Possible Impacts on Overwintering Fish of Trucking Granular Materials Over Lake and River Ice in the Mackenzie Delta Area

D. B. Stewart

FJMC

CANADA/INUVIALUIT
FISHERIES JOINT MANAGEMENT COMMITEE
TECHNICAL REPORT SERIES

Possible Impacts on Overwintering Fish of Trucking Granular Materials Over Lake and River Ice in the Mackenzie Delta Area

D. B. Stewart[1]

Canada/Inuvialuit Fisheries Joint Management Committee
Suite 201 – 107 Mackenzie Road
PO Box 2120
Inuvik, NT, Canada
X0E 0T0

Fisheries Joint Management Committee
Report 2003-1: v + 12p.

[1]Arctic Biological Consultants
Box 68, St. Norbert Postal Station
95 Turnbull Drive
Winnipeg, Manitoba
Canada, R3V 1L5

ISSN 1709-7738

Correct citation for this publication:

Stewart, D.B. 2003. Possible Impacts on Overwintering Fish of Trucking Granular Materials Over Lake and River Ice in the Mackenzie Delta Area. Canada/Inuvialuit Fisheries Joint Management Committee Report 2003-1: v + 12 p.

TABLE OF CONTENTS

ABSTRACT
In May 2001, the Fisheries Joint Management Committee (FJMC) received copies of proposals by Petro-Canada to quarry sand and gravel from the Swimming Point and Devil's Lake areas of the Mackenzie Delta. Much of the quarried sand and gravel was to be trucked over ice roads on the Mackenzie River. The proposed frequency and vehicle weight would be unprecedented in the area and raised the question of whether overwintering fish might be adversely affected. To address this question, a review of accessible, existing literature on the impacts of ice roads on overwintering fish was conducted.

General data on the responses of fishes to noise suggest that heavy trucks are unlikely to generate sound pressure levels under the ice sufficient to physically damage fishes, or to elicit startle or alarm responses. They may generate levels that cause avoidance reactions near the ice roads by species with sensitive hearing, such as suckers and minnows. Further analyses of extant data that may be relevant and additional specific studies should be considered.

PREFACE

This report was prepared for the Fisheries Joint Management Committee (FJMC), Joint Secretariat - Inuvialuit Renewable Resources Committees, P.O. Box 2120, Inuvik, NT, XOE OTO. Robert Bell, Chairman of the FJMC, was the Performance Authority for this contract.

The report was prepared by: D.B. Stewart, Arctic Biological Consultants, Box 68, St. Norbert Postal Station, 95 Turnbull Drive, Winnipeg, Manitoba, Canada, R3V 1L5, stewart4@mb.sympatico.ca.

The Fisheries Joint Management Committee (FJMC) Report Series was initiated in 1986 and reports were published sporadically in a variety of formats until 1998. Information on the earlier publications can be obtained directly from the FJMC office. The Series was re-initiated in 2003 and a common format established with concurrent publication on the FJMC website (www.FJMC.ca).

INTRODUCTION

In May 2001, the Fisheries Joint Management Committee (FJMC) received copies of proposals by Petro-Canada to quarry sand and gravel from the Swimming Point and Devil's Lake areas of the Mackenzie Delta (Figure 1). In these proposals, Petro-Canada was applying for 10-year Quarry Concessions to remove about 400,000 m^3 of granular material from Swimming Point (69°06'30"N, 134°24'00"W), beginning in June 2001, and 500,000 m^3 of granular material from the Devil's Lake area (68°53'30"N, 134°27'30"W), beginning in the winter of 2002 (Inuvialuit Environmental and Geotechnical Inc. 2001a and 2001 b). They planned to operate the Swimming Point Quarry year-round and the Devil's Lake Quarry from December to April. Much of the quarried sand and gravel was to be trucked over winter roads to destinations in the Mackenzie Delta area. End-dump trucks with a capacity of 20 yd^3, some towing 20 yd^3 pup trailers, were to carry it over existing winter roads wherever possible (J. King, pers. com.). This represents a volume of ice road traffic, both in frequency and vehicle weight, that is unprecedented in the area, and raises the question of whether overwintering fish may be adversely affected.

To address this question, a review of accessible, existing literature on the impacts of ice roads on overwintering fish was conducted. It focussed on information relevant to the movement of sand and gravel to locations in the Mackenzie Delta. Pertinent literature was identified through searches of key bibliographic databases and discussions with scientists knowledgeable of environmental impact studies in the Mackenzie Delta/Beaufort Sea area. A list of these databases and contacts is appended. This brief report summarizes key information and provides advice on future initiatives.

