.6.5 White whale

The most intense sound levels likely to be experienced by these highly vocal marine mammals will occur during their sojourn in the pack ice of Baffin Bay during late winter and spring when LNG tankers will be using full power to move ahead. At the average frequency of communicative sounds of 3.85 kHz, the auditory threshold is about 75 dB re 1 μPa (White et al. 1978). Using this value it can be deduced from Figure 7 that a tanker breaking ice at full power would first be heard at a distance of about 5 km. It is difficult to estimate what effect such increased sound might have on the ability of white whales to communicate with each other since nothing is known about the intensity of their calls. However it may not be important since white whales occur in very closely knit groups and there is no reason to assume that long distance communication is often used (Arctic Pilot Project 1981).

In July, August and September, when white whales move into Lancaster Sound, noise from the LNG tankers at 3.85 kHz will first be heard at a distance of about 1 km (Fig. 6) since the ships will be operating at reduced power levels. In the southeastern Beaufort Sea, the situation is complicated by the shallowness of the water, but field observations by Ford (1977) indicate that sounds originating from tugs pushing barges under full power, at estimated source levels similar to those of an LNG tanker travelling at 17 knots in open water (164 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m), are theoretically perceptible to white whales at ranges up to 4 km. However obvious reactions were not observed until the white whales were much nearer the source of disturbance. It should be noted that Ford (*ibid.*) considered only frequencies up to 2 kHz in his analysis since this was the dominant part of the noise spectrum produced by the tugs, dredges and various other components of the oil development activity. Sounds at the higher communication frequencies would have been perceptible to white whales at even shorter distances than 4 km.

At high frequencies, where echolocation is carried out, sound from the tanker will be attenuated rapidly, reaching the minimum ambient noise level in a few kilometres when the ship is under full power, and probably at distances below 1 km when the ship is in open water under reduced power (Arctic Pilot Project 1981).

3.2.6.6 Narwhal

Like the white whale, the narwhal spends the late winter and spring in the pack ice of Baffin Bay, where it prefers the heavier concentrations (McLaren and Davis 1981). It would be most vulnerable to noise at this time owing to the need for the tankers to use full power to move through the ice. However, without knowing anything further about the importance of particular frequencies, it would be difficult to estimate at what distance the sound levels of an LNG tanker might be disruptive. Until further evidence is available one might use the information for the white whale as a basis for discussion, but the range and structure of the calls are not readily comparable.

3.2.6.7 Bowhead

Vulnerability of this species will be greatest in the pack ice of Baffin Bay when the LNG tankers are producing maximum power. At a frequency of 100 Hz a tanker would just be heard at a distance of 300 km above the maximum ambient level of sound (81 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$) known to exist under arctic pack ice , while at 1 kHz it would still be heard at a distance of about 50 km above the maximum ambient level of 72 dB re 1 μPa/Hz$^{\frac{1}{2}}$ (Milne 1967).

Unfortunately nothing is known about the auditory sensitivity of bowheads at these low frequencies. However, if one assumes that the critical ratio at 100 Hz is similar to that for other mammals (about 20 dB; see Terhune 1981), and applies this value to the known intensity of the simple calls of bowheads, which are estimated to be as high as 176 dB re 1 μPa at 1 m (Arctic Pilot Project 1981), the masking effect of vessel noise can be calculated. At 1, 10, 25 and 50 km from a vessel in Baffin Bay breaking ice under full power communication distances would be about 450 m, 500 m, 1 km and 1.5 km respectively with the whale 20 m below the surface and about 800 m, 1.4 km, 4.0 km and 7.1 km respectively with the whale very close to the surface (Arctic Pilot Project 1982, Table 3.2.6). In open water in Lancaster Sound, communication distances at 1 and 10 km from a tanker travelling at 17 knots would be 500 m and 4.0 km respectively for a whale 20 m beneath the surface, and 1.4 and 32 km for a whale close to the surface (Arctic Pilot Project 1982, Table 3.2.7).

3.2.7 Potential effects of increased traffic frequency

The estimated distances at which an LNG tanker will be heard by various species of marine mammals can be used to estimate the periods of time that such sounds will be detectable. Since the animals most at risk from high sound levels are those that inhabit the fast ice (primarily the ringed seal) and the pack ice (bearded seal, walrus, narwhal, white whale and bowhead), the maximum speed of a tanker when in the icebreaking mode under full power is best used in the calculations.

The ringed seal will be able to detect the vessel up to at least 40 km away under low ambient noise conditions (see 3.2.6.2). Assuming that the track passes close to the animal in question, then the vessel will be heard while it progresses over a distance of 80 km. This will take approximately 7.2 hr at an icebreaking speed of 6 knots (11 km/hr).

After that the vessel will no longer be detectable. A similar assumption might be made for the bearded seal (see 3.2.6.3).

The white whale will be affected in much the same way, the tanker being detectable at distances within 5 km (see 3.2.6.5), or during a period of about 1 hr under the same conditions. Again, a similar assumption might be made for the narwhal (see 3.2.6.6).

The bowhead would be affected for a much longer period, since the 100 Hz spectrum level of the tanker would be detectable at 300 km (see 3.2.6.7). It would take 54 hr for the vessel's effect to be no longer discernible.

The above calculations suggest that under the conditions of a pilot experiment, with only two ships operating, all of the above species, with the exception of the bowhead whale, would experience short periods of increased sound levels, followed by comparatively long periods at the usual ambient noise level. However, at the full scale of development, with more than 100 tankers in operation (one every 5.5 hr in winter, see 2.2), continuous ensonification of the fast ice and pack ice environment would occur. The bowhead is in a demonstrably different position because of the long time during which a transiting vessel could be detected. A rough calculation shows that 11 tankers, equally spaced, could ensonify the bowhead's pack ice environment continuously, though different conditions would prevail in the open water period. In general the fluctuations in sound levels caused by the passage of LNG tankers through ice would depend on their number and spacing, it being assumed that the power output would remain constant. The effect might be minimized by convoying (Møhl 1981), but the implications are clear: increasing the number of tankers would result eventually in continuously elevated sound levels, though the actual level of sound experienced would depend on how close a particular animal was to a vessel's track.

3.2.8 Potential effects of continued exposure to high sound levels.

The very high sound levels that would be experienced by a marine mammal close to an LNG tanker under full power suggest that such an encounter could prove to be a painful experience, if not a damaging one. Noise at low frequencies, particularly below 200 Hz, can cause severe physiological effects in humans at high sound pressure levels. The effects range from the disturbance of hair cells in the inner ear, causing hearing impairment, to painful overloading of the middle ear and even rupture of the tympanic membrane; balance may also be affected by disturbance to the vestibular system (Møller 1981). Since the inner ear of marine mammals is basically similar to that of humans, similar effects might occur. The upper limit of sound intensity at low frequencies to which humans can be exposed for periods of up to a minute without physiological changes in hearing occurring is 120 dB re 20 μPa in air, a figure adopted in the United States as a guideline in the preparation of environmental impact statements (Gierke 1977, as quoted by Møller 1981). Although marine mammals produce sounds at slightly lower intensities than this, (for example, the bowhead's simple calls at 176 dB re 1 μPa at 1 m, which is equivalent to 114.5 dB re 20 μPa in air), it is not known if they could tolerate such sound levels continuously.

It has been pointed out by Norris (1981) that many mammals are known to have a middle ear reflex, in which the ossicular chain is thrown out of its normal path by the action of muscles in the middle ear. This reflex, which results in a reduction in sensitivity to sound, is caused by contraction of the tensor tympani and stapedius muscles and has been shown to occur in the harp seal (Møhl and Ronald 1975). How long a seal or whale could shut down its effective hearing at high ambient noise levels is unknown. Norris (ibid.) feels that a prolonged shut down of hearing might stretch the protective capacity of the system beyond its normal limits, since the middle ear reflex is usually used for brief impulsive sounds, and not for long sustained increases in ambient noise which are rare in nature. Clearly much more experimental work must be done before any firm conclusions can be drawn about the effects of continued exposure to high sound levels.

4. POTENTIAL CHANGES IN BEHAVIOUR AND PRODUCTIVITY OF MARINE MAMMALS

Marine mammals have evolved a thermally conservative body formsurrounded by a peripheral layer of fat (the blubber), which acts as an insulator and food store. Their comparatively large size results in a low specific metabolic rate and a large energy storage capacity, enabling many species to make extensive migrations into areas of intensive, seasonal food production. They also have capacious stomachs which allow them to ingest large quantities of food during periods of the day when prey are available in suitably dense and therefore economical concentrations (Brodie 1981).

Their often spectacular migrations have evolved to capitalize not only on marine production and concentration, but also on the nutritional value, or energy density, of the prey, which can fluctuate dramatically throughout the year. This is especially important to the newly weaned young, which must have catchable prey of high quality at this critical period of their lives (Brodie *ibid*.).

A further aspect of the thermally conservative nature of marine mammals is their behaviour during the calving or pupping period. Thus female white whales and their new born young seek out the shallow waters of estuaries in the summer where the warm surface layer of freshwater run-off, which may be 10-15° above the temperature of the underlying sea water, could provide a thermal advantage to both. This is analogous to the behaviour of pinnipeds which bear their young on land or ice, often in a sheltered micro-environment, and largely rest during lactation in order to conserve energy. Pinnipeds are often highly gregarious at this time, a habit that may have resulted from the need of some species to occupy island sites strategically placed near the most productive feeding areas. The inflexible nature of this habit, as exemplified by the northern fur seal Callorhinus ursinus (Gentry 1980), has left many species very vulnerable to intense exploitation and near-extermination by man.

Even though most marine mammals are opportunistic feeders, it is clear that it is not easy for them to change their feeding areas and migratory routes. Thus their behaviour, which may be interpreted as remarkable tolerance in the face of unusual disturbance, is probably better viewed as reaction to a situation in which they have little choice (Brodie 1981).

4.1 Normal Behaviour and Probable Reactions to Disturbance

Conducting research on the behaviour and acoustic abilities of marine mammals is a difficult task in the best of circumstances. Attempting to establish cause and effect relationships is a vastly more difficult undertaking owing to the problems involved in setting up an experimental situation in the field. Thus much of the available information on the reaction of marine mammals to ship traffic and its associated noise is largely anecdotal in nature, but it must suffice until the appropriate experiments have been performed. Generally speaking, more is known about the behaviour of pinnipeds than of cetaceans simply because pinnipeds must haul out on the land or ice to bear their young and moult, and they are therefore more easily observed.

4.1.1 Harp seal

This species, though congregating in very large numbers during the breeding and moulting seasons, is only a summer migrant to the arctic. The young of the year are usually solitary, but older immature animals and adults travel in small cohesive groups. They are highly mobile, as anyone who has observed their rapid, porpoising behaviour in open water can testify, and they are consequently difficult to hunt. This pattern of behaviour suggests that they could avoid LNG tankers quite easily while in the arctic and would therefore not be vulnerable to this kind of disturbance.

