SUMMER

ENVIRONMENTAL PROGRAM

MACKENZIE RIVER ESTUARY

VOLUME 1

AQUATIC STUDIES

IMPERIAL OIL LIMITED
Calgary Alberta

MARCH 1976

F.F. SLANEY & COMPANY LIMITED
VANCOUVER · BRITISH COLUMBIA · CANADA

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F.F. SLANEY & COMPANY LIMITED

ENVIRONMENTAL RESOURCE CONSULTANTS

402 West Pender Street, Vancouver, B.C. V6B 1T9 - (604) 687-0151 - Telex 04-55287

April 2, 1976
File: I341

Mr. G.G. Mainland
Manager, Frontier Planning
Imperial Oil Limited
500-6th Avenue S.W.
CALGARY, Alberta
T2P OS1

Attention: Mr. T.G. Watmore

Dear Sir:

We take pleasure in submitting this report entitled "Aquatic Studies". This is Volume 1 of a two volume report series dealing with studies undertaken during the 1975 Summer Environmental Program in the Mackenzie Estuary. The other volume is entitled "White Whale Studies" (Volume 2).

Both report volumes contain common introductory sections (Parts 1 through 3) which outlines the program of work undertaken and the study areas involved so that individual volumes are independent and can be read separately.

This report provides an assessment of effects arising from the 1975 summer construction of offshore artificial islands in the Mackenzie Estuary upon physical oceanography, water chemistry, plankton, benthos and fish. From the broad information base established by the comprehensive 1974 and 1975 summer aquatics programs and other previous studies, and as detailed in the "Summary of Important Points" for each major study component, all indications are that environmental effects to date of Imperial Oil activities have been minimal and site specific. The information gathered will be of considerable value in describing the implications of future island development and use, and can aid in environmentally-safe design and scheduling of future operations.

..../2

Mr. G.G. Mainland
Manager, Frontier Planning
Imperial Oil Limited

We appreciate having had the opportunity of working with you during this interesting and worthwhile project, and extend our thanks for your helpful co-operation and that of Imperial Oil Limited field personnel throughout the study.

Yours very truly,

F.F. SLANEY & COMPANY LIMITED.

Douglas Gordon

Dr. Douglas Gordon
Project Director

W.R. Olmsted

W.R. Olmsted
Project Manager

WRO:ct

1975

SUMMER ENVIRONMENTAL PROGRAM

MACKENZIE RIVER ESTUARY

VOLUME 1

AQUATIC STUDIES

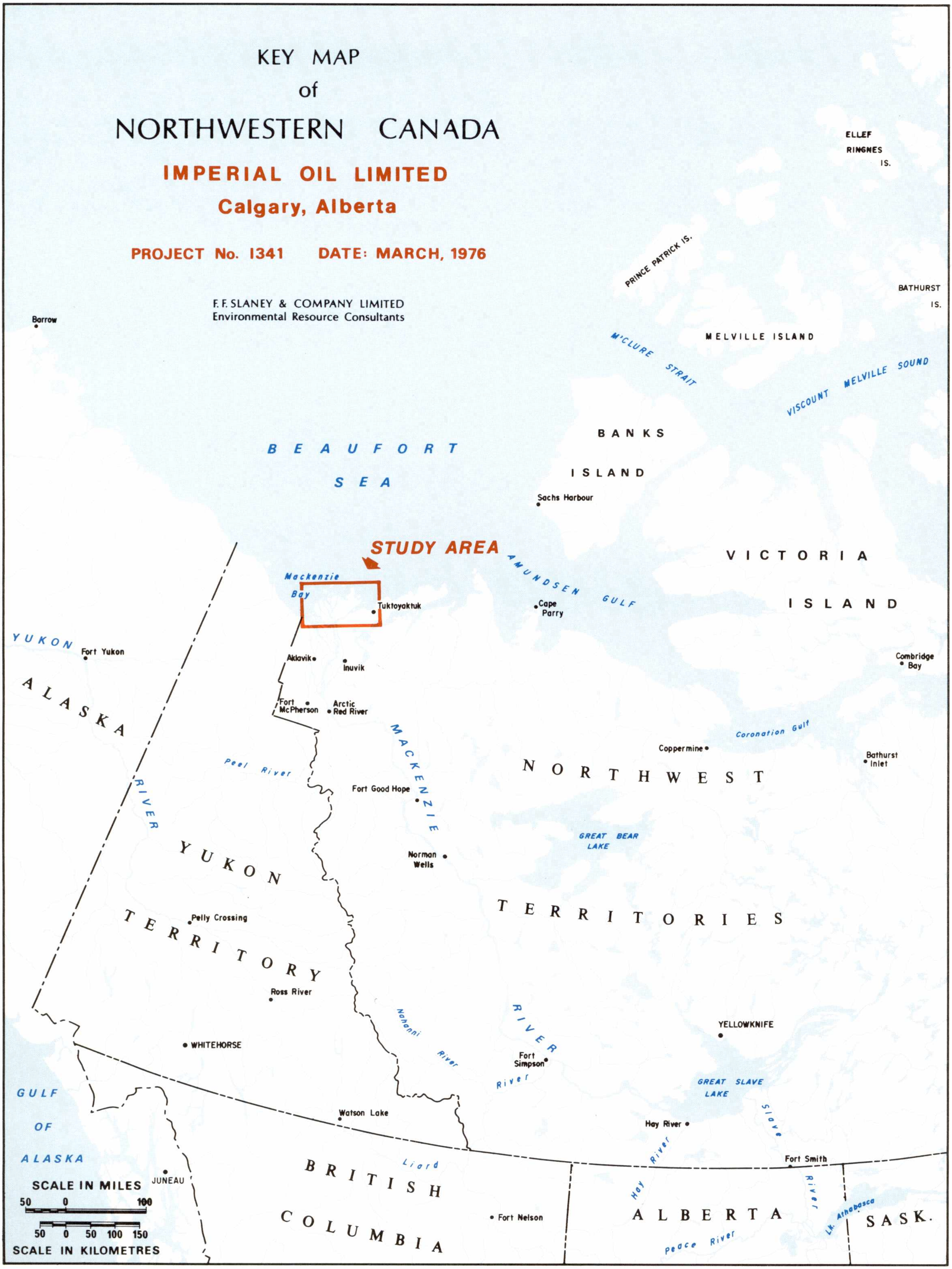
REPORT VOLUMES

VOLUME 1 - AQUATIC STUDIES

VOLUME 2 - MARINE MAMMAL STUDIES

MARCH, 1976

F.F. SLANEY & COMPANY LIMITED
VANCOUVER, CANADA


KEY MAP
of
NORTHWESTERN CANADA
IMPERIAL OIL LIMITED
Calgary, Alberta
PROJECT No. 1341
DATE: MARCH, 1976
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
ELLEF RINGNES IS.
PRINCE PATRICK IS.
BATHURST IS.
Barrow
MELVILLE ISLAND
M'CLURE STRAIT
VISCOUNT MELVILLE SOUND
BANKS ISLAND
BEAUFORT SEA
Sachs Harbour
STUDY AREA
AMUNDSEN GULF
VICTORIA ISLAND
Mackenzie Bay
Tuktoyaktuk
Cape Parry
YUKON
Fort Yukon
Aklavik
Inuvik
Cambridge Bay
ALASKA
Fort McPherson
Arctic Red River
MACKENZIE
Coronation Gulf
Coppermine
Bathurst Inlet
Peel River
NORTHWEST
Fort Good Hope
RIVER
GREAT BEAR LAKE
YUKON
Norman Wells
TERRITORIES
Pelly Crossing
TERRITORY
Ross River
Nahanni River
RIVER
YELLOWKNIFE
WHITEHORSE
Fort Simpson
River
GREAT SLAVE LAKE
GULF OF ALASKA
Watson Lake
Hay River
Slave
Liard
River
Fort Smith
BRITISH COLUMBIA
JUNEAU
SCALE IN MILES
50 0 100
50 0 50 100 150
SCALE IN KILOMETRES
Fort Nelson
Hay
ALBERTA
River
Lk. Athabasca
SASK.
Peace River

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Dr. D. Gordon directed the study and reviewed and edited the text. T.L. Slaney co-ordinated F.F. Slaney & Company field activities during summer, 1975. W.R. Olmsted later assumed project management and report co-ordination.

Authors of the individual environmental components were:

J.W. McDonald and L.C. Martin	Physical Oceanography and Water Chemistry
W.R. Olmsted	Plankton
W.E. Bengeyfield	Benthos
V.A. Poulin	Fish

Professional and technical staff who contributed to the collection and synthesis of data included:

A.R. Smith
T.L. Slaney
G.M. Smith
J.S. Hackett

Clerical staff who assisted in the preparation of this report were:

M. Chapman
B.C. Lehr
C.D. Tizzard

Report Graphics, unless otherwise stated, were designed and illustrated by the F.F. Slaney & Company Drafting Department.

A. Bennett
A. Beliaeff
J. Bradshaw
S. Galenzoski
C. Ludvigsen

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Detailed laboratory analyses of all collected water samples were performed by Cantest Limited, Vancouver. Chief chemist was Mr. A. Maynard. Chlorophyll _a_ analyses were conducted by Dr. L.J. Albright, Department of Biological Sciences, Simon Fraser University. Mr. J. Keayes, Department of Biological Sciences, Simon Fraser University, identified and enumerated all phytoplankton and zooplankton samples. Questionable fish species were identified by Dr. N.J. Wilimovsky, Institute of Animal Resource Ecology, University of British Columbia.

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Dr. W.S. Duval	Biological Sciences, S.F.U.
Mr. P.R. Murray	Biological Sciences, S.F.U.
Mr. J. Keayes	Biological Sciences, S.F.U.
Dr. E.H. Grainger	Arctic Biological Station, Ste. Anne de Bellevue, Quebec

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PART 1

THE 1975 SUMMER ENVIRONMENTAL PROGRAM

Exploratory drilling for hydrocarbons from artificial island structures in the nearshore waters of East Mackenzie Bay was initiated by Imperial Oil Limited in 1972 with the construction of Immerk Island. Exploration was continued through 1973 and 1974 with the construction of Adgo F-28, Adgo P-25, Pullen E-17 and Netserk B-44. Winter construction of the Adgo C-15 site was accomplished by March, 1975. Two additional islands, Netserk F-40 and Ikattok J-17, were completed in summer, 1975, and future islands are scheduled for construction during open water, 1976.