POSSIBLE IMPACTS

The construction and operation of ice roads that cross lakes or streams may adversely affect overwintering fish by: 1) causing erosion in the vicinity of the approaches and thereby increasing sediment inputs--particularly during spring runoff; 2) creating ice bridges that restrict seasonal flows or delay ice breakup, 3) entraining fish in water intakes during flooding operations, 4) releasing deleterious substances into the water; and 5) creating under-ice pressure and sound disturbances.

The first four of these problems are well documented in the Mackenzie River Basin, as a result of earlier pipeline and highway studies (eg. Dryden and Stein 1975; Beak Consultants Ltd. 1979a and 1979b; McKinnon and Hnytka 1988). With proper attention to vehicle maintenance, to existing winter road construction and operation guidelines (Dryden and Stein 1975; Adam 1978; Hardy BBT Limited 1988; Stanley Associates Engineering Ltd. and Sentar Consultants Ltd. 1993), and to advice from the Department of Fisheries and Oceans (see DFO reviews of Petro-Canada's proposals), their potential to adversely affect overwintering fish can be reduced to a generally acceptable level. Mitigating factors here include the use of existing ice roads wherever possible and the fact that most of the trucks will be carrying sand or gravel, which can cause local physical damage but do not pose the threat of under-ice pollution. Accidents are not common on ice roads in the Northwest Territories (Diavik Diamond Mines Inc. 1998) and spills of deleterious substances by the sand and gravel trucks should be limited to the fuel load and to leakage from hydraulic systems.

This review did not locate any studies of the effects of under-ice noise and pressure from heavy trucks on fish overwintering in the Mackenzie Delta region, or elsewhere. Heavy trucks depress the ice surface of lakes and rivers as they cross, creating waves in the ice and in the underlying water (Adam 1978; CRREL 1999). The amplitude of these waves depends upon the ice strength and thickness, water depth, distance from shore, vehicle weight and speed, and other factors. These low velocity waves do not have the capacity to damage fish in the way that high velocity shock waves from an explosion can (D. Wright, pers. com.). However, their magnitude is a concern at shorelines where they can damage ice and cause truck safety problems. Whether the amplitude of these waves is sufficient to disrupt shallow under-ice fish habitat is unknown and, given the variety of possible ice and traffic scenarios, very difficult to predict. In any case, their effects should be quite local given the damping effects of the ice and the truck drivers' strong vested interest in not creating large amplitude waves as they weaken the shore ice. The remainder of this report will consider whether our knowledge of fish sensitivity to noise and of under ice noise generated by heavy trucks suggests that the proposed traffic may adversely affect overwintering fish.

TERMINOLOGY

The following discussion will use two descriptors of sound. Sound pressure level, measured in decibels (dB), describes whether a sound is relatively quiet or loud. This is a logarithmic scale, which reflects how our ears respond to sound, so an increase of 1 dB represents an order of magnitude increase in the sound pressure level. In water, decibel measurements are related to a reference pressure of one micro Pascal (re 1 ?Pa), whereas in air the reference point is 20 ?Pa--the approximate threshold of human hearing. For comparative purposes, an automobile passing at a distance of 15 m at 55 km/h produces a sound pressure of 100 dB re 1 ?Pa or 74 dB re 20 ?Pa (Richardson *et al*. 1995).

Frequency, measured in Hertz (Hz), describes whether a sound is relatively low or high pitched. Low frequency sounds, like the boom of a base drum, have relatively long wavelengths and vice versa. Low frequency sound travels or propagates very poorly in shallow water because the wavelength is longer than the water depth (Popper and Carlson 1998). Over a rocky bottom, for example, the lowest frequency that will be propagated in water 1 m deep is about 300 Hz; if the water is 10 m deep the lowest propagation frequency is about 30 Hz. Consequently, fish in shallow habitats probably only detect lower-frequency sounds from sources that are extremely close to them.

For comparative purposes, humans hear sounds with frequencies of 20 to 20,000 Hz (low pitched to high pitched) and have hearing thresholds of 20 dB re 1 ?Pa at 1,000 Hz and 26 dB re 1 ?Pa at 1,000 Hz (Richardson *et al*. 1995).

HOW SENSITIVE ARE FISH TO NOISE?