4.1.2 Ringed seal

In contrast to the harp seal, the ringed seal is a sedentary species, the adults of which spend the winter and spring beneath the fast ice. What little is known of their behaviour (Smith and Hammill 1980b, 1981) suggests that this habitat is partitioned into territories, individual animals being associated with a small number of sub-nivean lairs. Even though it is likely that the adults and possibly even all but the youngest pups can move from one lair to another in response to potential predation by polar bears, foxes and man, their range of movement must be much restricted by the disposition of territories. This will apply particularly to females with young, especially during the early part of lactation when the maternal bond is strong. Towards the end of the lactation period of about two months, and following mating, territories most likely break down, allowing wider movement of all seals under the ice. If the territorial partitioning of the under-ice habitat does restrict the movement of seals, then it is clear that destruction of the fast ice should be kept to a minimum by the re-use of vessel tracks whenever possible. In this way the least disturbance would be created.

The habit of occupying lairs may predispose the ringed seal to make increased use of them during the close passage of an icebreaking tanker, thereby mitigating or largely eliminating the effect of increased underwater noise. Whether seals would learn to do this is a moot point, however.

One advantage of the passage of an icebreaking vessel is that the track provides ringed seals with access to open water, though this may be short lived in cold weather when refreezing occurs quickly. It is likely that some seals would stay in the track since evidence available from a study carried out at McKinley Bay near Tuktoyaktuk (Alliston 1980) showed a significantly higher density of seal holes in a refrozen track of the icebreaker 'Canmar Kigoriak' than in the surrounding ice. However it should be noted that only two tracks were made during this study, one from 7-21 January and the other from 27 February-10 March. It is possible that if icebreaking traffic increased significantly in any area, ringed seals would abandon the construction of their sub-nivean lairs in the vicinity of the tanker route, but the extent to which this might occur would be impossible to predict.

4.1.3 Bearded seal

The bearded seal is essentially an animal of the pack ice and only rarely resides under the fast ice. On the evidence of its vocal repertoire, the bearded seal is most likely a territorial species, but almost nothing is known of its behaviour. Its preference for pack ice with frequent cracks and leads would enable it to move more freely than the ringed seal, suggesting that it could avoid undue disturbance by swimming away from the path of an icebreaking tanker.

4.1.4 Walrus

Unlike the solitary bearded seal, the walrus is a highly gregarious pinniped that exhibits marked thigmotactic behaviour, forming small closely huddled groups on ice floes or, in the summer, large concentrations at traditional hauling-out sites on the land. It is primarily a benthic feeder and is therefore generally found inshore or over shallow offshore banks, as in western Greenland (Vibe 1950, McLaren and Davis 1981). However, in winter, extensive fast ice may force it to remain over deep water, as in the North Water polynya where Finley and Renaud (1980) observed 700 individuals off southeastern Ellesmere Island in March 1979, in an area where water depths exceeded 200 m. During the summer at least a thousand animals in scattered groups are estimated to be present in the eastern high arctic (Davis, Koski and Finley 1978).

The walrus' preference for inhabiting pack ice of more than 75% coverage (McLaren and Davis 1981) suggests that individuals would have little difficulty in moving away from a passing tanker if alarmed. However, by entering the water they would then expose themselves to increased sound levels. Whether they would learn to mitigate unwelcome noise by remaining out of the water in such circumstances is unknown.

4.1.5 White whale

The white whale, like many other small odontocete whales, is a highly social species which forms compact groups at all times of the year; it is therefore, not surprisingly, a highly vocal species as well. Most populations undergo extensive migrations, the females and newborn young seeking out the shallow waters of estuaries in summer. At this time white whales are very vulnerable to exploitation by man, a situation that has resulted in the decimation of three local populations in the eastern Canadian arctic: those in Cumberland Sound (Brodie 1981b, Mitchell and Reeves 1981), Ungava Bay, and along the eastern coast of Hudson Bay (Finley, Miller, Allard, Davis and Evans 1982).

In the eastern arctic, the main wintering area of white whales is in Davis Strait, close to the West Greenland coast, where the animals are found within the edge of the pack ice, most frequently where the ice is open and coverage is between 26 and 75%. The whales do not appear to frequent the ice-free areas at this time of year (McLaren and Davis 1981). If the LNG tanker traffic is routed through the centre of Davis Strait it is unlikely to impinge on wintering white whales, but if any whales are found near enough to the tankers to be disturbed by excessive levels of sound they could probably easily move away from the path of an oncoming vessel. In the spring, when the animals are migrating into Lancaster Sound, they will be close to the tanker route and will have less room to move away from any disturbance. However, as already indicated in section 3.2.6.5, acoustic disturbance is likely to be less owing to the reduced power of the ships when operating in open water or loose ice. In the summer, when the whales are in shallow water, disturbance will most likely be negligible.

In the western arctic, the situation is different, since whales willmeet tankers only in the period from May to September at the termination of their migration into the southeastern Beaufort Sea and Amundsen Gulf. It is in this region that most of the research on the reactions to disturbance have been carried out. Fraker (1977a) was able to observe the reactions of a large group of adult females and young to the movements of a tug and barge through their area of congregation in Niakunak Bay in the Mackenzie Delta. Aerial surveysshowed that most whales up to 1.5 miles (2.4 km) from the vessels' track responded by swimming rapidly away from the disturbance, very few remaining within 0.5 miles of the vessels. The scattering effect on their distribution was obvious 3 hours after passage of the vessels, but 30 hours later the whales had returned to their near-original distribution. The uniformity and distance of this reaction suggest that the whales were responding to sounds (Fraker ibid., Ford 1977). However the range at which the whales were reacting (2400 m) was considerably less than the estimated maximum perception range of the sounds emanating from the tug (4000 m), suggesting that such man-induced sounds do not necessarily cause a reaction until the level of sound reaches a certain critical level (Ford ibid.).

Fraker (1977b) also observed another short term effect of disturbance, namely the impeding of movement of whales along one of their travel routes by frequent boat traffic. This occurred in 1976 when about 150 white whales remained northeast of Tuft Point on Tuktoyaktuk Peninsula for a period of about two weeks, when barge movements from the borrow pit at Tuft Point to the artificial island site Kugmallit H-59 numbered about 25 per day; but the whales left as soon as the movements ceased temporarily. Since whales do not usually remain in this area for such an extended period, Fraker hypothesized that they might have been prevented from moving past Tuft Point by the small air bubbles produced in the wake of the vessels, which would have provided an excellent target for the whales' echolocation system. Such an effect has been observed during the capture of spotted and spinner porpoises in the fishery for yellowfin tuna in the eastern tropical Pacific (Norris, Stuntz and Rogers 1978).

Other behavioural observations recorded by Fraker (1977a, b) and Ford (1977) show that white whales react more positively to moving sources of disturbance such as barges than to stationary ones such as dredges. However, it seems quite clear from the annual studies carried out on white whales in the Mackenzie estuary since 1972 that neither logistics traffic nor the construction of artificial islands has had any serious effects so far on the use of various areas by white whales or on the success of the whale hunt (Fraker 1977a, b; Fraker, Sergeant and Hoek 1978; Fraker and Fraker 1980). It seems far more likely that if any long-term disturbance does occur to a local white whale population, it will result from continued hunting activity (Sergeant and Brodie 1975, Fraker and Fraker 1980), which is probably a traumatic experience to those individual whales repeatedly exposed to it. Yet, all evidence shows that white whales maintain their migratory patterns and return to their traditional summering areas in spite of hunting activities that might lead eventually to their extermination (Sergeant and Brodie 1975; Brodie 1981; Mitchell and Reeves 1981; Finley et al. 1982).

It is difficult to extrapolate from the above situations involving relatively small vessels to the situations where very much larger and much more powerful icebreaking tankers will be present. When open water is prevalent, and the tankers can proceed at a much reduced power output, the production of sound will differ little from that of very much less powerful tugs operating at full power: 165 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m for the tankers at 17 knots compared to 151-164 dB re

1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m for the tugs pushing fully laden barges (Ford 1977). Other behavioural observations suggest that white whales can co-exist with large vessel traffic, as in the estuary of the Churchill River where large grain ships take on their cargoes (Sergeant and Brodie 1975), and in the estuary of the St. Lawrence River, where there is a constant stream of large vessels moving to and from ports in the Great Lakes. However in both areas the populations have declined ; in the Churchill River, presumably from hunting by Cree and Inuit residents; and in the St. Lawrence River, presumably from hunting and constant harassment by man, and possibly from changes in water temperature and patterns of freshwater discharge brought about by hydro-electric developments (Sergeant and Brodie 1975, Pippard 1980).

4.1.6 Narwhal

Unlike white whales, narwhals do not congregate in dense herds, though they often move in pronounced migratory streams involving the passage of several hundred animals per hour (Greendale and Brousseau-Greendale 1976, personal observation). They are essentially animals of deep water, inhabiting the denser pack ice in Baffin Bay in winter and spring (McLaren and Davis 1981) and migrating inshore to the fiords of Baffin Island and northwestern Greenland in the summer (Vibe 1950; Mansfield, Smith and Beck 1975). They are rarely found in shallow water unless avoiding pursuit by Inuit hunters (Finley, Davis and Silverman 1980). Narwhals possess a much less complicated vocal repertoire than white whales (Ford and Fisher 1978), though their acoustic abilities have not been as intensely studied. They are also much less tied by their behaviour to specific summering localities than are white whales, their distribution and movements at this season being much less predictable. As a consequence, narwhals have not suffered the serious over-exploitation by man that has occurred with several local white whale populations (Mitchell and Reeves 1981).

The main wintering area of narwhals is in Baffin Bay, from Davis Strait to as far north as 70°40'N, the limit of aerial surveys so far carried out. They reside almost exclusively in areas where the ice cover is greater than 50%, with highest densities occurring where the ice cover is 91-99% (McLaren and Davis 1981). The strong northward movement of narwhals observed at the northern limit of surveys in March suggest that other narwhals are also present further north inBaffin Bay at this time of year. Certainly by May, narwhals are widely distributed in pack ice as far north as 74°30'N, usually where the ice cover is greater than 75% (Koski and Davis 1979, Koski 1980). Since ice conditions in Baffin Bay in May are similar to those in March, it is possible that narwhals spend the winter in the pack ice throughout Baffin Bay (McLaren and Davis 1981).

Whatever the proposed winter routing of LNG tankers in Baffin Bay, the ships will occasionally encounter small groups of narwhals along or close to their tracks (McLaren and Davis ibid.). The animals will be most vulnerable at this time since the ships will be operating at full power. As indicated in section 3.2.6.6, not enough is known about the vocalizations of narwhals to estimate at what distances the maximum sound levels of LNG tankers might be disruptive. However, because of the narwhals' ability to exist in close pack ice, it is possible that they will not be much impeded in moving away from sources of disturbance.

Concern has been frequently expressed that the passage of an icebreaking vessel through very close pack ice or fast ice will induce narwhals to follow in its track, until they eventually became trapped. The basis of this belief lies in the natural entrapments or 'savssats' that occur occasionally (Porsild 1918) and the apparent determination with which narwhals migrate through decaying fast ice into the heads of fiords in the spring (Wilkinson 1956, personal observation). The ability of narwhals to exist in close pack ice (McLaren and Davis 1981) suggests that a ship's track would only be used if it offered relatively easy access to the air. Owing to the choking of the track with ice rubble from the ship's propellors (Alliston 1980) this situation would be unlikely to occur, especially in winter when refreezing is rapid.