In order to assess the effects of island construction upon the environment and avoid potentially adverse effects, Imperial Oil Limited retained F.F. Slaney & Company Limited to conduct a program of environmental study and monitoring during the 1975 open water season.

1.1 INTRODUCTION

Concern regarding possible effects of island construction on the existing environment have been recognized by Imperial Oil Limited throughout this development period, and resulted in the support of three major aquatic oriented summer environmental studies related to development in the Mackenzie Bay area. The first, conducted in 1972, addressed potential environmental effects associated with construction of the Immerk B-48 site. The second, conducted in 1974, was a joint Imperial Oil-Sun Oil program which considered a number of activity sites within East Mackenzie Bay. The third, which forms the basis of this report, was carried out during the 1975 open water season and monitored past and current development sites in East Mackenzie Bay and future sites in Kugmallit Bay. In addition, two winter programs were conducted for Imperial Oil Limited in 1973 and 1974 in the Mackenzie Bay area. Other studies, not directly related to artificial island construction, were undertaken in nearby mainland areas in 1973 and 1975 by F.F. Slaney & Company Limited.

1.2 PURPOSE

The overall purpose of the 1975 summer program was to supplement the existing data base for the assessment of environmental effects in relation to summer artificial island construction in East Mackenzie Bay by Imperial Oil Limited, and to provide baseline bio-physical data at selected sites identified as potential development areas within the Mackenzie Estuary.

1.3 OBJECTIVES

The specific objectives of the 1975 summer environmental program were to:

1. Monitor the effects of construction and associated activities at the Netserk F-40 and Ikattok J-17 sites throughout July and August, with follow-up monitoring at selected old and abandoned borrow and artificial island sites within East Mackenzie Bay;

2. Conduct baseline bio-physical investigations at selected sites within Kugmallit Bay indicated as potential development areas;

3. Supplement the bio-physical data base acquired from 1974 studies with regard to physical-chemical conditions, and the

assessment of the relative distribution and abundance of plankton, benthic fauna and fish at selected island sites and borrow locations;

4. Sample deep water offshore potential artificial island sites, not reached during the 1974 season, as ice conditions permitted;

5. Provide surveillance and documentation of movements, distribution and relative abundance of white whales in relation to summer activities in Mackenzie Bay and Kugmallit Bay;

6. Within limits imposed by weather, advise Imperial Oil field supervisors regarding potential interference with white whale migration or native hunting activities, recommending preventative action, if required; and,

7. Prepare a comprehensive report dealing with all study sectors.

1.4 SCOPE OF WORK

Imperial Oil Limited recognizes the need for detailed environmental information from which to assess the effects of development activities, and to provide a basis for ensuring minimal and acceptable limits of environmental disturbance. To address these requirements, and to aid in environmentally safe design and scheduling of future operations, during the 1975 open water season F.F. Slaney & Company Limited conducted a multi-disciplinary environmental study program that focused on past, present and possible future island construction sites.

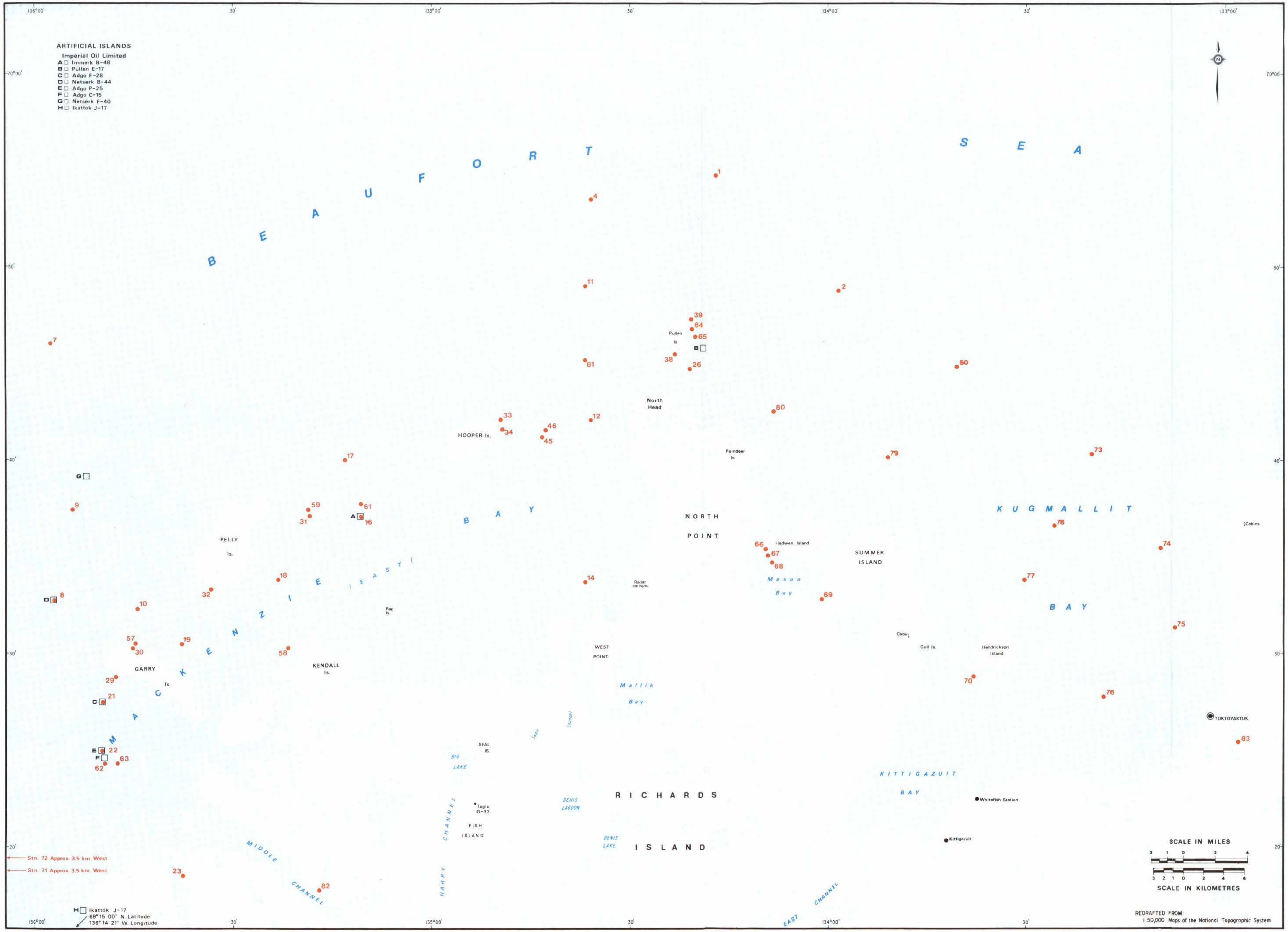
This integrated program consisted of six study disciplines, including:

Physical Oceanography
Water Chemistry
Plankton
Benthos
Fish
Marine Mammals

Also included were less extensive observations of meteorology and climate. All studies were designed to integrate with, or supplement existing information and ongoing work by other research agencies.

The study area included all active Imperial Oil construction sites, as well as existing artificial islands, and several planned locations for future construction. For most program disciplines, the study area extended to a distance approximately 24 km offshore of the "Barrier Island" group in East Mackenzie Bay, and approximately 19 km north of Tuktoyaktuk in Kugmallit Bay (Map 1). These areas are separated by the North Point of Richards Island and are collectively referred to as the Mackenzie Estuary for the purpose of this report.

Field studies were designed to be conducted before and during construction activities in 1975. Most studies commenced before construction began so that short-term shifts in faunal distribution, or behaviour, could be documented, if they were to occur. Marine mammal studies began on June 23, 1975 and continued until August 7. Aquatic studies, including water chemistry, plankton, benthos and fisheries investigations, began July 10 and continued through to August 23. Oceanographic investigations were timed to coincide with Earth Resources Technology (ERT) satellite passes during July 15 to 17, August 2 to 4, and August 20 to 22, 1975.



LEGEND

• Comprehensive Sampling Locations, 1975

MAP 1

KEY MAP OF

THE STUDY AREA

IMPERIAL OIL LIMITED
Calgary Alberta

Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants

F.F. Slaney & Company Limited utilized the 11 meter Wilson III as a self-contained research vessel equipped with field laboratory facilities and living quarters for personnel, and several smaller support vessels. On August 8, 1975, while moored in the vicinity of Imperial Adgo C-15 for repairs to the steering system, a fire broke out in the Wilson III and it subsequently burned to the waterline and sank. Most of the specialized sampling equipment, custom fabricated for the 1974 and 1975 programs, was destroyed. Identical replacement equipment (to ensure comparative data between the two study years) could not be acquired for the remaining season. Numerous preserved samples and original data records were also lost. Only limited sampling for some study components, conducted from the eight meter vessel Arcticus, was possible beyond August 8. The data set presented for all aquatic disciplines is therefore limited for the latter half of the program.

1.5 REPORTING OF THE PROGRAM

Reports dealing with the 1975 summer program were prepared in two volumes. Volume 1 deals with aquatic studies, while marine mammal investigations are presented in Volume 2.

PART 2

DESCRIPTION OF THE STUDY AREA

The study area lies immediately offshore of Richards Island in the Mackenzie Delta, some 145 km north of the town of Inuvik (Key Map). Terrestrial environments are, for the most part, deltaic in origin and character, and aquatic environments reflect the influence of the outflowing Mackenzie River. Until recently, the region was remote from human activity except for native trapping in winter and whale hunting in summer.

2.1 CLIMATE

Climatic conditions are severe and the region is placed within the Marine Tundra Climatic Zone. Winters are long and cold while summers are cool and of short duration. Compared with nearby inland areas, however, winters are appreciably warmer as a result of the moderating effect of the sea. The situation reverses in summer with coastal areas being cooler than those inland, again a result of marine influence.