Fish detect vibrational signals using two sensory systems, the ear and the lateral line. The lateral line responds to differences between motion of the fish and motion of the surrounding water. It receives low frequency signals (<1 to 345 Hz) that originate within two or three body lengths from the fish, whereas the ear detects signals at considerable distances from the fish over a much wider range of frequencies, from well below 50 Hz to over 2,000 Hz (Tavolga 1971; Schwarz 1985; Popper and Carlson 1998).

Hearing sensitivity varies between fish species (Figure 2) (Popper and Carlson 1998). Some fishes such as goldfish (*Carassius* sp.) have special hearing adaptations called Weberian ossicles that connect the swimbladder to the inner ear. They have lower hearing thresholds and detect a broader range of sound frequencies than fish, such as Atlantic salmon (*Salmo salar*) and Atlantic cod (*Gadus morhua*), that lack this adaptation. Minnows and suckers in the Mackenzie Delta have this specialized hearing adaptation (McPhail and Lindsey 1970) and should have more acute hearing than other fishes in the delta. Their hearing thresholds and ranges likely resemble those of the goldfish, while hearing of other fishes in the Delta may more closely resemble those of the salmon and cod which are illustrated in Figure 2.

The level at which fish can detect sound depends upon the level of background noise. Sound must be at least 10 dB more intense than background noise to avoid being masked by ambient noise at the same or nearby frequencies (Tavolga 1971). Fish show a positive avoidance reaction to vessels when the radiated noise levels exceed their threshold of hearing by 30 dB or more (ICES 1994). Seismic air guns cause subtle changes in rockfish (*Sebastes* spp.) behaviour at sound pressures as low as 154 dB re 1 μPa (Pearson *et al.* 1992; Skalski *et al.* 1992). These responses change to alarm behaviour over the range of 178-207 dB, with a threshold for startle responses between 200 and 205 dB.

Many factors may affect how fish react when they are exposed to a noise stimulus. The presence of predators or prey, seasonal and diel variations in physiology, spawning or migratory activities and other factors may make them more or less sensitive to unfamiliar sounds (Schwarz 1985; ICES 1994). White perch (*Morone americana*) and striped bass (*Morone saxatilis*), for example, show avoidance responses to broadband sounds below 1,000 Hz at sound pressure levels of 148 and 160 dB re 1 μPa during the day but only weak responses to sounds as high as 191 dB re 1 μPa at night (ESEERCO 1991 cited in Popper and Carlson 1998). At these levels, minnows and tomcod (*Microgadus tomcod*) showed weak avoidance responses but only during the day. Given the low light and temperature conditions under the ice fish may be less responsive to noise stimuli than they would be during daylight in open water.

Changes in sound intensity may be more important to fish's reactions than the maximum sound level (Schwarz 1985; ICES 1994). Sounds that reach their peak rapidly tend to elicit stronger responses from fish than sounds with longer rise times but equal peak intensities. Continuous sound levels, even when they are very high, are soon ignored if they are not associated with harm or reward--unless there is an abrupt change in their intensity. This phenomenon has been observed in a number of studies of vessel avoidance by marine fishes. Herring fishermen, for example, may spend several days travelling among the fish schools to accustom the herring to their presence before they begin fishing (Schwarz and Greer 1984). When fishing starts they then try to maintain a constant vessel speed so as not to frighten the fish. Fish are also more likely to avoid approaching sounds than departing sounds.

Sound pressure levels that exceed the hearing threshold by 60 dB can cause hearing damage to fishes (Popper and Carlson 1998). Fish may be most susceptible to hearing damage at the most sensitive frequencies in their hearing range; species with the most sensitive hearing may be affected at lower sound pressure levels than those with less acute hearing. Bennet *et al*. (1994 cited in Popper and Carlson 1998) found no effect of sound pressures of 105-167 dB re 1?Pa at 100, 800, and 5,600 Hz on the development of fish eggs and little or no effect on fishes. The exception was that 800-Hz signals appeared to cause a significant decrease in predation on cutthroat trout (*Onchorhynchus clarki*) by northern squawfish (*Ptychocheilus oregonensis*). It is not known whether the squawfish's more sensitive hearing was damaged or if they just found the sound annoying and so left the area where the trout were located.

HOW MUCH NOISE DO HEAVY TRUCKS MAKE UNDER THE ICE?