When narwhals are migrating into Lancaster Sound in the spring, they will suffer the same constraints as the white whales: they will be close to the tanker route and will have less room to move away from the path of an oncoming ship. Generally, acoustic disturbance will be less at this time owing to the reduced power required when the tankers are operating in loose ice or open water, but high noise levels will occur when the ships enter the fast ice again. It is possible that the disturbance resulting from renewed icebreaking activity at the floe edge will cause narwhals to leave the immediate area and migrate into other fiords where there is no shipping activity. Such an event may have occurred in northern Baffin Island in 1980 and 1981 where supposedly unusual migrations of narwhals into Foxe Basin via Prince Regent Inlet and the Gulf of Boothia have been attributed to the icebreaking activities of the ore carrier M.V. 'Arctic' at the entrance to Admiralty Inlet (D. Kalluk _in litt_. 13 May 1982.).

Available catch statistics (Baubier, Bradley and Vestey 1970, Mansfield et al. 1975, Mitchell and Reeves 1981, B. Wong _in litt_.) show that narwhals were taken in the Igloolik area in 1953 (10), 1968 (10, including an unknown number of white whales), 1969 (30, including an unknown number of white whales), 1973 (10), 1979 (108), 1980 (11) and 1981 (53). The large catch in 1979 resulted primarily from a 'savssat' at Agu Bay, just west of the entrance of Fury and Hecla Strait, and another entrapment near Igloolik accounted for 7 in 1981. It thus seems that narwhals have been caught sporadically at Igloolik over many years, suggesting that the pattern of break-up of the ice in the Gulf of Boothia may be the primary factor in determining these fluctuations and not the recent activities of a single vessel.

When the narwhals move into the fiords, sound levels are likely to be quickly reduced by the complex coastal topography and comparatively shallow depths.

4.1.7 Bowhead

Like most baleen whales, the bowhead occurs in widely scattered small groups or as solitary individuals. The interesting possibility exists that, even though a number of animals may be spread widely over a large area, they may still form a coherent group since they appear to be able to communicate easily with each other by means of their powerful low frequency vocalizations via the so-called deep sound channel (Payne and Webb 1971).

Bowheads are large, slow-moving whales which feed on small planktonic crustaceans, primarily copepods and euphausids (Lowry and Burns 1980), filtered from the water by several hundred finely fringed baleen plates suspended from the palate. The leisurely progress entailed in their method of feeding (Nemoto 1970) has left bowheads particularly vulnerable to predation by man. Thus the population in Baffin Bay, thought to number about 11 000 in its pristine state (Mitchell and Reeves 1981), has been reduced to several hundred only (Davis and Koski 1980), while the population in the Bering Sea, probably numbering about 20 000 in its pristine state, is now reduced to an estimated 2700 (Breiwick, et al. 1981).

In view of their present low levels, the future of these two populations is uncertain. The eastern arctic population, though protected by Canadian law from exploitation, may still be suffering a small but significant mortality from shooting by Inuit (Mitchell and Reeves 1982). The western arctic population, which summers in the Beaufort Sea, is also protected from exploitation by Canadian Inuit but is subject to the traditional hunt of the Alaskan Inuit, under a quota imposed by the International Whaling Commission (Mitchell and Reeves 1980). Within the quota, the hunt is regulated by the Alaska Eskimo Whaling Commission (Anon. 1981).

In the eastern arctic the distribution of the bowhead is broadly similar to that of the white whale, but unlike the latter species the bowhead may spend the winter in open water south of the ice edge in Davis Strait, as well as in leads and cracks well within the pack ice where ice coverage may be as high as 99% (McLaren and Davis 1981).

In the spring the bowhead probably migrates through the more open pack ice in eastern Baffin Bay to the edge of the fast ice in Pond Inlet and Lancaster Sound, eventually moving into some of the fiords as the ice breaks up (Davis and Koski 1981).

In the western arctic, the spring movement northwards in April and May from the wintering area in the Bering Sea becomes a pronounced migratory stream along the northwest coast of Alaska. From Point Barrow, bowheads leave the coast and move through seemingly impenetrable pack ice to leads along western Banks Island and in Amundsen Gulf (Braham, Fraker and Krogman 1980). As ice breaks up in July and August, bowheads become more widespread in the southeastern Beaufort Sea, particularly in the area northwest of the Mackenzie Delta where the major oil exploration activities are occurring (Fraker and Bockstoce 1980).

Until recently most of what is known of the behaviour of bowheads was recorded in the 19th century by two of the most successful whaling captains, William Scoresby, Jr. (1820), and Charles W. Scammon (1874). Unfortunately, it is difficult to extrapolate their observations to the present situation since the whales were under the stress of pursuit by sailing ships and boats, though these were relatively quiet. This lack of useful information on the behaviour of bowhead whales has been partially remedied by a number of recent studies, principally those carried out in Baffin Bay by Davis and Koski (1980) and in the southeastern Beaufort Sea by LGL Ecological Research Associates (Richardson 1982). While the normal behaviour has been studied in great detail (Würsig et al. 1982), especially in relation to the distribution and abundance of food organisms (Griffiths and Buchanan 1982), the most important aspects of the work are the observations on bowhead phonations, already described in section 3.2.5, and the animals' reactions to disturbance by boats (Fraker, Richardson and Würsig 1982).

In the field experiments described, bowheads were seen to move away quickly from both a 16 m crew boat and a 60 m supply vessel when they approached within approximately 0.8 - 3.0 km of the whales. Some whales appeared to try and outrun the boats, but when overtaken they changed course at right angles to the boats' tracks. Disturbed whales spent significantly less time at the surface, blew fewer times during each surfacing and made briefer dives. They also became more widely separated. After the vessels had passed, the whales ceased to move away from the site of disturbance; but the increased inter-animal distances and the social interruption that this may have entailed persisted for at least an hour, or possibly several hours (Fraker et al. ibid.).

Much of the above observed behaviour was in response to noise levels that were generally lower than the levels expected from icebreaking tankers. However the large supply vessel produced its peak tone (56 Hz) at an estimated source level of between 144 and 167 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m, compared to the level of 165 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m expected for an icebreaking tanker moving through loose ice or open water under reduced power (Arctic Pilot Project 1982) and to the level of 164 dB re 1 $\mu Pa/Hz^{\frac{1}{2}}$ at 1 m estimated for a tug pushing a fully laden barge (Ford 1977).

What evidence there is from the reactions of other species of baleen whales to ship traffic is equivocal. There is one well documented instance of grey whales Eschrichtius robustus abandoning a nursery area in Guerrero Negro Lagoon, Baja California, following a marked increase in shipping traffic involved in transporting salt, but the whales returned to the lagoon in substantial numbers after shipping was eliminated (Gard 1974). Another lagoon was abandoned for several years following an increase in fishing boat traffic, but the total population of whales wintering in Baja California remained more or less stable during the period from 1956 to 1973 as other lagoons became more densely populated (Gard, ibid.). It seems clear from this example that gray whales in particular, and perhaps baleen whales in general, will readily move from one locality to another as a result of disturbance, but will not entirely vacate an area that supports an important activity of their life cycle.

There appear to be no other clear examples of baleen whales abandoning an area owing to heavy interference from human activities. Norris and Reeves (1978) cite one case of humpback whales Megaptera novaeangliae abandoning one of their wintering areas along the southeastern coast of Oahu in the Hawaiian Islands where there has been a drastic increase in boating activity, marine construction and siltation since the 1930's. However they caution that this apparent decline in numbers may relate to natural, long-term cycles, or to heavy whaling for humpbacks on the Aleutian grounds in the early 1960's rather than to this increased human activity. Nishiwaki and Sasao (1977) cite another case of what appears to have been a displacement by heavy marine traffic of minke whales Balaenoptera acutorostrata from the area around Yobiko in northern Honshu and of Baird's beaked whale Berardius bairdii, an odontocete, from the area east of Tokyo Bay. However, as Fraker et al. (1981) note, their conclusions are based on changes in catch-per-unit effort calculated from data obtained from different types and numbers of vessels fishing for different periods of time. As a consequence of so many variables, the data are difficult to interpret.

In contrast to the preceding examples, there is evidence to show that baleen whales in other areas become largely oblivious to human activities or may actively associate with them. Sergeant (unpublished

MS 1978) recorded personal observations of the capelin fishery off southern Labrador and Newfoundland in the 1970's, which supported an eastern European fleet of about 40 large factory trawlers and auxiliary vessels. In spite of the disturbance caused by this concentration of vessels, humpbacks, fin whales *Balaenoptera physalus* and minke whales were present in the general area, but only the humpbacks were seen in close proximity to the vessels that were actively fishing. The presence of whales among the fishing fleet could simply mean that both men and whales were exploiting the common food resource, the capelin, but Sergeant (*ibid.*) suggested that the humpback whales aggregated around actively fishing trawlers were probably making use of dead, injured, and disoriented fish that had passed through the meshes of the nets.

Following the rapid decline in the stocks of capelin off southern and eastern Newfoundland in the late 1970's, humpbacks began to pursue them inshore during their spawning migrations in spite of much coastal activity from small fishing boats. The inevitable result was that many whales became entangled in gill nets and traps, posing a social and economic problem for fishermen and increasing the mortality of the whales substantially. In 1981 the number of whale entanglements was much reduced, most of the humpbacks evidently remaining offshore where the capelin stocks had largely rebuilt (Whitehead and Lien 1982).

An example of the habituation of baleen whales to non-fishing shipping activities is described by Evans (1982). In Venezuela, Bryde's whale *Balaenoptera edeni* moves seasonally into the coast in pursuit of anchovy and herring. Frequently the whales are observed very close to the ferries (hovercraft, hydrofoils and conventional ships) that ply between Isla Margarita and the mainland. The ferries are large vessels that generate substantial levels of noise when loaded, but these do not seem to modify the feeding or migratory behaviour of the whales.

A final example is that recorded by Sears, Wenzel and Williamson (1981). They observed blue whales Balaenoptera physalus feeding intently in the shipping lane at Pointe des Monts in the estuary of the St. Lawrence River and showing little evasiveness in the presence of shipping (largely bulk carriers) at close quarters.

4.2 Potential Effects of Disturbance on Productivity

The foregoing observations suggest that it is unlikely that disturbance by vessels will cause either seals or whales to abandon large areas of their habitat, though their local distribution may change if disturbance is particularly intense. Even if it is accepted that the need of marine mammals to feed and to bear and care for their young in certain areas is of paramount importance and is, therefore, likely to continue no matter what disturbance ensues, the concern remains that some form of chronic stress may occur. This could result in a diminished reproductive capacity of the population, either through failure of normal mating behaviour, abortion, or decreased ability of parturient females to care for their young. This in turn could result in undernourishment of the young and subsequent retardation of their sexual maturity. It is possible that, even though disturbance from vessel traffic or hunting might be tolerated, the combined stress would be sufficient to cause the possible effects described.

As will be shown in the next section, such changes are occurring in marine mammal populations at the present time. It is necessary, therefore, to examine these changes to see if they are large enough to obscure the variation that might occur as a result of vessel traffic disturbance.