Weather records are available for Tuktoyaktuk (Department of the Environment), and for a station immediately south of the study area at Taglu. Weather data was collected at Taglu (Map 1) in 1972 and 1974 by F.F. Slaney & Company.

Mean annual temperature at Tuktoyaktuk, a coastal location in the southeastern corner of the study area, was $-11.0^{o}C$ over ten years (1960-70). At Taglu (1972-73), a mean annual temperature of $-10^{o}C$ was recorded. Temperature variation in the study area is extreme, ranging from -44°C to 27.8°C at Tuktoyaktuk (1960-70). Growing degree days per annum range from 600 to 1000.

The sun is above the horizon continuously from May 24 to July 19, and continuously below the horizon from December 2 to January 10 each year (Burns, 1973). Total net incoming solar radiation is nevertheless similar to temperate latitudes in June at 5.2 x 10^2 Langleys/day, and reaches 0 Langleys/day in mid-December.

Winds are high throughout the year in the study area, and are little affected by topography. Mean monthly wind velocities are highest in summer-fall and lowest in winter-spring. Annual mean speeds are greater than 16 km/h on the coast. Summer-fall winds are from a predominantly northerly direction, while those in winter-spring are generally from the east.

Precipitation is light, with rain occurring from June through September, and snowfall throughout the year. Total precipitation at Tuktoyaktuk averages 13.5 cm per year (1960-70) with most falling as rain in July and August. Snow cover in winter is light, but subject to drifting.

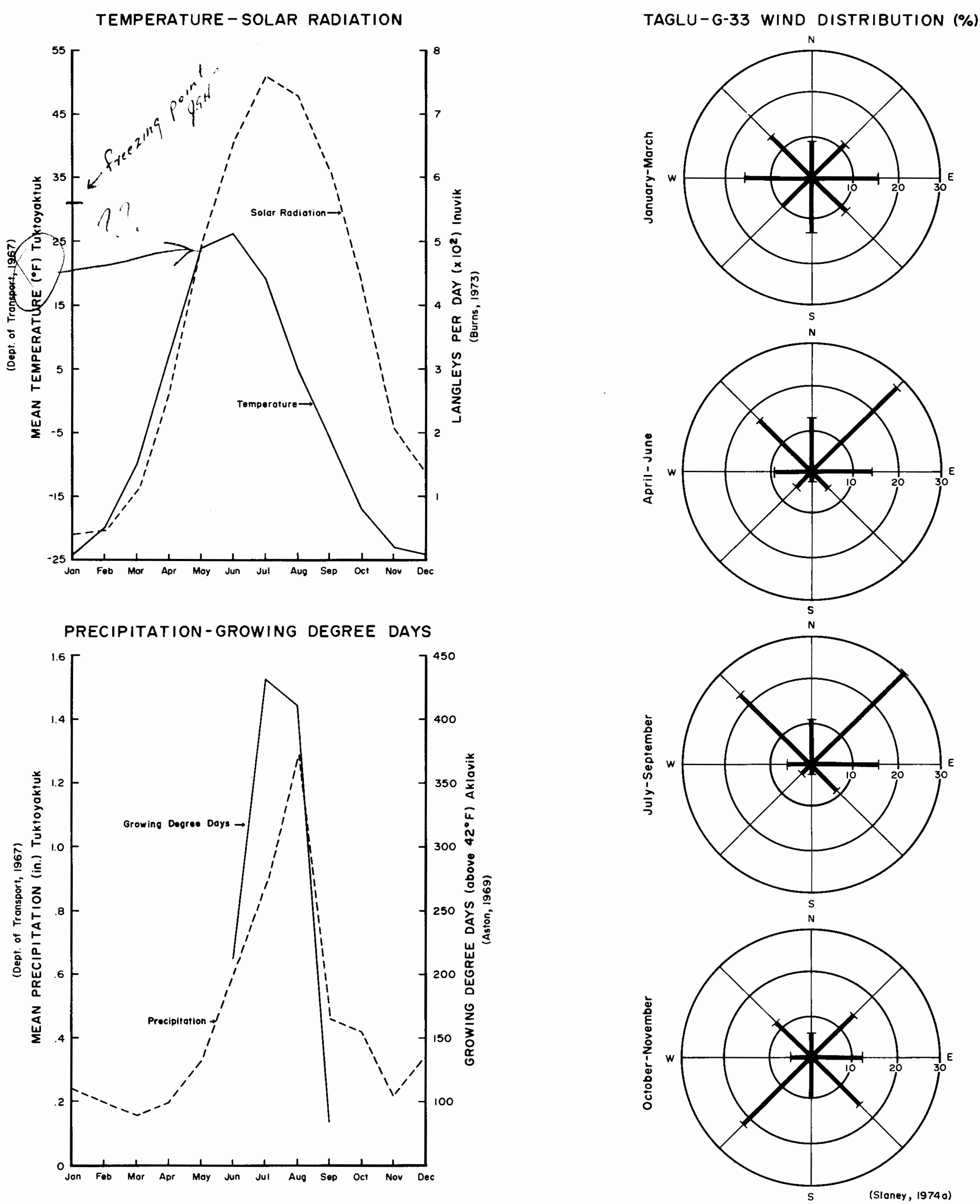
Selected climatic records, including sources and periods of records, are presented in graphic form (Figure 1).

2.2 TERRESTRIAL ENVIRONMENTS

Terrestrial portions of the study area include several moderately sized offshore Barrier Islands (Garry, Pelly, Kendall, Hooper and Pullen) rising 33 to 69 m above sea level, numerous deltaic islands rising only centimeters above the water, and the northern shoreline of the much larger Richards Island, the latter forming the southern

FIGURE 1

Mean Climatic Conditions of the Mackenzie Delta



boundary of the study area and physical division between East Mackenzie Bay and Kugmallit Bay (Map 1). Two general physiographic types are present:

1. Low-lying, poorly-drained floodplains dominated by a vegetative cover of sedges and willows; and,

2. Well-drained upland areas supporting a more varied vegetational cover dominated by shrubby ericaceous species.

Floodplains consist of recently deposited river-borne materials. Substrates tend to be fine-grained, with additional silts and clays being deposited by flooding river waters each spring. Summer flooding may also occur when wind storms create increased water levels along the coast. Floodplains are present along all river channels emptying into Mackenzie Bay, and on some Barrier Islands where slumping and wave action redistribute upland deposits. Relief is flat, broken only by frost-generated landforms such as polygonal ridging and pingos.

Uplands are underlain by a variety of pleistocene fluvial, estuarine and morainal materials. Substrates range from fine-grained marine deposits through coarse gravels associated with glacial deposits. River flooding does not occur in upland areas. Topographic relief is varied ranging from gently sloping hillsides to steep banks caused by thermokarst slumping. Uplands occur on all the larger offshore Barrier Islands, and comprise the bulk of the northeastern region of Richards Island. All uplands in the study area are remnants of pleistocene deposits as yet unaffected by the modern river's erosional action. In the case of offshore and Barrier Islands, erosion is proceeding at a rapid rate, exceeding 2 m per year along some seaward facing cliffs.

Permafrost underlies the entire study area. Active layer depths on floodplains average 38 cm in late summer, while those in upland situations vary from 25 to 91 cm during the same time period, depending on drainage, soil characteristics and vegetational cover.

Distribution of vegetation is, for the most part, controlled by drainage. Floodplains are poorly-drained and often retain several centimeters of surface water throughout the summer. Plant communities in such areas consist of water tolerant species, especially sedges and willows. Sedges dominate in the wettest areas, and willows in those that are dry for at least part of the growing season. Areas along the coast of Richards Island, being only centimeters above sea level, are characterized by almost pure sedge stands.

Upland plant communities reflect varied drainage conditions, but in most situations are dominated by shrub species. Best-drained areas are characterizied by cottongrass tussocks and ericaceous shrubs. As drainage deteriorates, larger shrubs (alder and willow) begin to dominate. Upland communities on offshore islands, while similar in most respects to those of the mainland, tend to be dwarfed, reflecting the increased exposure to wind in these locations.

2.3 AQUATIC ENVIRONMENTS

Two major water bodies comprised the 1975 study area. The largest, East Mackenzie Bay, an extension of the Beaufort Sea, is located directly offshore of Richards, Ellice and Langley Islands to a distance of 16 to 24 km (Map 1). Kugmallit Bay, the smaller component of the study area, lies essentially northeast of Richards Island. Also included were the numerous channel mouths of the outflowing Mackenzie River. These waters are shallow throughout, ranging from less than one m along northern Richards Island, and parts of East Mackenzie

Bay, to a maximum of 15 m on the study area's northern and most seaward boundary. River channels are sometimes deep in upstream locations, but shelve off at channel mouths where decreasing current velocity allows heavier sediments to drop out and form sills. Such channel-mouth sills make access to Mackenzie Bay difficult.

Outflowing river waters carry heavy sediment loads resulting in turbid conditions throughout the area during spring and summer. Peak levels are experienced during spring freshet. Some decrease in turbidity is evident in fall and winter, however, storm generated wave action in late fall can increase turbidity to levels approaching those of spring.

Substrates in channels and throughout the study area are generally fine-grained. Larger particles occur only in the vicinity of offshore islands where eroded pleistocene island materials are present. Island shorelines reflect erosion taking place, with seaward beaches having a greater frequency of larger particles than leeward shores. Wave and current action transport and redeposit eroded island materials forming spits and mudflats in the lee of most offshore islands.

Water throughout all but the most seaward areas is fresh in summer as a result of the outflowing Mackenzie. Salinity increases in deeper waters beyond the Barrier Islands. Surface salinities reach maximum levels in fall during freeze-up.

Water currents in the study area are, for the most part, wind generated and move along an east-west axis. A small northerly current component arising from river outflow is also apparent. Deep currents do not develop in shallow areas lying close to the Barrier Islands. In offshore portions of the area studied, some indication of a weak estuarine flow is apparent.