Most underwater noise studies deal with marine vessel traffic or seismic exploration. This review did not locate any measurements of the underwater noise generated by heavy trucks passing over freshwater lake and stream ice; however, a single marine study was located. In the winter of 1981-82, Greene (1983) measured noise under the sea ice during construction at Seal Island in the Alaskan Beaufort Sea. At a distance of 1.6 km from the ice road which was 2.5 to 3 m thick, he detected noise from heavy gravel trucks (70 m^3) in the frequency range of 250 to 475 Hz at sound pressures up to about 43-45 dB re 1?Pa (Figure 3). These frequencies are within the hearing range of fishes. At that distance from the road the sound levels were about 10 to 15 dB greater than the ambient noise but still well below the hearing threshold of most fishes. Noise generated by the trucks did not propagate well in the shallow water (12 m) and could not be detected 3.2 km from the road.

Data were not available on the level of noise generated by these trucks in the immediate vicinity of the ice road. However, it may be possible to obtain this information from a recent study of construction noise at Seal Island. Dr. Greene (pers. com.) believes the results of this study may be of more value to this review than his 1983 work. I have requested a copy of the study, which is to be completed later this summer. In the interim, he has offered to look at his data later this month to see if he can estimate the level of under-ice noise generated in the immediate vicinity of the ice road.

WHAT DO WE KNOW ABOUT THE AMBIENT NOISE?

The level of ambient or background noise can drastically reduce a fish's ability to detect other sounds. Wind and precipitation at the surface, ice movement, water turbulence, animal sounds, human activity and many other factors create significant levels of underwater noise with or without ice cover (ICES 1994; Richardson *et al.* 1995; H. Cleator, pers. com.), most of it within the hearing range of fishes. High levels of natural sound at a particular frequency can effectively mask man-made sounds at that frequency. This review did not find any ambient under-ice or open water noise measurements for lakes or streams in the Mackenzie Delta.

Levels of ambient noise measured under ice in the Alaskan Beaufort Sea by Greene (1983) were typically 20-30 dB below those presented by Knudsen *et al.* (1948) for calm open ocean conditions. If a similar difference exists between ice-covered and ice-free conditions in Mackenzie Delta lakes and rivers, then ambient underwater noise may be significantly less in winter than summer except perhaps under surface storm conditions.

Sound transmission directly through the ice appears to be very good, as evidenced by the need for Inuit hunters to remain absolutely motionless so that the seals they are stalking do not hear snow scrunching under their feet. Cleator (pers. com.) did not find significant differences between sound transmissions through freshwater and marine ice.

WHAT DOES ALL THIS MEAN?

Little or nothing is known about noise generated under freshwater ice by heavy trucks or about the effects of under ice noise on fishes in the Mackenzie Delta.

General data on the responses of fishes to noise suggest that heavy trucks are unlikely to generate sound pressure levels under the ice sufficient to physically damage fishes, or to elicit startle or alarm responses. They may generate levels that cause avoidance reactions near the ice roads by species with sensitive hearing, such as suckers and minnows. Any noise impacts from the trucks will be mitigated by the fact that they will be seasonal, occurring when the water is cold and dark, and periodic, as trucks must be spaced well apart on the ice for safety. The sound pressure levels will build and recede gradually as the trucks pass and attenuate quickly in the relatively shallow waters of the Mackenzie Delta.

A more definitive assessment may be possible once further data have been received from Dr. Greene. If his data show high noise levels near the ice road, perhaps 115 dB re 1 ?Pa, a literature review should be undertaken to determine whether a more detailed assessment of the effects of this noise is possible using existing data. If Dr. Greene's data are not useful, then a field study of under-ice noise should be considered. A cost effective method might be to use a hydrophone(s) placed at varying depths and distances from the ice road over a range of fish habitat types. The purpose would be to measure the levels and frequency range of underwater noise the trucks are generating relative to the ambient noise. This information could then be correlated with existing data on fish behaviour in relation to noise. If the sound levels are relatively high and pertinent noise data for area fishes are lacking, laboratory studies might be considered as a means of assessing the sensitivity of key fish species to under-ice noise.

This measured approach should be possible since the Inuvialuit recently decided to conduct a new inventory of granular resources before granting further gravel concessions and Petro-Canada is now applying only for a one-year concession at Swimming Lake (J. King, pers.com.).

REFERENCES

Adam, K.M. 1978. Building and operating winter roads in Canada and Alaska. Can. Dep. Ind. N. Aff. Environ. Stud. 4: vi + 221 p.

Beak Consultants Limited. 1979a. Northern linear facilities in Canada: a catalogue of environmental literature. Can. Env. EPS Tech. Rev. Rep. EPS 3-NW-79-3: i + 342 p.

Beak Consultants Limited. 1979b. Impact of linear facilities in northern Canada: a review of environmental literature. Can. Env. EPS Tech. Rev. Rep. EPS 3-NW-79-3A: 157 p.