4.3 Natural Variability in Marine Mammal Populations

Apart from the harp seal, which has been subject to an intense and sustained fishery for two hundred years (Sergeant 1976b), and a continuing research program for at least 30 years, only the ringed seal has been studied for a long enough period for changes in population abundance to be detected. This has been well documented by Smith and Stirling (1978) and Stirling, Archibald and DeMaster (1977) who observed a large scale decrease in numbers of ringed seals and bearded seals in the southeastern Beaufort Sea and Amundsen Gulf between the years 1973 and 1975. Analysis of reproductive tracts showed a marked drop in pregnancy rates for the ringed seals (Smith and Stirling ibid.), but this could not account for the exceptionally large reduction in abundance between the two years. Stirling et al. (1977) postulated that severe ice conditions and heavy snow cover might have reduced the quantity of light transmitted through the ice to such an extent that production of phytoplankton and, subsequently, the invertebrates and fish on which ringed seals ultimately feed, could have been insufficient to support many local seal populations. It has also been postulated by Smith and Stirling (1978) that under these circumstances the adult male seals may have joined the immature seals on their migration to richer feeding areas in the Bering Sea, leaving the adult female seals unmated at the next conception time in early spring. Whatever the cause of this decrease in abundance of the ringed seal population, numbers had returned to an even higher level in 1978 than was recorded in 1974 (Stirling, DeMaster and Calvert 1980).

Although these observations were made only in the southeastern Beaufort Sea and Amundsen Gulf, it is possible that similar changes in populations can occur elsewhere. If this is so, it is difficult to see how one could attribute any changes in population numbers to the effects of vessel traffic without long-term monitoring of all the local ringed seal populations throughout the Northwest Passage, clearly a very difficult and costly task.

None of the other species of marine mammals, except the harp seal, has been investigated in sufficient detail to provide information on natural changes in population abundance and reproductive success.

Davis, Finley and Richardson (1980) have described at some length what needs to be known in order to be able to predict changes in population size and structure, but there are many difficulties to be overcome in obtaining good observational data, collecting adequate unbiased samples, and constructing meaningful population models.

It is instructive to compare this lack of information for most arctic marine mammals with what we have for the harp seal, a species that has been intensively observed, marked and sampled for over 30 years. However, in spite of the collection of ten or more thousand specimens, the tagging of many thousands of pups, the carrying out of a number of aerial surveys of both whelping and moulting herds, and the collection of reasonably accurate catch statistics, it is only in the last 5-10years that population models have been developed (Lett and Benjaminsen 1977; Winters 1978; Mohn 1979; Lett, Mohn and Grey 1981; Roff and Bowen 1981) that come close to dealing effectively with the many uncertainties in the data.

It is clear from these studies on the harp seal and ringed seal that unless one can sample a population adequately and calculate its size and natural fluctuations over time with some accuracy, it will be very difficult to predict the outcome of a change in man-induced mortality, whether imposed by hunting or by some perceived environmental stress.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

Since the output of high levels of sound is considered to be the characteristic of the icebreaking tankers most likely to affect marine mammals, a convenient way of considering the requirements for research is by utilizing the Source-Path-Receiver model adopted by the Acoustical Society of America (1981) in its study on the interaction between man-made noise and vibration and arctic wildlife.

5.1 The Source: Vessel Design and Sound Production

Whatever the results of experiments designed to test the effects of icebreaking tankers on marine ecosystems, it is clear that deleterious effects could be alleviated by reducing sound transmission levels. This should therefore be a major consideration of the designers and builders of such vessels. The matter is already being addressed since a change in the propulsion configuration of the LNG tankers has been proposed which would be much quieter than the original design (Arctic Pilot Project 1982).

Reassessment of the theoretical aspects of sound production by the LNG tankers suggests that earlier estimates by Leggat et al. (1981) were too high since no account was taken of the ability of the hull surface close to the propellers to deform slightly at the expense of acoustic pressure (Brown 1982). In order to resolve these differences between the several estimates of vessel noise levels, further acoustic data need to be acquired from icebreakers operating under a variety of conditions, particularly when putting out full power in the icebreaking mode.

5.2 The Path: Vessel Movements and Propagation of Sound

The major concern expressed over the operation of the LNG tankers is when they are in the icebreaking mode, particularly when working through fast ice. The problem relating to the occupation of ships' tracks by marine mammals is being addressed and should be continued, but another problem about which little is known is the effect of icebreaking on the disruption and movement of fast ice. This could conceivably change the local movements of migrating marine mammals, particularly in the spring when narwhals and beluga are concentrated along the floe edge in Lancaster Sound and Pond Inlet, but annual variations in ice cover and local climate would make prediction of effects difficult. Nevertheless a practical study relating ship movements, ice movements and local weather to marine mammal distribution might provide some useful answers.

As discussed in an earlier section, the sound production of icebreaking tankers is at its most intense when they are breaking ice under full power. Propagation of sound under the ice, especially in shallow water such as the Beaufort Sea, and in the medium depths of the confined channels of the Northwest Passage, needs to be more critically assessed. Ambient noise and propagation losses have also yet to be measured under the winter ice in Baffin Bay. The transmission of sound through the ice to the overlying surface needs elucidating in order to determine whether ringed seals will be able to mitigate the effects by remaining in their sub-nivean lairs. Further data are also required on the tendency of sound reflected from the sea surface to cancel sound propagated directly from the near surface source to the receiver; and also on the reduction in perceived sound level when a receiver (marine mammal) is near the surface, which acts as a pressure relief system. Since all marine mammals must spend time at the surface to breathe, it is possible that by doing so more frequently they might largely mitigate any untoward effects of high levels of underwater sound.

As Brown (1982) has pointed out, surface pressure effects were not taken into account in the calculations presented at the Arctic Pilot Project Workshop in Toronto (Peterson 1981), though they have been included in the ship source level estimates provided in the revised Integrated Route Analysis (Arctic Pilot Project 1982, Tables 3.2.3-3.2.14).

5.3 The Receiver: Marine Mammal Acoustics and Biology

In many ways this is the most difficult research task to accomplish owing to the practical problems involved in carrying out appropriate studies under field conditions and in obtaining sufficient data.

5.3.1 Sound production and reception

Much is now known of the range of sounds produced by arctic marine mammals since these can be readily recorded in the field. However the sensitivity of marine mammals to sounds, both biological and man-made, is known for only a few species and can only be elucidated by experimenting on captive animals. In the future we may well see audiograms obtained for the bearded seal, narwhal and walrus, in addition to those already produced for the harp seal, ringed seal and white whale, but nothing is likely to be learned of the bowhead whale in this respect.

Marine mammals, particularly the large whales, can emit sounds of surprising strength. More information on this aspect of sound production would help in assessing their ability to communicate with other members of their own species in the face of high background levels of noise.

Little is known of the informational content of those marine mammal sounds that are not used specifically for orientation and target discrimination. Among the pinnipeds, the bearded seal offers a good opportunity to begin such a study, especially in those local populations associated with fast ice, as in the western arctic. Perceived differences in the characteristic 'song' may provide clues to the distribution and behaviour of the territorial males which are believed to give vent to the sounds. Among the cetaceans, the white whale is the most vocal and most accessible to study in the wild. However its very accessibility makes it particularly prone to exploitation by man, and its gregariousness makes it difficult to study except in large groups. Fortunately most of the local populations in Lancaster Sound are not subject to human interference in their preferred summer inshore locations, which removes at least one difficulty from such studies.

5.3.2 Behaviour - seals

Much needs to be learned of the behaviour of all species of arctic marine mammals. Since the traversing of fast ice by the LNG tankers may be the most critical phase of their operation to marine mammals, more information on the distribution and site tenacity of seals under the ice is called for. Also, since the whelping and nursing period is probably the most vulnerable part of the life cycle of the ringed seal, it would be important to find out the strength of the bond between mother and pup, and whether it declines progressively or is maintained throughout lactation. If it were weakly developed, this could have serious implications for the populations wintering in the Northwest Passage and the Beaufort Sea, which would be directly exposed to the tanker traffic.

5.3.3 Behaviour - whales

Although some field experiments have been carried out on the reactions of white whales and bowheads to vessel disturbance, little is known about the behaviour of narwhals in this respect. While they actively avoid small craft during hunting, presumably learning to associate them with danger, it is not known if they would habituate to the sounds of large vessels moving on a steady course. Obviously much more behavioural work needs to be done on all three species before it will be possible to predict the effects of vessel traffic.

5.3.4 Population dynamics

As suggested in section 4.3, changes in distribution and productivity that might result from vessel traffic would be difficult to distinguish from those occurring as a result of natural events unless populations were monitored carefully over many years. This is a complex task which would require large resources to obtain the appropriate information (the Acoustical Society of America (1981) estimates $30 million over a 5 year period for an acoustical program in the Beaufort Sea connected with the bowhead whale), but some of the data will undoubtedly be collected in order to serve the needs of management of marine mammals as renewable resources. The importance of such information should need no emphasising.

6. SUMMARY

The preparation of the Green Paper on Lancaster Sound and the current review of the Environmental Impact Statement (EIS) for hydrocarbon development in the Beaufort Sea have provided the Department of Fisheries and Oceans (DFO) with the opportunity to prepare public statements on the important issues relating to management of living aquatic resources. In order to aid preparation of suitable policy discussion papers covering these and other related issues, the Arctic Research Directors Committee agreed to provide DFO's Arctic Offshore Developments Committee (ARCOD) with supporting scientific papers on the effects of oil on arctic fisheries and the effects of vessel travel in the arctic on marine mammals and other parts of the ecosystem. The present paper is an attempt to fulfil the latter requirement and follows the format adopted by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) in addressing the oil and fisheries issue on the east coast. Accordingly a number of similar questions were asked, the answers to which form the basis of the report.

1. What is the scale and frequency of vessel traffic expected from the development and exploitation of mineral and hydrocarbon resources in the arctic in the foreseeable future (considered to be the year 2000)?

Although the mining of base metals such as lead and zinc is occurring, and the mining of iron ore will undoubtedly be undertaken when market conditions are right, the major volume of traffic along the projected Northwest Passage transportation route will be involved with the movement of oil and liquefied natural gas (LNG).

A measure of the development in vessel transportation that is likely to occur is afforded by the Arctic Pilot Project. The unique feature of the two vessels involved in this project is their ability to operate all year round in ice covered waters. These very large LNG tankers will be capable of moving through ice up to 3 m thick at a speed of 6 knots.

To exploit the full potential of the gas reserves in Sverdrup Basin, 18 of these tankers will be required, and a further 16 tankers will be required to transport LNG from the Beaufort Sea if this method is preferred over transportation via a pipeline. If transportation of LNG from the North Slope of Alaska through the Northwest Passage to east coast markets should occur, up to another 20 icebreaking tankers will be required.

Transportation of oil from the Beaufort Sea will require similar sized tankers, each capable of carrying 1 500 000 barrels of oil; a total fleet of 26 oil tankers will be needed to bring production up to 1.25 million barrels per day. A further 24 icebreaking tankers will be required for transportation of oil from the Prudhoe Bay area of northern Alaska through the Northwest Passage.

If all these projected vessel operations for transporting oil and LNG are put into effect, 104 super-tankers will be required. Assuming that the vessels are regularly spaced during their voyages, this will mean that a tanker will pass any point on the route about every 2.3 to 5.5 hours, depending on the season.

2. What are the most likely effects of this increased traffic on the marine biota (especially marine mammals)?

Birds and polar bears were not considered as they are properly the concern of the Department of the Environment. Fish, plankton and other components of the marine biota were also ignored as not enough is known, or likely to be known in the next few years, about their ecology and inter-relationships and how they would be affected by vessel traffic. The concern with marine mammals alone is considered justified in view of their primary importance to the Inuit economy and their high profile in any discussions of northern problems.