Production in most trophic levels is generally low in nearshore waters within the Barrier Islands, but increases in a seaward direction. This situation may reflect estuarine conditions which exist some distance offshore rather than in nearshore waters.

PART 3

DESCRIPTION OF ISLAND CONSTRUCTION

Prior to summer, 1975, Imperial Oil Limited had completed construction of six artificial islands in East Mackenzie Bay: Immerk B-48; Pullen E-17; Adgo F-28; Netserk B-44; Adgo P-25; and, Adgo C-15 (Map 2). These islands essentially utilized two basic designs (Figure 2), with modifications dictated by variables of water depth and season of construction.

3.1 PAST ISLAND CONSTRUCTION

Construction of Immerk island was initiated during summer 1972 and completed in summer 1973. Borrow material was taken from areas near the island location and transported to the site using a suction dredge and floating pipeline. After the accumulated fill was well above water, the island was protected from wave erosion with a filter cloth, sandbags and wire riprap. Drilling and other activities, after construction, took place directly on the island surface (Figure 2).

At the Adgo F-28 site (Map 2), summer construction in 1973 followed a different pattern. A berm consisting of heavy sandbags was placed around the island perimeter and the interior filled with local silt deposits. This fill material was dredged from nearby locations and put in place using a clamshell dredge (Figure 2).

Two artificial islands, Adgo P-25, and Netserk B-44, were constructed in summer, 1974, using the berm and fill design developed for Adgo F-28 (Figure 2). Construction activities began on July 15, when equipment was moved to Immerk and the Garry Island borrow site to begin the construction of Netserk B-44 (South Netserk). Activities at both construction sites had terminated by September 30 with freeze-up in East Mackenzie Bay.

3.2 CONSTRUCTION IN 1975

Adgo C-15, located approximately 0.8 km SSE of Adgo P-25 (Map 2) was constructed during winter, 1975. Gravel was trucked from the Ya Ya Lake source on Richards Island from January through March. The island design was generally similar to that of the initial Adgo site (Figure 2), but utilized gravels exclusively as construction material. Filter cloth and sand bag protection were added after the island was sufficiently above water.

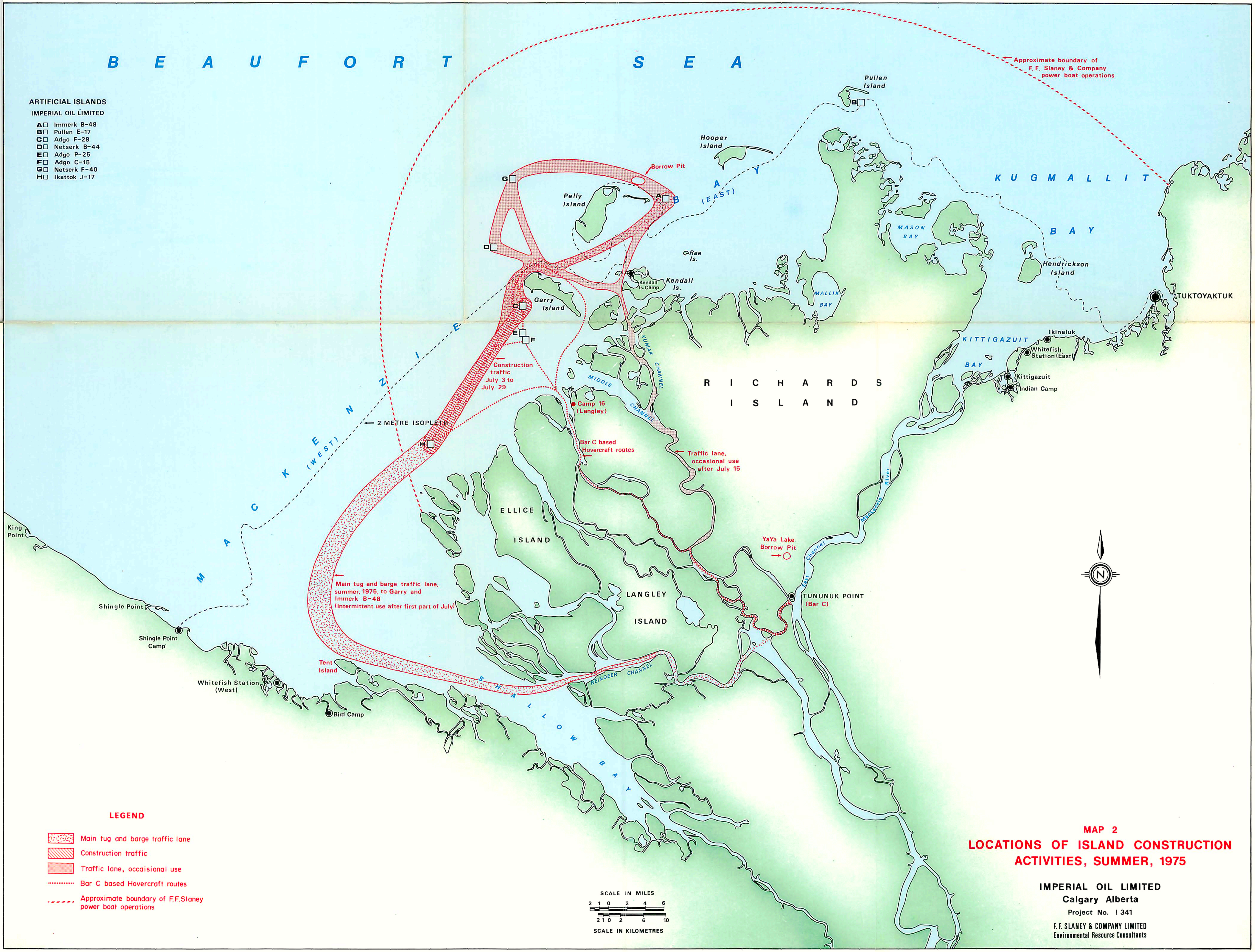
Netserk F-40 (North Netserk) and Ikattok J-17 were completed during the summer of 1975 (Map 2). Netserk F-40 was a circular island, constructed of sand and gravels.

A winter stockpile of Ya Ya Lake gravel was maintained on the north tip of the Pelly spit for use on Netserk F-40.

Two-cubic yard sand filled bags were used as a permanent berm throughout construction, with four-cubic yard bags on the most exposed side. The Ikattok J-17 site, with a central gravel core, utilized two-cubic yard sand bags as a berm from the bottom substrate to sea level and as slope protection.

3.2.1 Construction Activities

Summer construction of Ikattok in 1975 began on July 4 and was completed by July 30. Gravel for the island core was winter-hauled from the Ya Ya Lake pits and stockpiled nearby for summer transport by barge. Construction of North Netserk commenced on July 30 and ceased



MAP 2
LOCATIONS OF ISLAND CONSTRUCTION ACTIVITIES, SUMMER, 1975

IMPERIAL OIL LIMITED
Calgary Alberta
Project No. I 341

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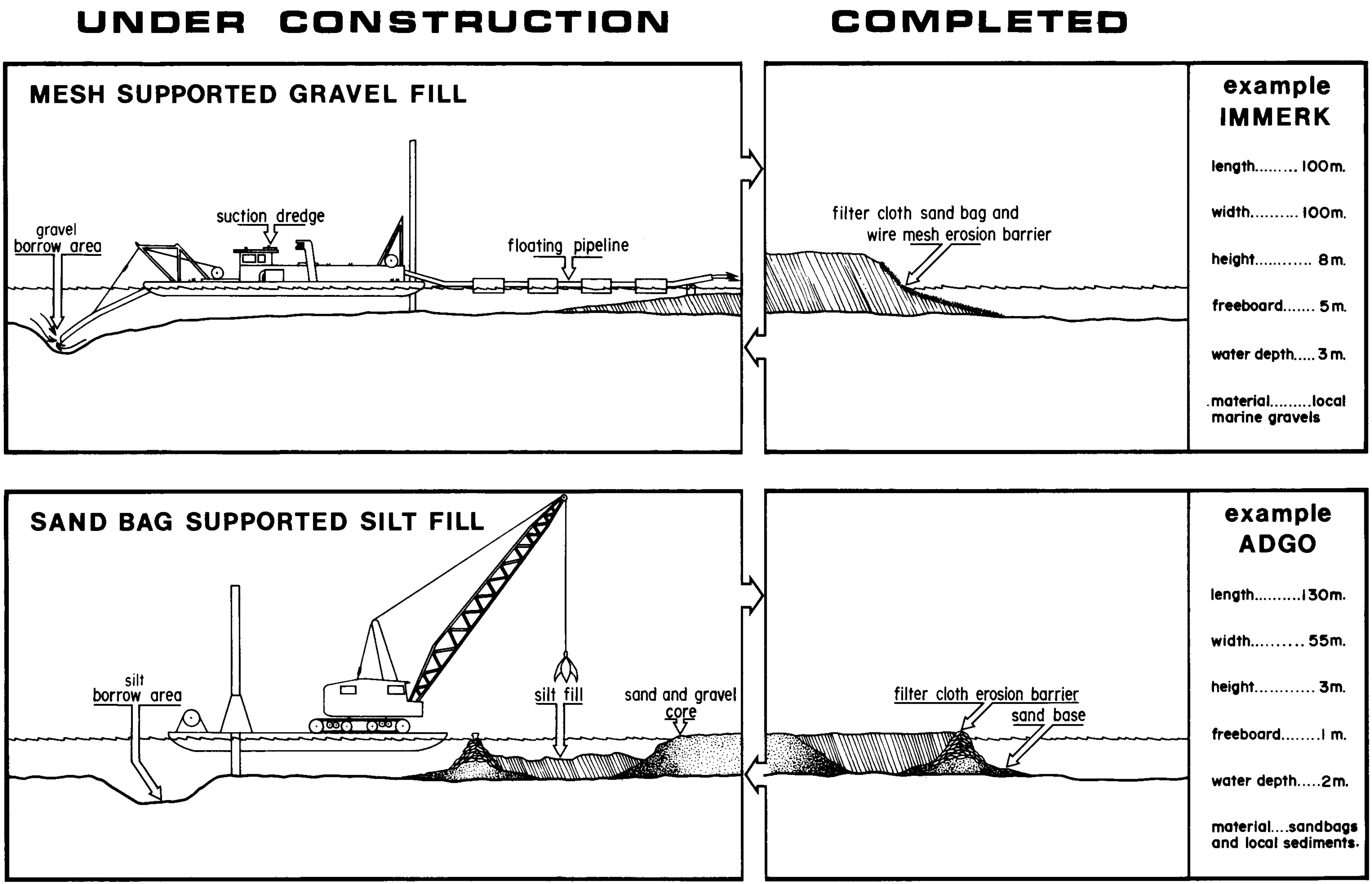
Environmental Resource Consultants

FIGURE 2

ARTIFICIAL ISLAND DESIGN AND CONSTRUCTION



on September 18. The Netserk F-40 site was located in deeper waters, and core materials were transported by barge from the Pelly Island borrow pit (Map 2). During 1975, Immerk island was initially used as the major equipment staging area for both the Ikattok and Netserk sites, and later as a gravel source for slope protection to complete Netserk F-40. A limited amount of equipment for summer construction was transported by barge via Inuvik and Bar C from Hay River.