CRREL (Cold Regions Research and Engineering Laboratory) 1999. Safety on floating ice sheets. US Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. 5 p.

Diavik Diamond Mines Inc. 1998. Diavik Diamonds Project, Environmental impact assessment. 1 CD.

Dryden, R.L., and J.N. Stein. 1975. Guidelines for the protection of the fish resources of the Northwest Territories during highway construction and operation. Can. Fish. Mar. Serv. Tech Rep. CEN/T-75-1: vi + 32 p.

Greene, C.R. 1983. Characteristics of underwater noise during construction of Seal Island, Alaska, 1982, p. 117-149. In B. J. Gallaway (ed.) Biological studies and monitoring at Seal Island, Beaufort Sea, Alaska 1982. Prepared by LGL Ecological Research Associates, Inc., Bryant, TX for Shell Oil Company, Houston, TX.

Hardy BBT Limited. 1990. Environmental operating guidelines: northern seismic operations. Prepared by Hardy BBT Limited, Calgary, AB for Canada Department of Indiana nd Northern Development, Ottawa, ON. iv + 34 p.

ICES (International Council for the Exploration of the Sea). 1994. Report of the study group on research vessel noise measurement. Copenhagen, Denmark. ii + 81 p. [Fish Capture Committee C.M. 1994/B:5]

Inuvialuit Environmental and Geotechnical Inc. 2001a. Project description for the proposed Petro-Canada Devil's Lake quarry. Prepared for Petro-Canada, Calgary, AB by Inuvialuit Environmental and Geotechnical Inc., Calgary, AB and Inuvik, NT. (Project # 745-00) iii + 43 p. + appendices.

Inuvialuit Environmental And Geotechnical Inc. 2001b. Project description for the proposed Petro-Canada Swimming Point quarry. Prepared for Petro-Canada, Calgary, AB by Inuvialuit Environmental and Geotechnical Inc., Calgary, AB and Inuvik, NT. (Project # 745-00) iii + 42 p. + appendices.

Knudsen, V.O., R.S. Alford, and J.W. Emling. 1948. Underwater ambient noise. J. Mar. Res. 7: 410-429.

McKinnon, G.A., and F.N. Hnytka. 1988. The effect of winter pipeline construction on the fishes and fish habitat of Hodgson Creek, NWT. Can. Tech. Rep. Fish. Aquat. Sci. 1598: iv + 44 p.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (Sebastes spp.). Can. J. Fish. Aquat. Sci.49: 1343-1356.

Popper, A.N., and T.J. Carlson. 1998. Application of sound and other stimuli to control fish behaviour. Trans. Am. Fish. Soc. 127(5): 673-707.

Richardson, W.J., C.R.Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, Toronto. xiii + 576 p.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (Sebastes spp.) Can. J. Fish. Aquat. Sci. 49: 1357-1365.

Schwarz, A.L. 1985. The behaviour of fishes in their acoustic environment. Env. Biol. Fish. 13(1): 3-15.

Schwarz, A.L., and G.L. Greer. 1984. Responses of Pacific herring, Clupea harengus pallasi, to some underwater sounds. Can. J. Fish. Aquat. Sci. 41: 1183-1192.

Stanley Associates Engineering Ltd. and Sentar Consultants Ltd. 1993. Environmental guidelines for the construction, maintenance and closure of winter roads in the Northwest Territories. Prepared for Department of Transportation, Government of the Northwest Territories, Yellowknife. ii + 73 + appendices.

Tavolga, W.N. 1971. Chapter 6. Sound production and detection, p. 135-205. In W.S. Hoar and D.J. Randall (ed.) Fish Physiology, Volume V, Sensory systems and electric organs. Academic Press, NY.

APPENDIX I DATABASES SEARCHED

• Arctic and Antarctic Regions Database (ASTIS): Includes library collections at the Arctic Institute of North America, Boreal Institute, Scott Polar Research Institute, Cambridge Arctic Shelf Program, INAC, etc.

• Arctic Biological Consultants' Arctic bibliographic databases (>5,000 refs);

• ASFA: Aquatic Sciences and Fisheries Abstracts, a broad-based database of published material;

• CRREL Cold Regions Database: Includes the US Army Cold Regions Research and Engineering Laboratory collection;

• DFO Winnipeg: Internal databases of the Central and Arctic Region's Fish Habitat and Arctic Fisheries sections and staff publications;

• GNWT-RWED Library database;

• WAVES: Includes grey literature held by the Department of Fisheries and Oceans Libraries.