Vessel traffic will affect marine mammals in two ways: by physically impinging on individuals both in open water and while breaking ice, and by interfering with their sound production and hearing.

Very large vessels could present a serious hazard for marine mammals in their path, particularly the slower moving baleen whales. It is impossible to predict mortality from this cause, though occasional collisions might be expected at the full scale of development.

The ships could exert detrimental effects on animals inhabiting close pack ice or fast ice. The species most frequently encountered in the ice would be the ubiquitous ringed seal Pusa (Phoca) hispida. Use of available data suggests that a maximum of about 1% of the ringed seal pups born in Parry Channel each year would risk being destroyed by the two proposed LNG tankers of the Arctic Pilot Project; this represents an estimated 65-530 pups. With many tankers plying the same route, pup production might be reduced almost completely in Parry Channel, but the overall effect in this region of the eastern arctic would be much less drastic since an estimated 73% of pups are born in the inshore bays and inter-island channels.

Several other species of marine mammals are known to frequent the moving offshore pack ice in winter and spring, but most are widely scattered and few animals would occur near the intended track of a tanker.

The enormous power of the proposed icebreaking tankers will introduce high levels of sound into the marine environment which could interfere with the ability of marine mammals to communicate. High sound levels might also affect the ability of the small whales to navigate and find their prey by their highly developed echolocation system.

When breaking ice the tankers will undoubtedly increase noise from that source substantially, but probably no more than the noise levels already recorded for natural ice ridging . It is assumed that marine mammals will not be seriously disturbed by this level of sound. More important is the high level of sound produced by the vessel itself, caused principally by cavitation from the propeller blades.

An important point to note is that the tankers will not be operating at full power the whole year round. About half the time will be spent in open water, most of that cruising at a much reduced power output, with a corresponding decrease in the level of sound produced.

Both seals and whales use relatively low frequencies when vocalizing, which makes their inter-communications particularly prone to masking by the high noise levels produced by the ships. The masking effects are hard to evaluate since little is known about the intensity of sounds produced by seals and whales, the distances over which they normally communicate, and the importance of particular frequency bands in communication. Several species are considered to be vulnerable. Ringed seals could be affected by sound up to a distance of about 40 km, but without further information on the behavioural context of vocalizations and on their intensity, it would be impossible to determine the effect that such widely audible sound would have on the ringed seal population of Parry Channel, for example.

White whales will likely experience the most intense sound levels during their sojourn in the pack ice of Baffin Bay during late winter and spring when LNG tankers will be operating at full power. At the average frequency of communication, sound from the LNG tanker will not be reduced to the whales' auditory threshold until a distance of about 5 km from the ship. At distances less than this, it is impossible to say what the effect of increased sound might be, but it may not be important since white whales occur in very closely knit compact groups and probably do not rely on long distance communication.

Little is known of the acoustic behaviour of the narwhal.

The bowhead is the whale species most likely to be affected by icebreaking tankers since most of the low frequency sounds it produces fall within the loudest part of the tankers' sound spectrum. Vulnerability will be greatest in the pack ice of Baffin Bay when the tankers are producing maximum power. At a frequency of 100 Hz a tanker would still be heard at a distance of 300 km above the maximum ambient level of sound known to exist under arctic pack ice.

Under the conditions of the Arctic Pilot Project, with only two ships operating, all of the above species, with the exception of the bowhead whale, would experience short periods of increased sound levels, followed by comparatively long periods at the usual ambient noise level. However, at the full scale of development, with more than 100 tankers in operation, continuous ensonification of the fast ice and pack ice environment would occur.

The bowhead is in a demonstrably different position because of the long time during which the lower frequencies emitted from a transiting vessel could be detected. A rough calculation shows that 11 tankers, equally spaced, could ensonify the bowhead's pack ice environment continuously. The effect might be minimized by convoying, but the implications are clear: increasing the number of tankers would result eventually in continuously elevated sound levels, though the actual level of sound experienced would depend on how close a particular animal was to a vessel's track.

3. <u>What is the likelihood of such effects causing changes in the behaviour and productivity of the marine biota, and how could this be distinguished from natural variability?</u>

Among the Pinnipedia, the ringed seal is probably the most vulnerable species because of its sedentary habit. What little is known of its behaviour suggests that the fast ice habitat is partitioned into territories, individual animals being associated with a small number of sub-nivean lairs. If this territorial behaviour restricts the movement of seals, then it is clear that destruction of the fast ice should be kept to a minimum by the re-use of vessel tracks whenever possible. One positive aspect of the movement of icebreaking vessels is that the track provides ringed seals with access to open water, though this may be short lived in cold weather when re-freezing occurs quickly.

The walrus might also be vulnerable since it is a highly gregarious pinniped that is generally found inshore or over shallow offshore banks, where it feeds primarily on benthos. Its preference for inhabiting pack ice of more than 75% coverage suggests that individuals would have little difficulty in moving away from a passing tanker if disturbance proved to be excessive. Unwelcome noise could be mitigated by remaining on the ice, but whether the walrus would learn to do this is unknown.

The white whale, is a highly social species which forms compact groups at all times of the year. In the eastern arctic, the main wintering area is in eastern Davis Strait where the animals are found within the edge of the pack ice; thus the LNG tanker traffic is unlikely to impinge on wintering white whales. In the spring, when the animals are migrating into Lancaster Sound, there is more potential for interaction with tankers, but disturbance is likely to be low owing to the reduced power of the ships when operating in open water or loose ice. In the summer, when the whales are in shallow water, disturbance will most likely be negligible.

In the western arctic, white whales will meet tankers in the period from May to September at the termination of their migration into the southeastern Beaufort Sea and Amundsen Gulf. Observed reactions to moving vessels in this area show that most whales swim rapidly away from disturbance, but return to their near-original distribution within 30 hours. However, frequent boat traffic can impede migration, possibly from production of a sonar-reflecting barrier of air bubbles in the wake of the vessels. Other behavioural observations show that white whales react more positively to moving sources of disturbance such as barges than to stationary ones such as dredges.

Neither logistics traffic nor the construction of artificial islands appear to have had any serious short-term effects on the use of various areas by white whales or on the success of the whale hunt. Whatever long-term disturbance might eventually occur will more likely result from continued hunting activity, which must be a traumatic experience to those individual whales repeatedly exposed to it.

It is difficult to extrapolate from the above situations involving relatively small vessels to the situations where very much larger and much more powerful icebreaking tankers will be present, but other behavioural observations suggest that white whales can co-exist with large vessel traffic, as in the estuaries of the Churchill River and the St. Lawrence River.

Narwhals are much less tied by their behaviour to specific summering localities than are white whales, their distribution and movements at this season being much less predictable. The LNG tankers will occasionally encounter small groups of narwhals along or close to their tracks. The animals are likely to be most vulnerable at this time since the ships will be operating at full power. However, because of the narwhals' ability to exist in close pack ice, it is considered unlikely that they will be much impeded in moving away from sources of disturbance.

Concern has been frequently expressed that narwhals will become entrapped in ships' tracks, this belief being based on the natural entrapments that occur and the narwhal's apparent urge to move through decaying fast ice in the spring. This is deemed unlikely to occur since ships' tracks are filled with ice rubble that would make access to the air difficult, especially in winter when refreezing is rapid.

A more recent and specific concern is that icebreaking activity at the edge of the fast ice in Admiralty Inlet has created enough disturbance to cause narwhals to move into Prince Regent Inlet, whence they have made unusual migrations to northern Foxe Basin. However, sporadic earlier catches at Igloolik suggest that changes in the pattern of ice breakup in Prince Regent Inlet and the Gulf of Boothia may be the causative factor, rather than the recent activities of a single icebreaking ore carrier.

The bowhead whale, like most baleen whales, occurs in widely scattered small groups or as solitary individuals. In field experiments conducted in the Beaufort Sea bowheads were seen to move away quickly from vessels when they approached within approximately 1.0 km of the whales, but after the vessels had passed, the whales ceased to move away from the area of disturbance. This observed behaviour was in response to noise levels that were generally lower than but, in one instance, similar to the levels expected from icebreaking tankers. Until further observations are made one can only speculate on what the effects of tanker traffic might be. Unfortunately, available evidence on the reactions of other species of baleen whales to ship traffic is equivocal.

The foregoing observations suggest that disturbance by vessels will cause neither seals nor whales to abandon important areas of their habitat, though their local distribution may change if disturbance is particularly intense. However, the concern remains that some form of chronic stress may occur, which could result in large scale changes in population size. Such changes occur naturally in marine mammal populations, (the ringed seal population in the southeastern Beaufort Sea and Amundsen Gulf, for example), and it is difficult to see how one could attribute changes in population numbers to the effects of vessel traffic without long-term monitoring of all the local ringed seal populations throughout the Northwest Passage. This would not be easy to accomplish considering the difficulties in obtaining good observational data, collecting adequate unbiased samples, and constructing meaningful population models.

It is clear from studies on the ringed seal and the better known harp seal that unless one can sample a population adequately, it will be impossible to predict the outcome of a change in man-induced mortality, whether imposed by hunting or by some perceived environmental stress.

4. What kinds of research will need to be undertaken to answer the more important problems implied in the above questions?

Whatever the results of experiments designed to test the effects of icebreaking tankers on marine ecosystems, it is clear that the designers and builders should attempt to produce vessels that will transmit the lowest levels of sound possible.

The major concern expressed over the operation of LNG tankers is when they are in the icebreaking mode, particularly when working through fast ice. The problem relating to the occupation of ships' tracks by marine mammals should continue to be addressed. Another problem about which little is known is the physical effect of icebreaking on the disruption and movement of fast ice. This could conceivably change the local movements of migrating marine mammals, but annual variations in ice cover and local climate would make prediction of effects difficult.

Propagation of sound under ice, especially in shallow water such as the Beaufort Sea and in the medium depths of the confined channels of the Northwest Passage, needs to be more critically assessed. Ambient noise and propagation losses have also yet to be measured under the winter ice in Baffin Bay. The transmission of sound through the ice to the overlying surface needs elucidating in order to determine whether ringed seals will be able to mitigate the effects of underwater noise by remaining in their sub-nivean lairs. Similarly the reduction in perceived sound levels close to the surface needs to be evaluated since all marine mammals must spend time at the surface in order to breathe.

The sensitivity of marine mammals to sounds, both biological and man-made, is known for only a few species and can only be elucidated by further studies on captive animals. Unfortunately nothing is likely to be learned of the bowhead whale in this respect.

Information on the strength of sound production of seals and whales would help in assessing their ability to communicate with other members of their own species in the face of high background levels of noise.

The informational content of marine mammal sounds that are not used specifically for orientation and target discrimination is largely unknown but the bearded seal offers a good opportunity to begin such a study, since perceived differences in the characteristic 'song' may provide clues to the distribution and behaviour of the territorial males which are believed to give vent to the sounds.

Since marine mammals are most likely to be affected by LNG tankers when in the icebreaking mode, more information on the distribution and site tenacity of seals under the ice is called for. Also, since the whelping and nursing period is probably the most vulnerable part of the life cycle of the ringed seal, it would be important to find out if the mother-pup bond is maintained so that desertion of pups would be minimal, even at high levels of disturbance.

Although some field experiments have been carried out on white whales and bowheads, the reaction of narwhals to vessel traffic is largely unknown. Though they avoid small craft during hunting, it is not known if they would habituate to the sounds of large vessels moving on a steady course.