Island construction was largely water based, and relied upon barges and tugs for transport, operation and support of construction equipment and materials. Crew rotation and transport of lightweight equipment and consumables was accomplished by helicopter and hovercraft.

3.2.1.1 Barge Transport

Prior to mid-July, tugs and barges moving equipment and supplies avoided the boundaries of the Kendall Island Migratory Bird Sanctuary by routing through Reindeer Channel, across Shallow Bay close to Tent Island and NE towards East Mackenzie Bay (Map 2). Later traffic, after July 15, utilized a deep channel flowing north from Middle Channel and emptying into the Bay immediately west of Kendall Island (Map 2). This channel has been referred to as Kumak Channel in previous Slaney reports, and that name is retained for this study. Selected shallow channels outside the Sanctuary bounds were also utilized by hovercraft traffic and other shallow draft vessels.

Barges used during the summer varied in size and function with a range in drafts from less than 1.5 m to approximately 2.7 m under full load. Similarly, several varieties of tugs were used, primarily of shallow draft design. Imperial Oil Limited and their sub-contractors operated eight tugs, five dump barges, five spud barges (including one with a sandbagger), six flat barges, three crew boats, six launches and two survey boats throughout the summer construction period. Barge traffic was generally most intense near the mouth of Kumak Channel, and at or near construction and borrow sites. General traffic patterns throughout summer, 1975, are illustrated (Map 2).

3.2.1.2 Aircraft Support

Most air support during the summer season utilized Bell 212 and 206 and Aerospatiale Gazelle helicopters for daily flights to the area from inland base camps. Flight restrictions governing the altitude and routing of both helicopter and fixed wing craft were in force throughout the summer period. These regulations are included in Appendix 1.

3.2.1.3 Camps

A maximum of three camps housing construction personnel, located on barges anchored near worksites, were used during the summer. A large oceangoing camp-ship was used throughout the season. Several shore-based camps (Langley and Bar C) were also used in support of construction operations, but not by construction personnel. A camp was established at the Immerk B-48 site to support staging activities and provide sandbags for island construction.

All camps were self-contained with individual lighting, heating and sewage systems. Camp operations were regulated under annexes to Land-Use Permits, copies of which are included in Appendix 1. Under these regulations, camp sewage was treated through aeration systems and activated sludge processes. Camp wastes, other than sewage, were incinerated daily in a fuel-fired furnace. Ashes and non-combustible wastes were removed to approved disposal sites ashore.

In addition to regulations set out in Land-Use Permits regarding the avoidance of wildlife harassment (Appendix 1), Imperial Oil Limited restricted the activities of off-duty personnel to the immediate campsites to further prevent disturbance on nearby Barrier Islands and spits.

F.F. Slaney & Company field crews utilized various existing Imperial Oil camps throughout the area when necessary, but for most of the field season operated from the Langley base camp and from the Wilson III (Map 2).

3.2.1.4 Dredging and Fill Material Sources

Materials from which artificial islands were constructed came from essentially three sources. These included; bottom silt materials from areas adjacent to island sites (50 to 100 m distant), bottom sands, and gravels from the north Pelly Island borrow pit. Winter-hauled gravel from Ya Ya Lake pit, located inland on Richards Island, was used for the construction of Ikattok J-17 and Adgo C-15. Bottom sediments, however, formed the bulk of island construction materials and were obtained by dredging.

Summer island construction by Imperial Oil Limited utilized a suction dredge operated by Northern Construction Limited. This machine took material from the bottom and transported it in a semi-liquid state to the island site by floating pipeline, or loaded it through a transfer barge into bottom-dump barges which were then towed to the construction site. At construction sites, fill was unloaded by dumping from the barges. Clamshell dredges then transferred materials from the dump site (adjacent to the island) to the required location within the island perimeter. Two and four cubic yard sand bags were removed from scows by clamshell dredge. Additional local sands and gravels were dredged, when available, by clamshells. Suction dredging was concentrated in an area north of the Pelly Island spit (Map 2).

Crew boats and a hovercraft were used at all construction and borrow sites to transport men to and from work locations. These craft, as a general rule, remained in close proximity to work sites.

3.2.1.5 Other Activities

Several large craft, which were not related to island construction, were occasionally present in and near the study area.

Two seismic boats, the Arctic Explorer and the Arctic Surveyor, operated north and east of the study area and came into East Mackenzie Bay only occasionally. Both vessels were involved in seismic exploration using an aqua-pulse system.

An SRN-6 air cushion vehicle (hovercraft) operated out of the main water-based camps and Langley Camp on Langley Island, and made regular trips into the western and central portions of the study area. The craft, however, was restricted to the nearshore and shallow water regions as much as possible to avoid potential interaction with beluga whales present in the area.

Areas of Kittigazuit Bay and the East Channel were subject to the usual barge traffic travelling between Inuvik and Tuktoyaktuk.

PART 4

A SUMMER SURVEY OF THE PHYSICAL OCEANOGRAPHY AND WATER CHEMISTRY OF THE MACKENZIE RIVER ESTUARY, N.W.T., 1975

BY

J.W. McDONALD
and
L.C. MARTIN

FOR

IMPERIAL OIL LIMITED

F.F. SLANEY & COMPANY LIMITED
VANCOUVER, CANADA

PART 4

PHYSICAL OCEANOGRAPHY AND WATER CHEMISTRY

4.1 INTRODUCTION

Since the dredging and construction of Immerk artificial island in 1972, Imperial Oil Limited has expanded its offshore hydrocarbon exploration program to include eight artificial islands. The purpose of such islands is to support and protect the exploratory drill rigs and their field camps from the harsh arctic climate, and to provide secure and self-contained drilling platforms which minimize disturbance to the estuarine environments of Mackenzie and Kugmallit Bays.

Associated with island building and camp operations are a number of construction activities which could potentially affect the existing physical oceanography and water chemistry of the Mackenzie Estuary. In order to provide a basis for assessing the impact of such activities on the aquatic environment, a comprehensive physical oceanography and water chemistry study was initiated by Imperial Oil Limited during the 1974 open water season (Slaney, 1975). With further exploration and construction in 1975, the offshore environmental program was continued for most previous stations in East Mackenzie Bay, and expanded into newly proposed areas for artificial island construction in Kugmallit Bay.

4.2 PURPOSE

The overall purpose of the 1975 physical oceanography and water chemistry program was to further evaluate the natural variability of the major physical and chemical processes which occur in the Mackenzie Estuary, and to assess the impact of present and potential island-building activities on the existing physical and chemical water regimes.

4.3 OBJECTIVES

The specific objectives of the 1975 physical oceanography and water chemistry program were to:

1. Determine the vertical and horizontal distribution of principal water body characteristics including; temperature, salinity, dissolved oxygen, turbidity and the magnitude and direction of surface and bottom water currents;

2. Correlate variations in specific oceanographic parameters with weather conditions in the area including; strength, duration and direction of mean winds, proximity of sea ice, and temperature of surrounding air; and,

3. Monitor and assess the general effects of 1975 dredging and island building processes on the observed oceanographic regime.

4.4 SCOPE OF WORK

F.F. Slaney & Company have collected climatic, physical oceanographic and water chemistry data from the Mackenzie Delta area since July, 1972 (Slaney, 1973, 1974a, 1974b, 1974c, 1974d). Investigations were continued during the 1974 open water season in order to assess the effects of summer artificial island construction on natural physical, chemical and biological conditions. As part of this integrated study, a comprehensive physical oceanography and water chemistry program was conducted from July 8 to September 28, 1974 (Slaney, 1975) and from July 8 to August 20, 1975.

In summer, 1974, through a combination of intensive and extensive spatial sampling, it was possible to delineate general waterbody and ocean current distributions in East Mackenzie Bay. However, because summer winds prevailed from the N-NW, multi-year ice floes intruded the Mackenzie Bay area frequently throughout summer, 1974, preventing access to offshore areas. Oceanographic sampling at offshore stations was therefore limited and it was felt further current and waterbody measurements were necessary to adequately describe the oceanographic regime under all weather conditions.

In 1975, the study area was also expanded to include Kugmallit Bay.

4.5 1975 DATA COLLECTION METHODS

This section presents a brief description of sampling frequencies and field methods that were utilized to address the specific objectives of the 1975 physical oceanography and water chemistry program.

Two research vessels and one smaller craft were used to support the summer oceanographic program. From July 8 to August 8, 1975, the Wilson III was used during all E.R.T. satellite passes, as well as for extensive offshore work. Nearshore work was conducted using a 5.5 m aluminum boat (Lund) with twin 20 hp outboards. On August 8, 1975, the Wilson III sank and the eight m Arcticus was used to complete the summer sampling program.

4.5.1 Sampling Sites

Forty-one stations representative of oceanographic conditions in East Mackenzie and Kugmallit Bays were sampled throughout the open water period from July 8 to August 20, 1975 (Map 4.1).