APPENDIX II CONTACTS

Byers, T. Head, Byers Environmental Studies, #2-740 Dorchester Ave., Winnipeg, MB R3M 0R6.

Cleator, H. Marine Mammal Biologist, Department of Fisheries and Oceans (DFO), 501 University Crescent, Winnipeg, MB, R3T 2N6.

Cosens, S. Research Scientist, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Dahl, J. Fish Habitat Biologist, DFO, Box 2310, Yellowknife, NT, X1A 2P7.

Deuck, L. Marine Mammal Biologist, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Falk, M. President, Falk Environmental, 83 Waterhouse Bay, Winnipeg, MB, R3R 2N5.

Fallis, B. Resource Impact Biologist, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Greene, C. President and Principal Scientist, Greeneridge Sciences, Inc., 4512 Via Huerto, Santa Barbara, CA, USA, 93110.

Gyselman, E. Anadromous and Freshwater Fish Biologist, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Hnytka, F. Resource Impact Biologist, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

King, J. Environmental Scientist, Inuvialuit Environmental and Geotechnical Inc. 1338R-36th Ave NE, Calgary, AB, T2E 6T6.

Olsen, P. Librarian, Marine Environment and Habitat Sciences Division, DFO, 9860 West Saanich Road, Sidney, BC, V8L 4B2.

Simundsson, E. Head, Science Information, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Stein, J. Director, Habitat Management Program, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

Wright, D. Coordinator, Environmental Affairs and Scientific Licencing, DFO, 501 University Cres., Winnipeg, MB, R3T 2N6.