Changes in distribution and productivity that might result from vessel traffic would be difficult to distinguish from those occurring as a result of natural events unless populations were monitored carefully over many years. This is a complex task which would require large resources to obtain the appropriate information.

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8. FIGURES

Figures 1-7

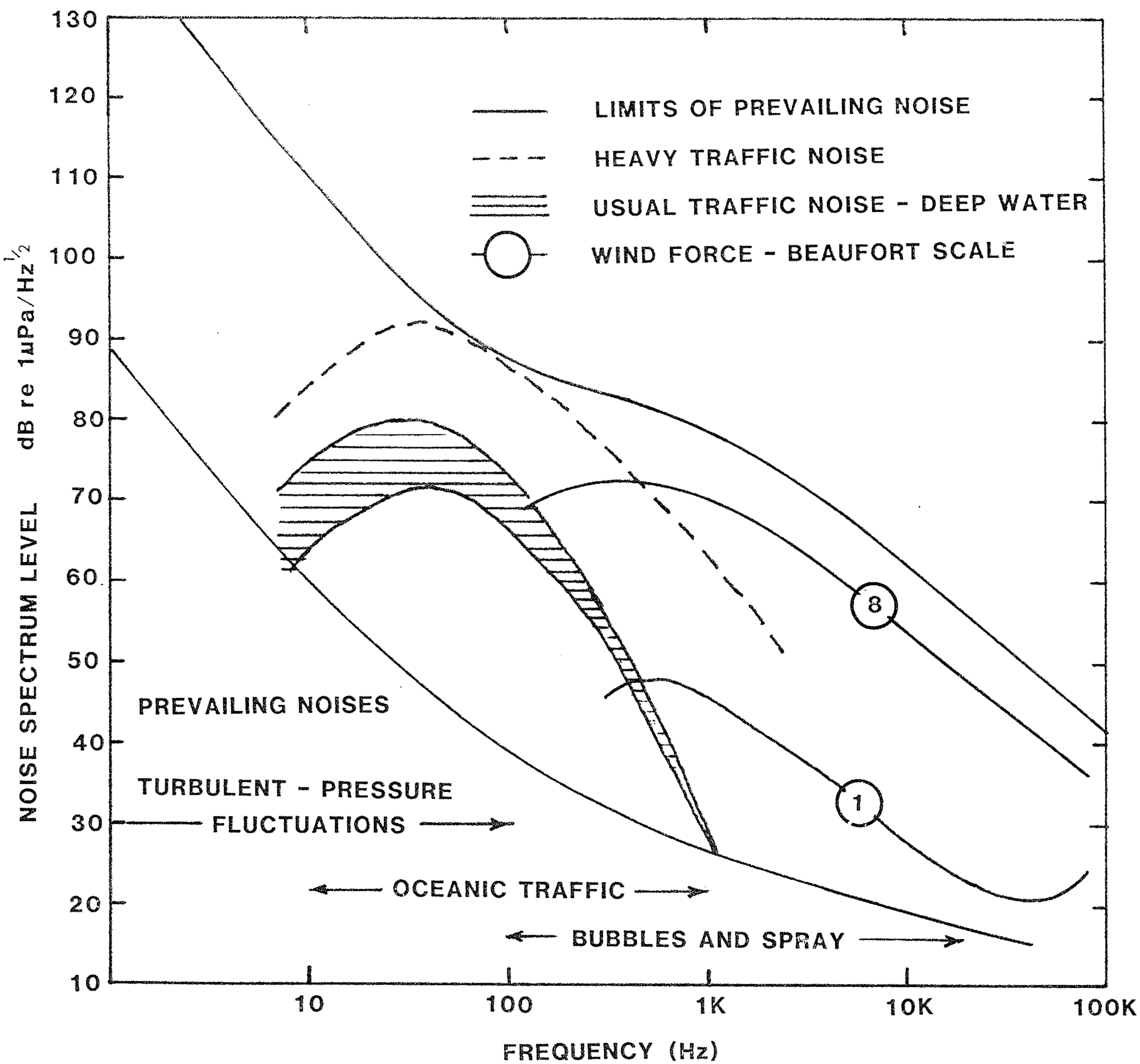


Fig. 1. A composite spectrum of ambient noise levels in the marine environment (modified from Wenz 1962).

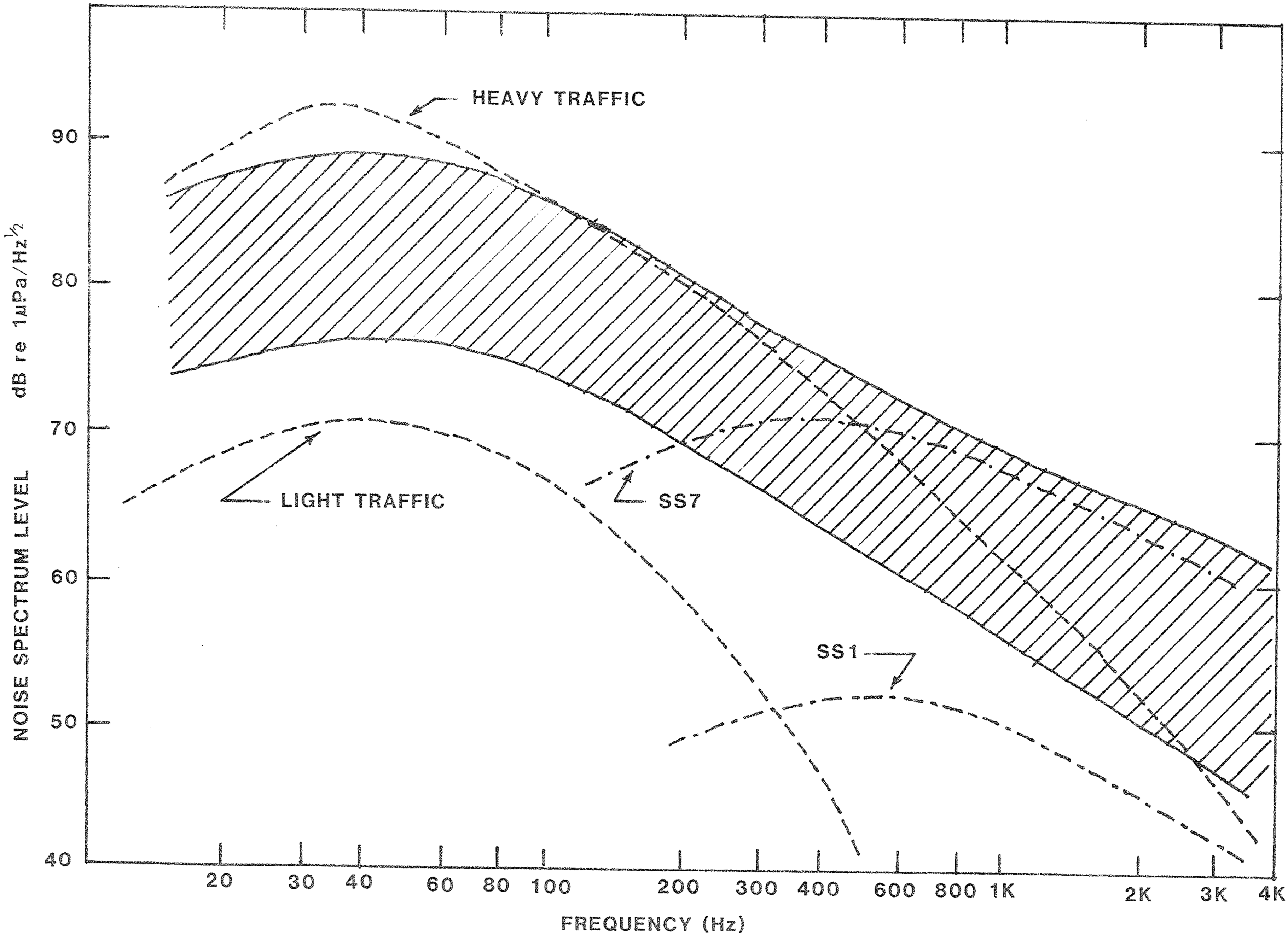


Fig. 2. Range of average underwater noise spectrum levels observed in Baffin Bay (shaded area) in the summers of 1972 and 1973 (after Leggat et al. 1981). Curves for light and heavy traffic, and sea states (SS) 1 and 7 are taken from Wenz 1962.

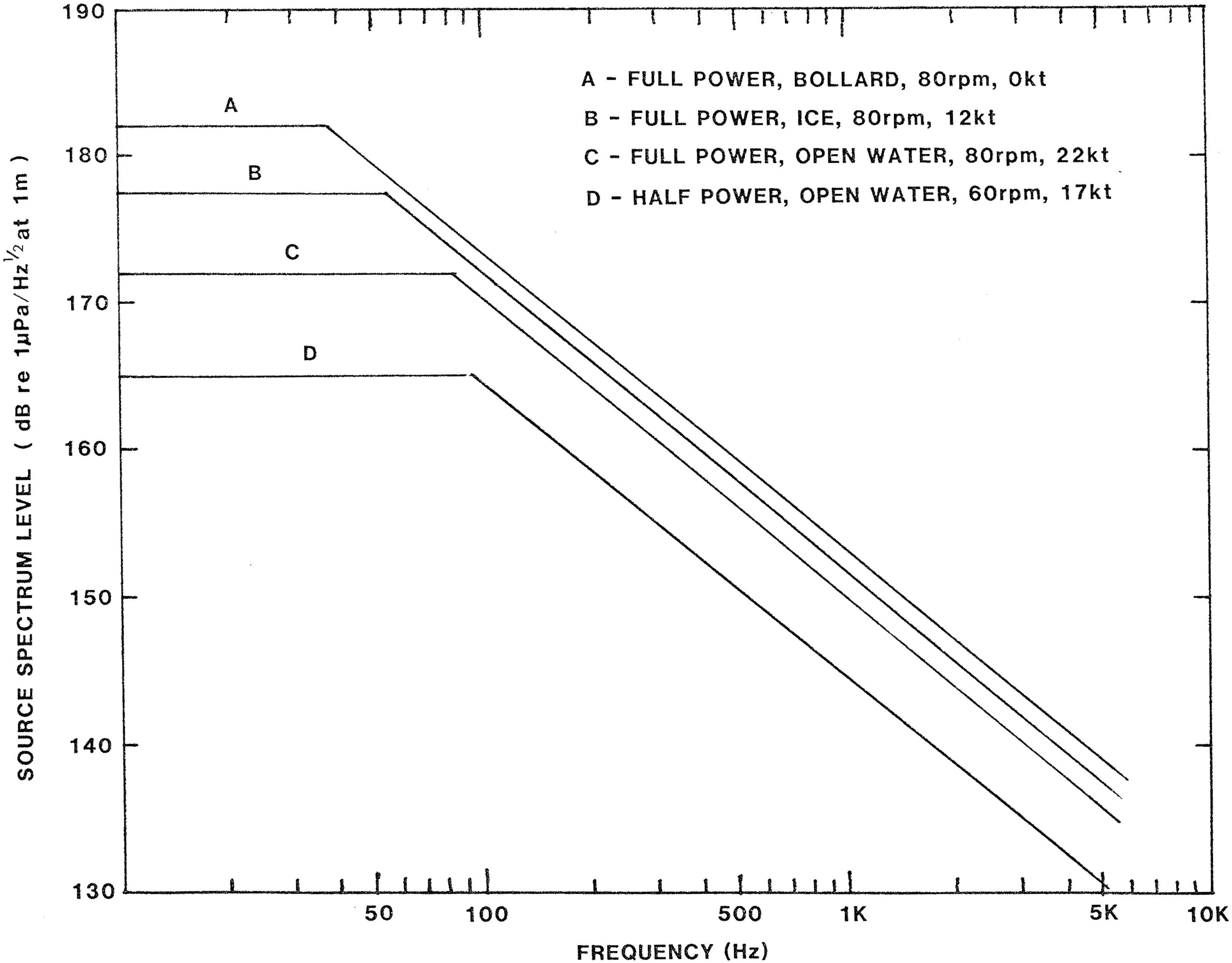


Fig. 3. Estimated source spectrum levels for the revised design of the proposed LNG tanker under various operating conditions (from Arctic Pilot Project 1982).