Stations sampled in 1975 were selected with regard to construction site locations, borrow site locations and undisturbed sites, as well as sites sampled in 1974 (Table 4.1). New 1975 stations were located in Kugmallit Bay, Mason Bay and East Mackenzie Bay off the mouth of Middle Channel.

4.5.2 Sampling Frequency

The frequency of oceanographic and water chemistry sampling was designed to provide a basis for identifying and assessing the effects of major trends in the hydrologic regime, and different patterns of wind distribution. Water chemistry sampling commenced in early July, and was expanded to include more offshore stations as the ice receded. As a minimum requirement, sampling was attempted for each of three summer E.R.T. satellite passes (July 15, August 2 and August 20), and was supplemented by sampling at fisheries stations during favourable weather conditions.

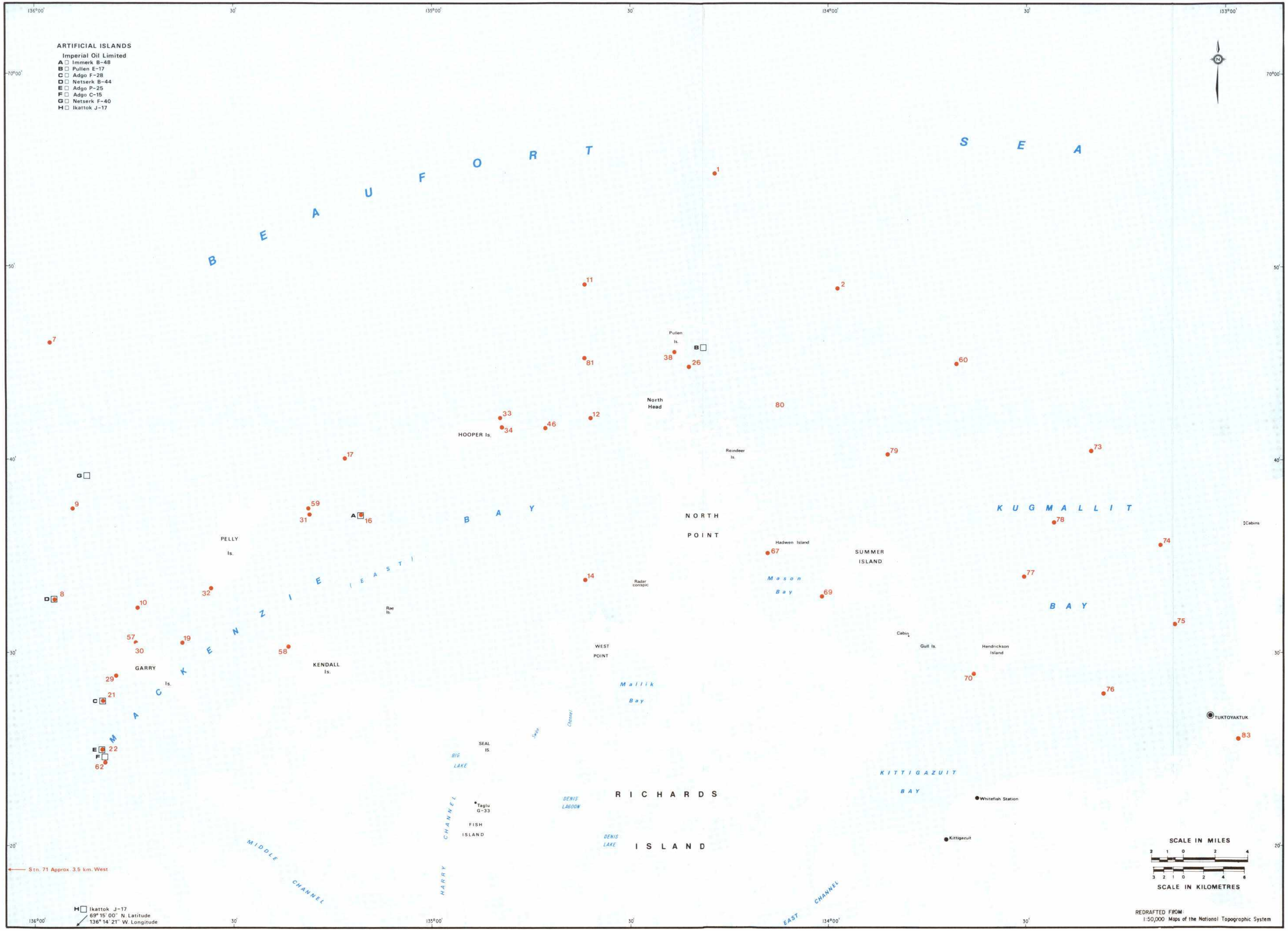
4.5.3 Sampling Methods

Ocean Currents

In 1975, measurements were made for surface and bottom currents at all oceanographic stations from anchored ship platforms. The current direction and current speed were recorded using a Hydro Products model 465A current speed and direction sensor and a model 452A readout module. Instantaneous surface readouts were monitored for one minute to establish short-term average flows and to minimize any ship motion effects.

Meteorology

Winds and other important meteorological data were collected at each marine station in conjunction with the water chemistry and



MAP 4.1
Water Chemistry and Physical Oceanography Stations Sampled, 1975

IMPERIAL OIL LIMITED
Calgary Alberta

Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants

TABLE 4.1

STATIONS SAMPLED FOR PHYSICAL OCEANOGRAPHY AND WATER QUALITY IN MACKENZIE BAY AND KUGMALLIT BAY, 1974 AND 1975

	1975 No. of Samples			1974 No. of Samples		
Offshore Stations	Physical Ocean.	Vertical Structure	Nutrients & Heavy Metals	Physical Ocean.	Vertical Structure	Nutrients & Heavy Metals
1	2	1	1	NS	NS	NS
2	2	2	4	4	2	1
7	1	1	-	1	1	-
9	1	1	-	NS	NS	NS
60	1	1	2	1	-	-
Garry Island						
8	3	2	1	8	-	2
10	1	-	1	9	-	2
19	1	-	1	5	-	1
21	2	1	1	7	-	1
22	1	-	1	7	-	2
29	3	-	1	3	-	-
30	2	1	-	NS	NS	NS
57	1	-	-	NS	NS	NS
Hooper Island						
12	3	2	1	4	-	2
14	2	1	1	6	-	2
33	1	-	-	2	-	-
34	1	-	-	4	-	-
46	1	-	2	1	-	-
Pelly Island						
16	3	2	1	8	-	2
17	1	-	1	4	1	2
31	2	1	-	1	-	-
32	1	1	-	1	-	-
59	1	1	-	NS	NS	NS
Pullen Island						
11	3	2	1	4	-	2
26	4	1	4	4	-	2
38	1	-	-	1	-	-
Kendall Island						
58	2	2	-	NS	NS	NS
Kugmallit Bay						
70	1	-	-	NS	NS	NS
73	3	2	6	NS	NS	NS
74	3	2	4	NS	NS	NS
75	2	2	3	NS	NS	NS
76	1	1	2	NS	NS	NS
77	2	1	4	NS	NS	NS
78	2	1	2	NS	NS	NS
Mason Bay						
67	1	-	-	NS	NS	NS
69	1	-	-	NS	NS	NS
Tuktoyaktuk Harbour						
83	1	-	-	NS	NS	NS
North Head						
79	1	1	-	NS	NS	NS
80	1	1	1	NS	NS	NS
Adgo and Oliveia						
62	2	-	-	NS	NS	NS
71	1	1	-	NS	NS	NS

NS = Station not sampled
\- = Measurements not taken

current measurements. Supplemental meteorological data were also obtained from Shell Farewell and Garry Island. Wind speed was measured using a Dwyer wind speed indicator. Wind direction was indicated by relating the orientation of the wind speed sensor to the ship's compass. Dry bulb and wet bulb air temperatures were measured using a hand-held psychrometer.

Water Chemistry

Twenty-two parameters were analyzed from water samples collected during the water chemistry program (Table 4.2). In addition, ambient air temperature, water depth, and general substrate conditions were recorded at each station.

Water samples for turbidity determinations were collected in clean one litre poly vinyl chloride (P.V.C.) bottles and transported to base camp at Langley Island. Analyses were performed within 24 hours on a Hellige model 7000 TS meter using a precalibrated "B" bulb and turbidity graph. Each sample was vigorously shaken prior to being placed in the turbidimeter. Results of turbidity determinations were the mean of three consecutive readings taken by one observer.

Settleable material samples were collected in clean one litre P.V.C. bottles and transported to base camp for analyses. After vigorously shaking the sample, one litre was poured into an Imhoff cone and allowed to settle for 45 minutes. The sample was then stirred with a glass rod, allowed to settle for an additional 15 minutes, and the volume of settleable matter determined.

Dissolved oxygen, pH, alkalinity, and hardness were measured in situ using a Hach model AL-36B field kit. Due to high natural turbidity levels, the oxygen end point was generally obscure. To compensate for the obscured end point, one drop of dilute starch was added about midway through the titration which aided end point determination. All other analyses were done according to Hach directions.

Hach techniques for hardness and alkalinity determinations give only approximate values. However, these values can be used to assist in delineating saline water in the Mackenzie Estuary. Salinity, conductivity and temperature were measured in situ by a model YSI S-C-T meter. Readings were generally taken 0.5 m below the surface, and 0.1 m above the bottom when water depths were greater than 1.5 m.

Water samples used for nutrient and further detailed water chemistry analyses were collected in new one litre P.V.C. bottles using sterile collection techniques. Immediately before sample collection, each bottle and cap was rinsed two or three times with sample water. Care was taken not to contaminate the bottle, bottle cap, or aliquot. Samples were kept cool and in darkness while being transported to the base camp where they were then frozen and shipped to Cantest Limited, Vancouver, for laboratory analyses by standard methods and atomic absorption spectroscopy. The samples were stored in a freezer until initiation of each analysis. Each sample was then filtered through a 0.45 μ cellulose-acetate membrane. The collected suspended matter was air-dried, dessicated and weighed, using blank papers to control procedure. The detailed analysis was conducted on the filtrate thus obtained so that all results were on the "dissolved" basis.