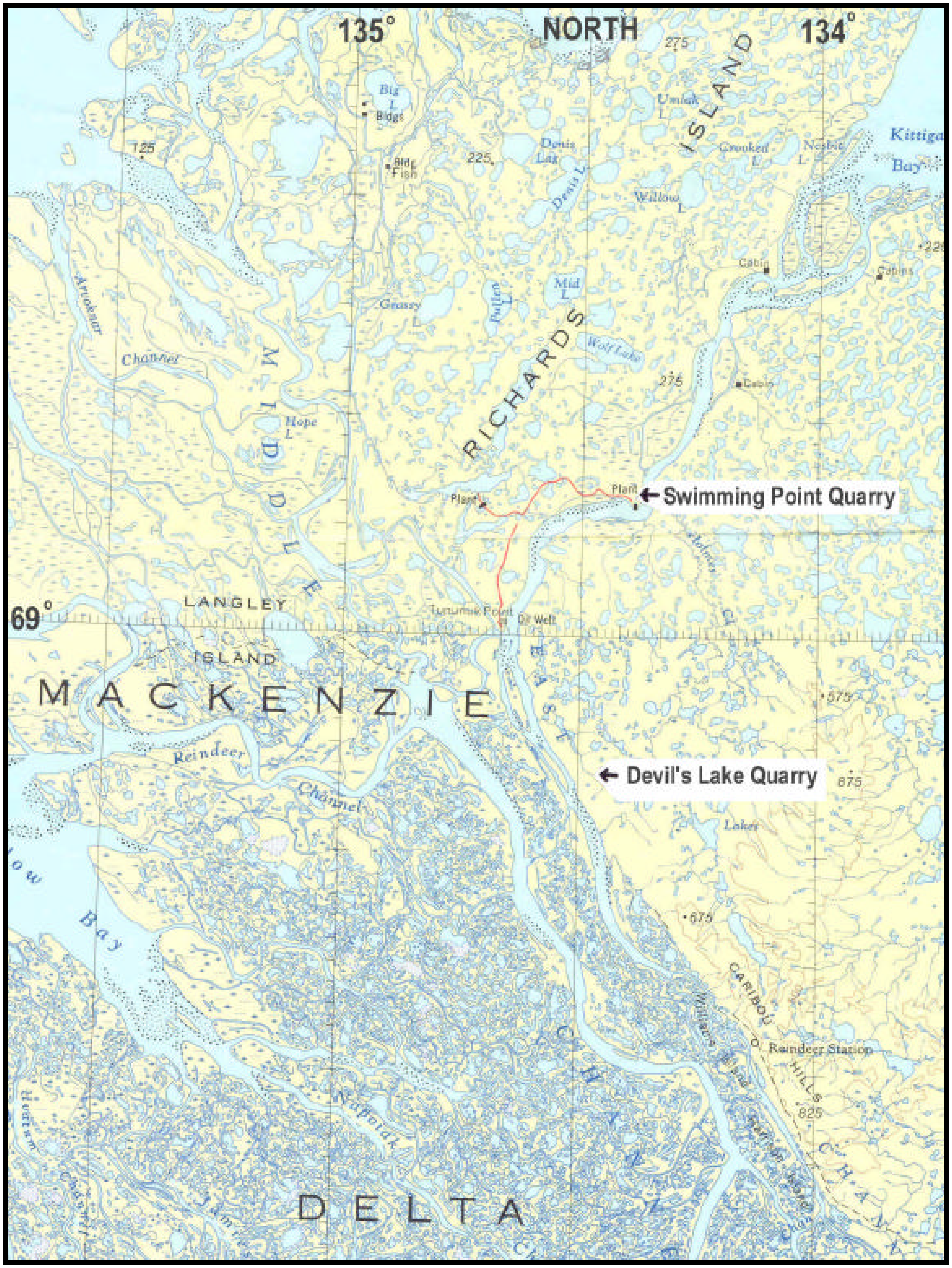

Figure 1. Map showing locations of proposed quarry operations (from Canada NTS Map 107 SE and 107 SE).

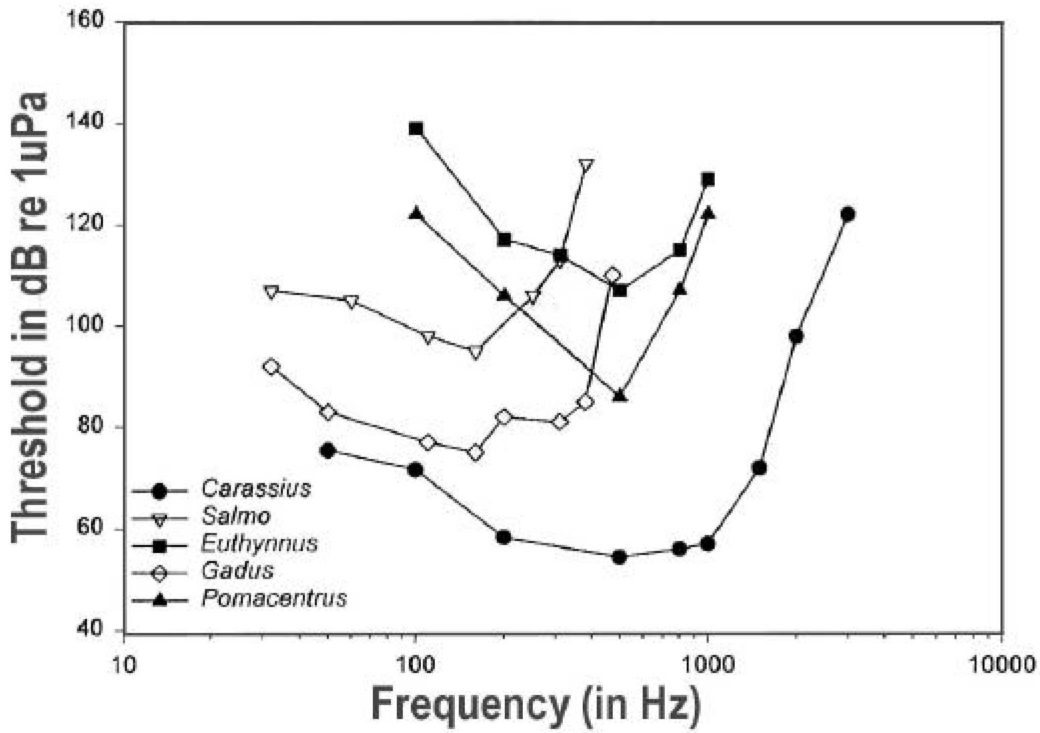

Figure 2. Hearing thresholds (in decibels with reference to 1 ?Pa) of several fish species, determined via behavioural methods in which fish were trained to perform some task whenever they hear a sound (from Popper and Carlson 1998). The goldfish (*Carassius auratus*) illustrates the more sensitive hearing of fish species that have a Weberian apparatus connecting the ear to the swimbladder (e.g. suckers and minnows in the Mackenzie Delta). They hear sound frequencies from 50-3000 Hz and in their most sensitive range hear sound about 20 dB quieter than species such as the Atlantic salmon (*Salmo salar*) and Atlantic cod (*Gadus morhua*) which lack this specialized hearing adaptation (e.g. species other than suckers and minnows in the Mackenzie Delta). Within the tested range, the latter species also hear a narrower range of sound frequencies, roughly 30-500 Hz.