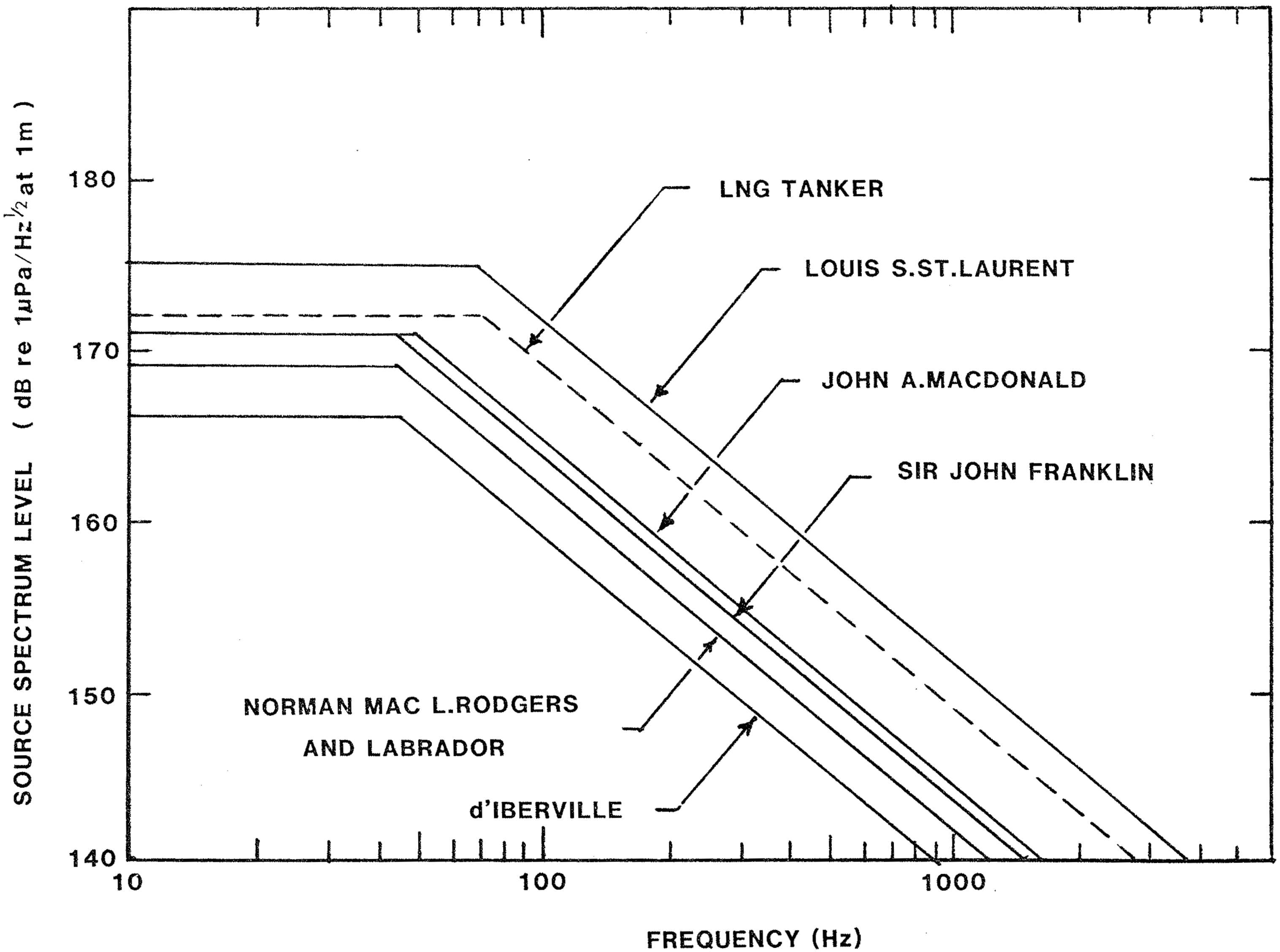


Fig. 4. Estimated source spectrum levels for six conventional Canadian icebreakers compared with the LNG tanker under full power in open water (from exhibit 673 to National Energy Board hearings, Ottawa, 5 July 1982; see Brown 1982).

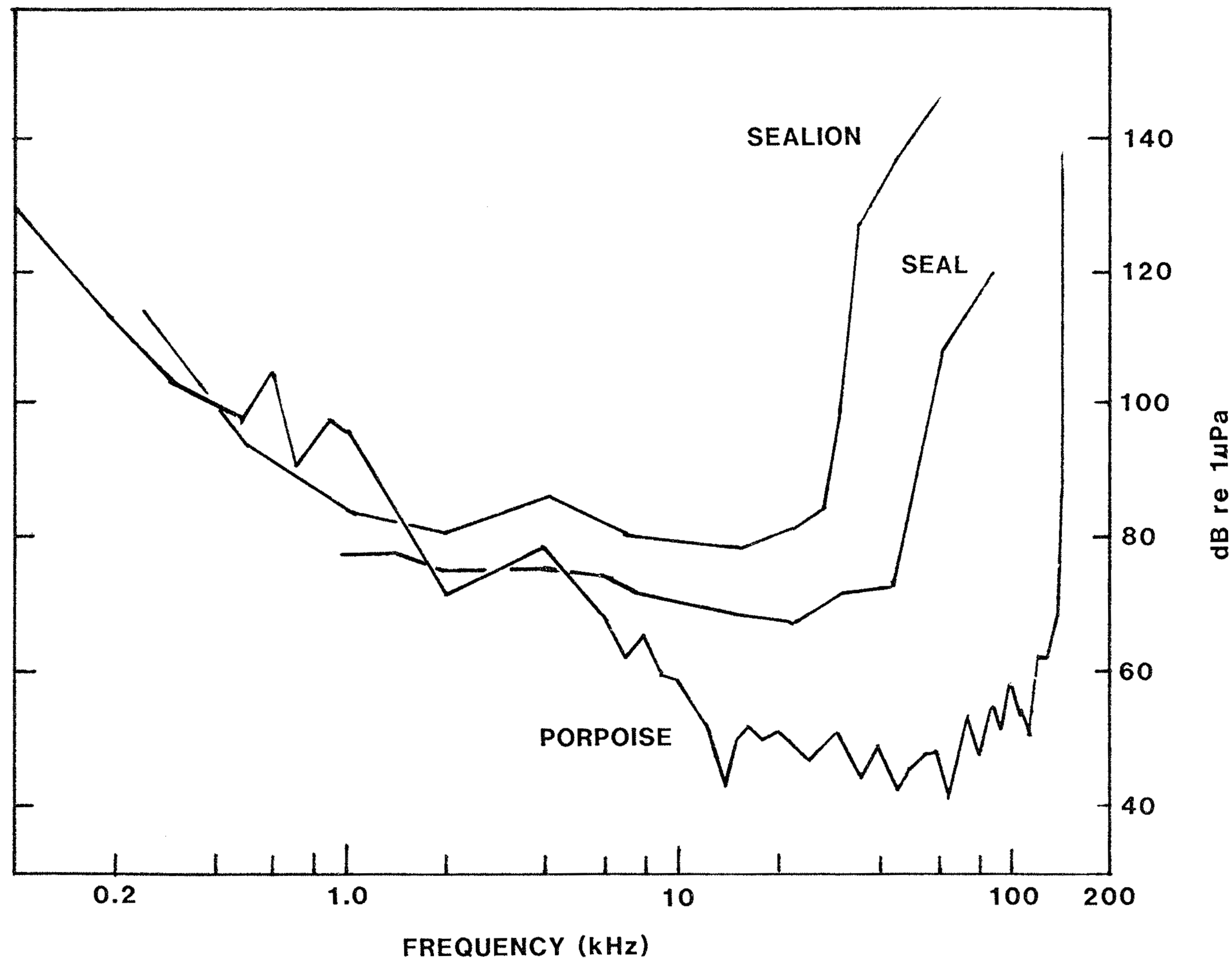


Fig. 5. Underwater audiograms of a sealion (Schusterman et al. 1971), several seals (Terhune and Ronald 1975a), and a porpoise (Johnson 1966).

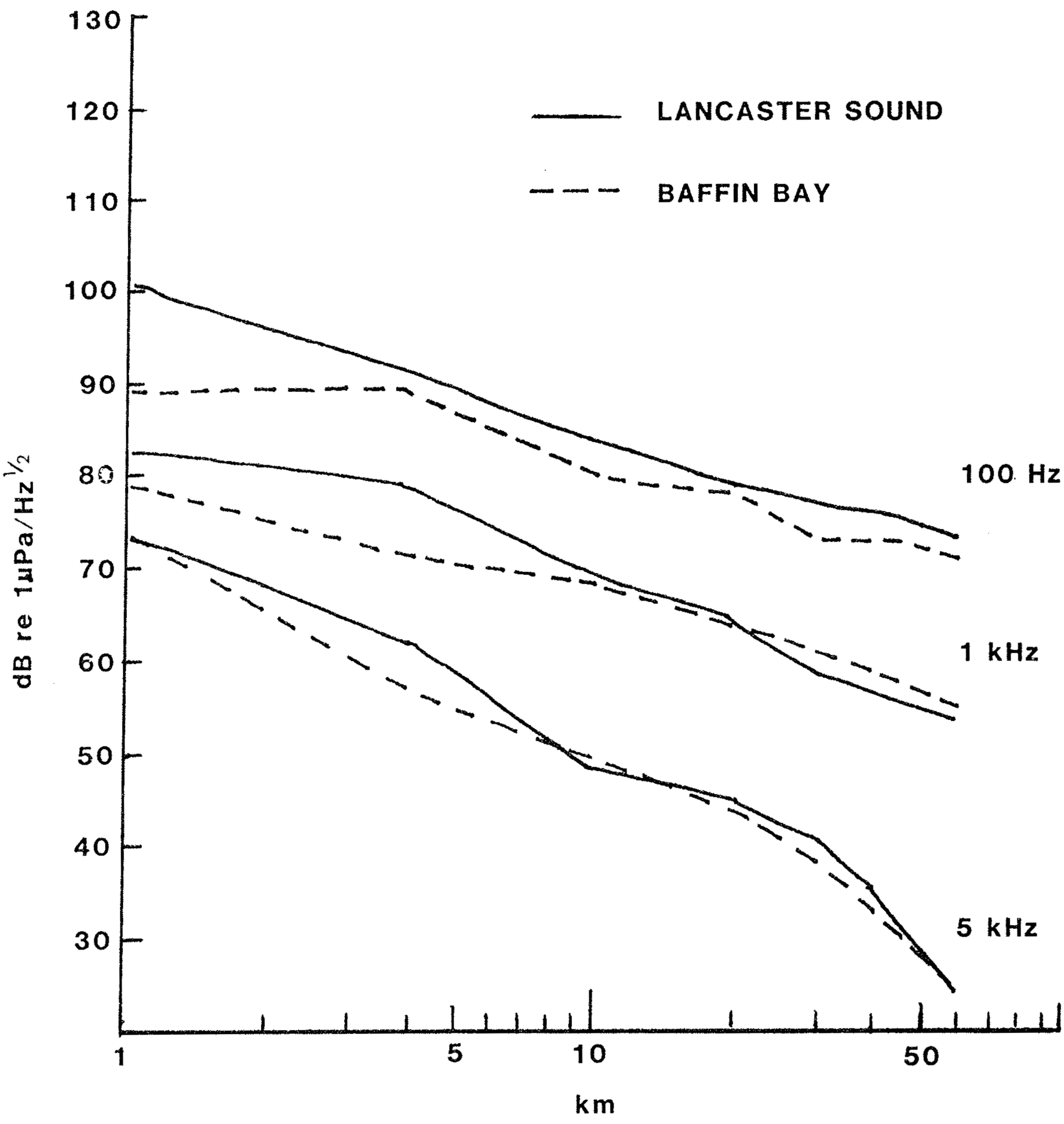


Fig. 6. Estimated sound pressure levels received at a depth of 20 m at various distances from an LNG tanker travelling at half power in open water (based on data from Arctic Pilot Project 1982, Tables 3.2.6-3.2.13).