Water samples used for heavy metal analyses were collected in the same manner as nutrient samples. Sterile techniques were utilized to avoid contamination of the aliquot. Samples were frozen and shipped to Cantest Limited, Vancouver, for laboratory analyses by atomic absorption spectroscopy.

TABLE 4.2

WATER CHEMISTRY CHARACTERISTICS MONITORED IN MACKENZIE BAY AND KUGMALLIT BAY, 1975

Parameters Monitored	Abbreviations	Units
1. Dissolved Oxygen	D.O.	mg/l (milligrams/litre)
2. Carbon Dioxide	CO_2	mg/l
3. Hydrogen Ion Concentration	pH	$pH = \log \frac{1}{[H+]}$
4. Alkalinity		
Total	-	
Bicarbonate	HCO_3	ppm (parts per million)
Carbonate	CO_3	
5. Hardness	-	ppm
6. Salinity	-	^{o}/oo (parts per thousand)
7. Conductivity	Cond.	umhos/cm (micro mhos/ centimeter)
8. Temperature	Temp.	^{o} Centigrade
9. Turbidity	-	JTU (Jackson Turbidity Units) ppm SiO_2
10. Settleable Material	Set. Mat.	ml/l (mililitres/litre)
11. Dissolved Silica	SiO_2	ppm
12. Nitrate Nitrogen	NO_3	ppm
13. Orthophosphate	PO_4	ppm
14. Calcium	Ca	ppm
15. Magnesium	Mg	ppm
16. Chromium	Cr	ppm
17. Lead	Pb	ppm
18. Cadmium	Cd	ppm
19. Nickel	Ni	ppm
20. Suspended Solids	-	ppm
Total	-	
Fixed	-	
Volatile	Vol.	
21. Dissolved Solids	-	ppm
Total		
Fixed	-	
Volatile	Vol.	
22. Carbon	-	ppm
Total	-	
Organic	T.O.C.	
Inorganic	T.O.C.	

4.5.4 Sampling Interruptions

The loss of the Wilson III affected the planned physical oceanography and water chemistry program as follows:

1. All recorded physical and chemical oceanographic data for Kugmallit and Mackenzie Bays during the E.R.T. satellite passes of August 2, 3, and 4 were lost. However, since all frozen water samples collected during this survey had been taken off the ship and stored in the freezer at Langley Camp, a considerable amount of the data could be retrieved through laboratory analyses. Data which could not retrieved included:

   a. All meteorological information collected on site;
   b. Measurements of surface and bottom currents;
   c. Vertical profiles of temperature and salinity; and,
   d. Surface water temperatures.

2. Sampling time was lost while mobilizing the Arcticus as a replacement vessel. A total of about 8 sampling days were missed during the August survey period, thus reducing the anticipated extent of the oceanographic data base.

Of lesser consequence, but still an important interruption in data sampling during 1975, was the mechanical breakdown of the Arcticus at Pullen Island on August 21, 1975. As a result, the oceanographic survey of East Mackenzie Bay which had been planned to coincide with the E.R.T. satellite passes of August 21 and 22, was cancelled.

4.6 1975 RESULTS

The annual variability of sea surface state in Mackenzie Bay is considerable, and of major importance to both the local peoples and those engaged in transportation, construction, hydrocarbon exploration and associated development activities. Many people presently depend upon the use of the sea surface for transportion purposes such as barge transport during the open water season and vehicle transport over the winter ice cover. Thickness, movement and the general character of ice cover are also very important in the design of artificial islands which must withstand the stresses of moving pack ice. Baseline water chemistry, oceanography and ice data are also necessary in the design of contingency planning for emergency situations such as blowouts and spills.

4.6.1 Ice

Total ice cover prevails in Mackenzie Bay for a usual winter period of approximately eight to nine months each year. For the open water period of approximately three months, nearshore coastal areas are replaced by turbid fresh waters from the Mackenzie River, and offshore areas by broken floe ice and mixtures of saline and fresh waters.

Historical records, monthly averages, monthly extreme and a complete documentation of 1974 changes of Mackenzie Bay ice cover are provided; Slaney, 1975, (Vol. 1). The following sections document the changes in ice cover which occurred from May to October, 1975, in the Mackenzie Estuary.

4.6.1.1 1975 Break Up - Mackenzie Estuary

On May 4, 1975, E.R.T. satellite photographs of the Mackenzie Delta region (Figure 4.1) revealed landfast ice from Richards Island out

FIGURE 4.1

E.R.T. SATELLITE PHOTOGRAPH OF ICE CONDITIONS

MACKENZIE BAY, MAY 4, 1975

to the shear zone (about 40 km off the North Head of Richards Island) where a large irregular lead had formed. Maximum width of this lead was about six km, with numerous fractures extending north into the pack ice. Such fracturing evidenced the considerable ice movements which must have been occurring along the shear zone.

In comparison to ice conditions in May, 1974, the break-up pattern in May, 1975 was further advanced. In 1974, only small fracture lines were observed along the shear zone and it was not until mid-June that the shear zone opened up and revealed significant areas of open water.

By mid-May, 1975, there were signs of surface melting near the mouths of Kanguk Channel, Middle Channel and at the head of Shallow Bay. Melt water was also evident along the edges of Middle Channel south of Tununuk Point. On May 22, 1975, E.R.T. satellite photographs showed the lead along the shear zone was still approximately six km wide, but jammed with floe ice for approximately 25 km off the North Head of Richards Island (Figure 4.2). By late May, melt water was evident along the shores of most channels in the Delta and melt water extended 12 km into Mackenzie Bay from the mouth of Kanguk Channel.

During the first half of June, 1975, temperatures averaged above normal. The first movement of river ice at Inuvik was reported on June 2, 1975. By June 4, the river at Inuvik was clear of ice, and this was two days earlier than normal. The peak 1975 flood level at Inuvik was 8.58 m above the winter low, three m higher than the mean established for peak flood levels for 1964 to 1975. Taglu G-33, on Harry Channel in the outer Mackenzie Delta, broke up June 7, 1975, approximately five days after first ice movement at Inuvik (Slaney, 1976).

E.R.T. satellite photographs of June 9 were partially obscured by cloud, but the shoreline of the Mackenzie Delta from Middle Channel to Mallik Bay was visible. Melt water extended out from Middle Channel and Kumak Channel to the southern tip of Garry Island. Although ice was still fast inside Mallik Bay, melt water extended from the mouth of Harry Channel to the NE along the shoreline of Mackenzie Bay to West Point on north Richards Island. Mackenzie Delta lakes were still ice covered. The offshore lead appeared wider on June 9, but clouds obscured its southern edge so that its exact width could not be determined.

Ice reconnaissance flights in June by the Atmospheric Environment Service (A.E.S.) indicated that the pack ice had continued to move NW, and its edge was 160 km off Cape Bathurst. The fast ice along the Tuktoyaktuk Peninsula had begun to fracture, and heavy puddling with a few openings was evident.

By June 20, 1975, open water extended from Shallow Bay to Mallik Bay. However, landfast ice was still adhered to the seaward shores of the Barrier Islands (Map 4.2). All Mackenzie Delta channels were clear, and only a few lakes were still ice-covered.

The E.R.T. satellite photograph of Mackenzie Bay on June 29, 1975, is shown (Figure 4.3). Landfast ice was locked to the North Head of Richards Island, but was discoloured and in the process of breaking up between Pelly and Hooper Islands. A large fracture in the landfast ice was evident about 20 km WNW of Garry Island.

Temperatures continued to be warmer than normal during the first half of July, and prevailing winds were from the NE (A.E.S., 1975). These two factors caused break-up to proceed ahead of normal throughout the western arctic.