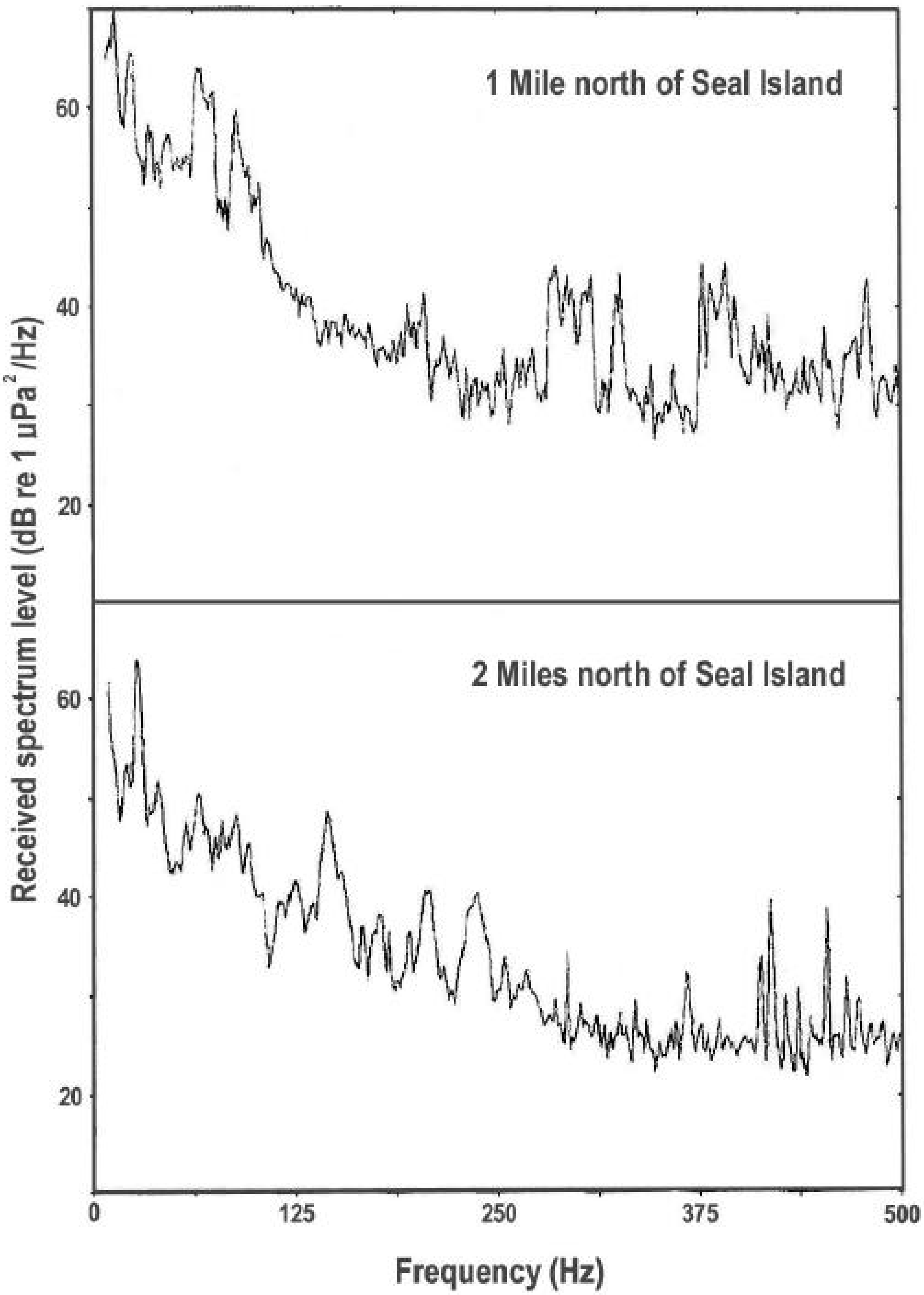

Figure 3. Under-ice sound pressure spectra for final island construction, 1.6 (top) and 3.2 (bottom) km north of Seal Island, Alaska (adapted from Greene 1983). Trucks were moving over the ice at a distance of about 1.6 km when the upper recording was made. At that distance they generated sound levels up to 10 dB above the ambient noise in the general frequency range of 250-500 Hz. [Note: decibel readings of dB re 1 ?Pa²/Hz on this figure can be converted to dB re 1 ?Pa by adding between 0 and 2.3 dB].