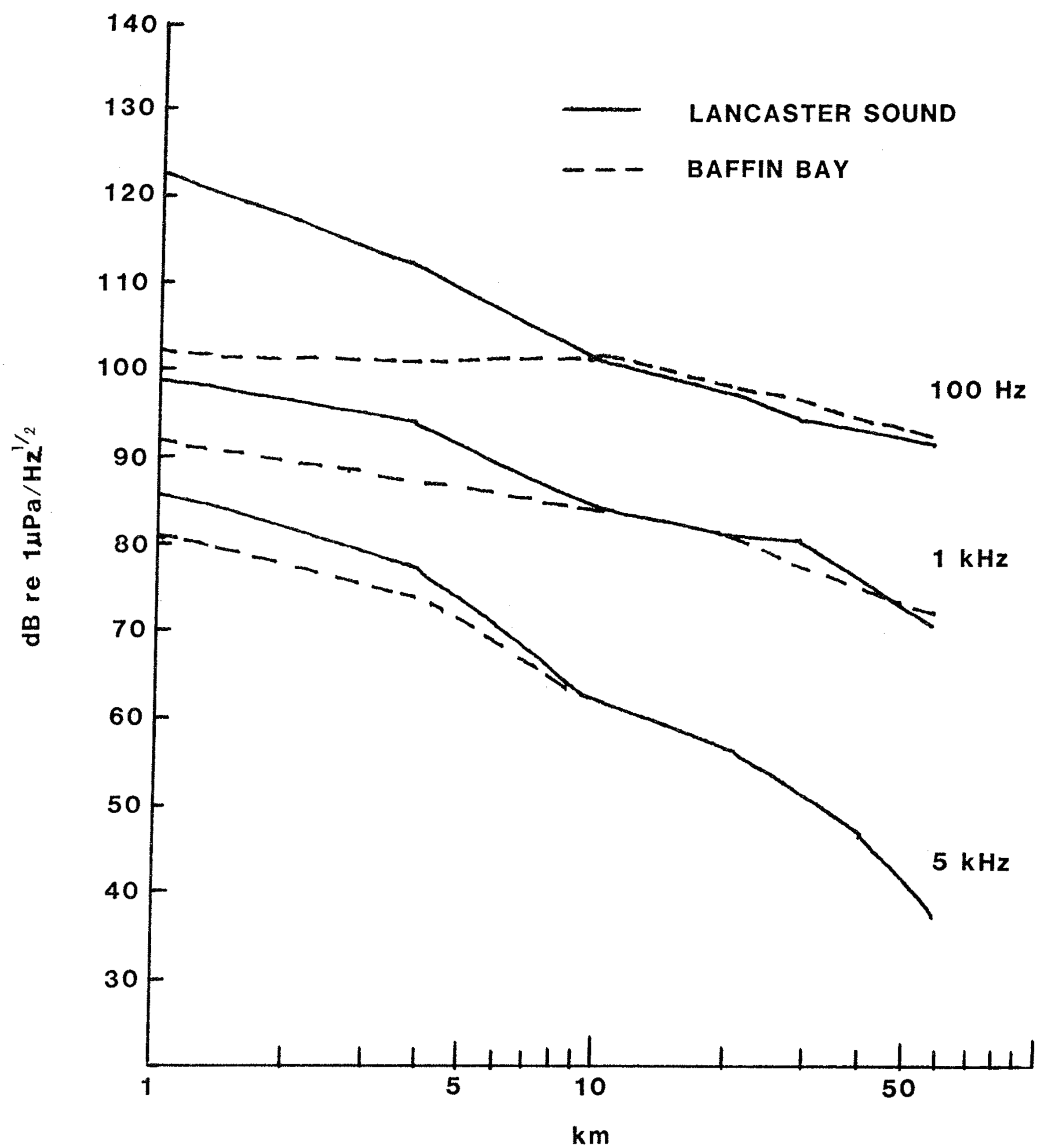


Fig. 7. Estimated sound pressure levels received at a depth of 20 m at various distances from an LNG tanker travelling at full power in ice (based on data from Arctic Pilot Project 1982, Tables 3.2.6-3.2.13).

9. TABLES

Table 1

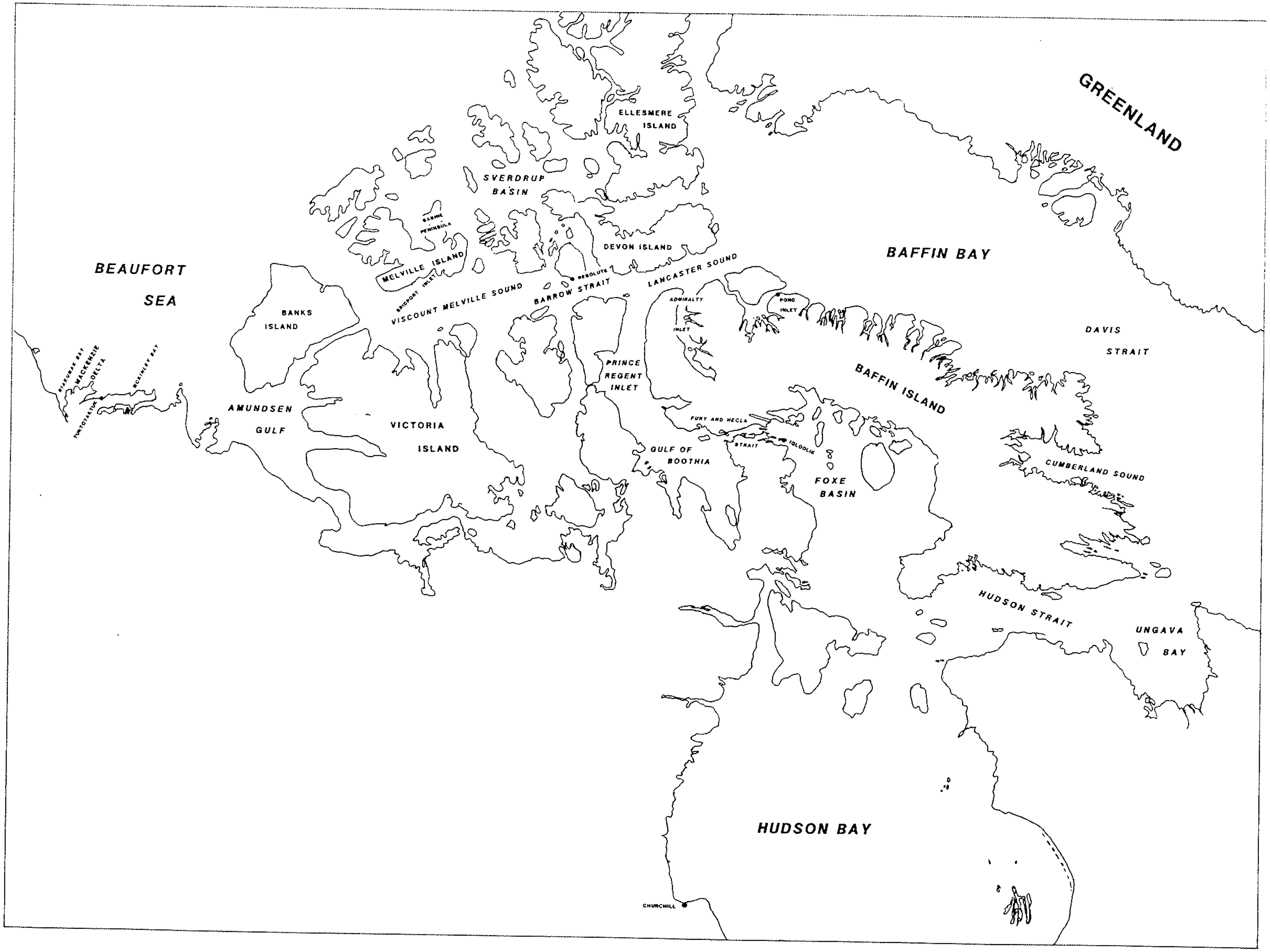
Table 1. Comparison of commonly experienced noises in air with marine mammal calls and lowest hearing thresholds under water (modified from Ginn 1978 and U.S. Naval Oceanographic Office 1965).

Air dB re 20 μPa		Water dB re 1 μPa	
160		221.5	
140	human pain threshold jet aircraft taking off	201.5	
120	pneumatic drill at operators position	181.5	bowhead whale calls
100	power mower or table saw	161.5	
80	inside car, heavy street traffic	141.5	harp seal calls
60	general office noise	121.5	
40	quiet living room	101.5	
20	rustle of leaves	81.5	sea lion hearing threshold
0*	normal human hearing threshold	61.5*	seal hearing threshold
-20		41.5	white whale hearing threshold

* equivalent to 10^{-12} watts/m^2

10. MAP

Place names in the Canadian arctic mentioned in the text.



GREENLAND
ELLESMERE ISLAND
SVERDRUP BASIN
SABINE PENINSULA
DEVON ISLAND
BAFFIN BAY
BEAUFORT SEA
MELVILLE ISLAND
BRIDPORT INLET
RESOLUTE
LANCASTER SOUND
BARROW STRAIT
VISCOUNT MELVILLE SOUND
BANKS ISLAND
ADMIRALTY INLET
POND INLET
DAVIS STRAIT
MACKENZIE DELTA
TUKTOYAKTUK
PRINCE REGENT INLET
BAFFIN ISLAND
AMUNDSEN GULF
VICTORIA ISLAND
FURY AND HECLA STRAIT
IGLOOLIK
GULF OF BOOTHIA
FOXE BASIN
CUMBERLAND SOUND
HUDSON STRAIT
UNGAVA BAY
HUDSON BAY
CHURCHILL