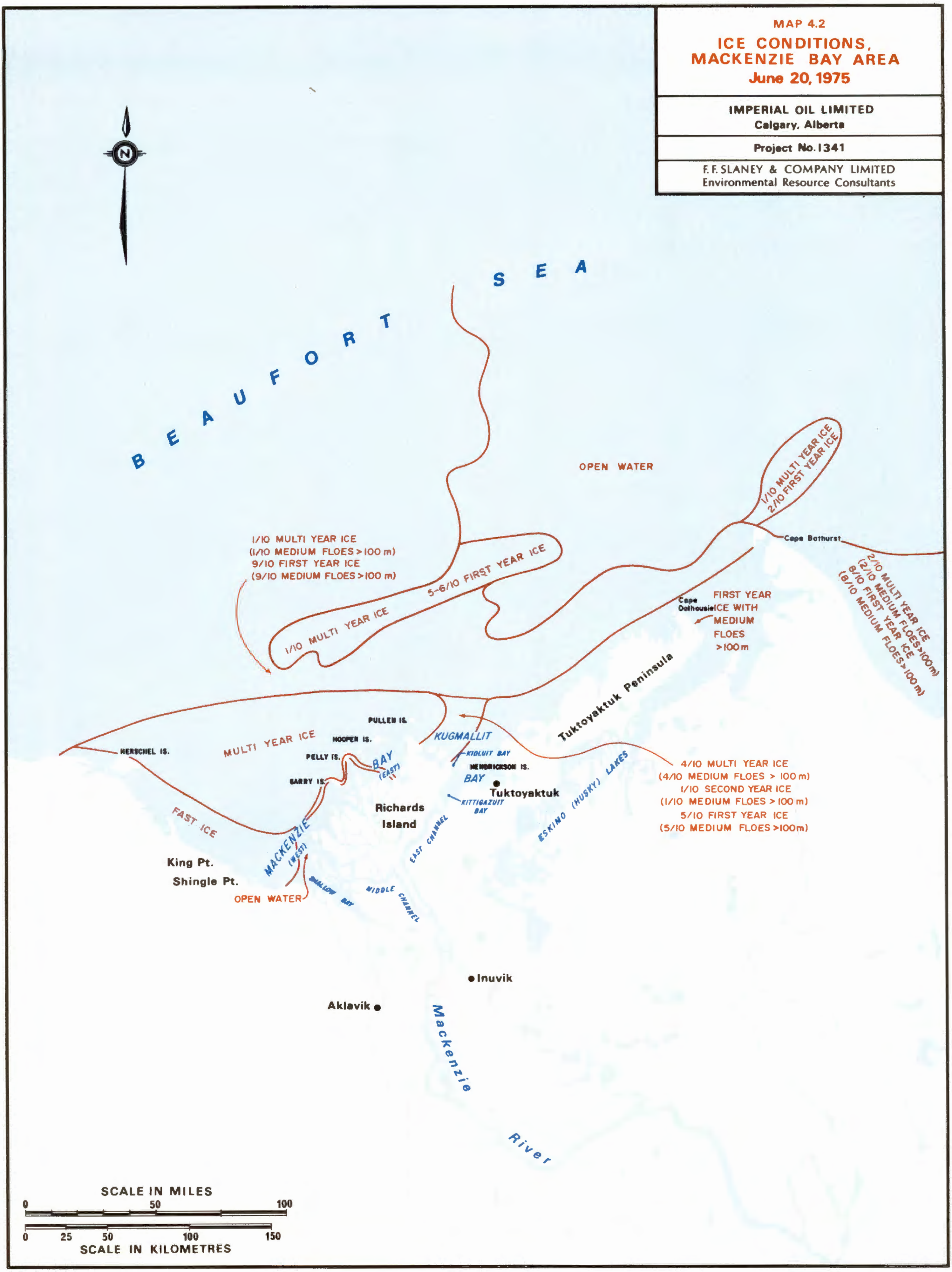

MAP 4.2
ICE CONDITIONS, MACKENZIE BAY AREA
June 20, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
BEAUFORT SEA
OPEN WATER
1/10 MULTI YEAR ICE
2/10 FIRST YEAR ICE
Cape Bathurst
1/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
9/10 FIRST YEAR ICE
(9/10 MEDIUM FLOES > 100 m)
5-6/10 FIRST YEAR ICE
1/10 MULTI YEAR ICE
2/10 MULTI YEAR ICE
(2/10 MEDIUM FLOES > 100 m)
8/10 FIRST YEAR ICE
(8/10 MEDIUM FLOES > 100 m)
Cape Dalhousie
FIRST YEAR ICE WITH MEDIUM FLOES >100 m
Tuktoyaktuk Peninsula
PULLEN IS.
HOOPER IS.
PELLY IS.
GARRY IS.
HERSCHEL IS.
MULTI YEAR ICE
KUGMALLIT BAY
KIDLUIT BAY
HENDRICKSON IS.
Tuktoyaktuk
KITTIGAZUIT BAY
BAY (EAST)
4/10 MULTI YEAR ICE
(4/10 MEDIUM FLOES > 100 m)
1/10 SECOND YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
5/10 FIRST YEAR ICE
(5/10 MEDIUM FLOES > 100 m)
ESKIMO (HUSKY) LAKES
FAST ICE
Richards Island
EAST CHANNEL
MACKENZIE (WEST)
King Pt.
Shingle Pt.
OPEN WATER
SHALLOW BAY
MIDDLE CHANNEL
Inuvik
Aklavik
Mackenzie River
SCALE IN MILES
0 50 100
0 25 50 100 150
SCALE IN KILOMETRES

FIGURE 4.2

E.R.T. SATELLITE PHOTOGRAPH OF ICE CONDITIONS

MACKENZIE BAY, MAY 22, 1975

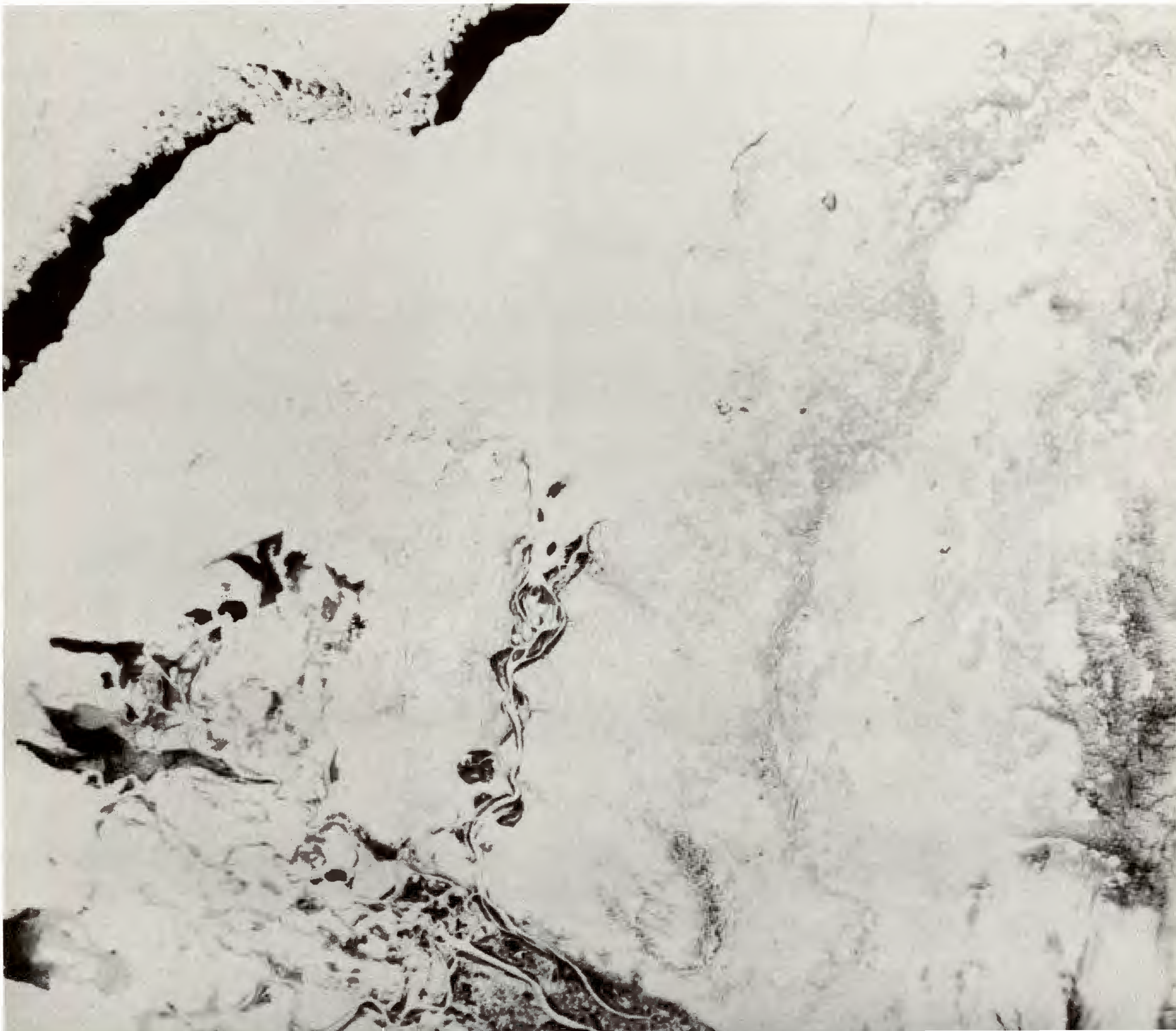


FIGURE 4.3

E.R.T. SATELLITE PHOTOGRAPH OF ICE CONDITIONS MACKENZIE BAY, JUN. 29, 1975

Figure 4.4 shows the E.R.T. satellite photo of July 7, 1975. Large multi-year ice floes lay five to ten km off Pelly Island, but open water now extended into Kugmallit Bay. The ice that remained in Kugmallit Bay was discoloured and fragmented.

By July 11, 1975, open water extended from Herschel Island to Cape Parry except for some areas of medium ice floes (Map 4.3). Beyond the area of open water NW of the Delta, only two large floes of first year ice, which had broken away from the landfast ice, were still intact NW of Herschel Island.

Ice continued to move offshore during the last half of July (Map 4.4) and the first week of August. Map 4.5 shows 130 km of open water off Hooper Island, August 15, 1975. During 1974, the edge of the ice floes receded a maximum of about 50 km off Hooper Island during the open water season. Although temperatures in late August, 1975, were below normal, warm weather throughout the spring and early summer had significantly weakened the ice, and prevailing E to NW winds helped move the broken ice well offshore.

4.6.1.2 1975 Freeze-up - Mackenzie Estuary

Cool temperatures and SE winds in the last half of August caused the Beaufort Sea ice pack to advance toward the Tuktoyaktuk Peninsula. By September 5, 1975, a tongue of heavy ice associated with the polar pack had moved into Mackenzie Bay (Map 4.6), and the advance of the ice pack and below normal temperatures signalled the onset of freeze-up.

In September, 1975, ice conditions off the Mackenzie Delta and Tuktoyaktuk Peninsula were heavy, and resembled conditions described by Burns (1974) for the most ice cover observed for September between

1964 to 1969 (Slaney, 1975; Vol. 1, Map 10). E.R.T. satellite photographs of Mackenzie Bay were obscured by cloud throughout most of September.

A.E.S. (1975) reported that temperatures for late September were below normal with mean windflows easterly. As a result, most outer Delta lakes were ice-covered by late September or early October, and new ice had begun to form in the shallows of the river channels (Slaney, 1976). Ice conditions in Mackenzie Bay area, October 3, 1975, are shown (Map 4.7). Large areas of new ice (5/10 rafted) had formed inside the Barrier Islands. The only regions of open water were in Shallow Bay and E of Kugmallit Bay.

Colder than normal temperatures continued in October, resulting in an advanced freeze-up about two weeks ahead of normal. E.R.T. satellite photographs for October 6 (Figure 4.5) showed a band of landfast ice approximately 40 km wide extending from Herschel to Shallow Bay and across Mackenzie Bay to the North Head of Richards Island and the Tuktoyaktuk Peninsula. Some small open water areas extended as far as 25 km into the Mackenzie Bay fast ice at the western mouths of larger and warmer Delta channels. Beyond about 50 km offshore, vast areas of darker-appearing new ice and open water extended out to beyond the 70th parallel.

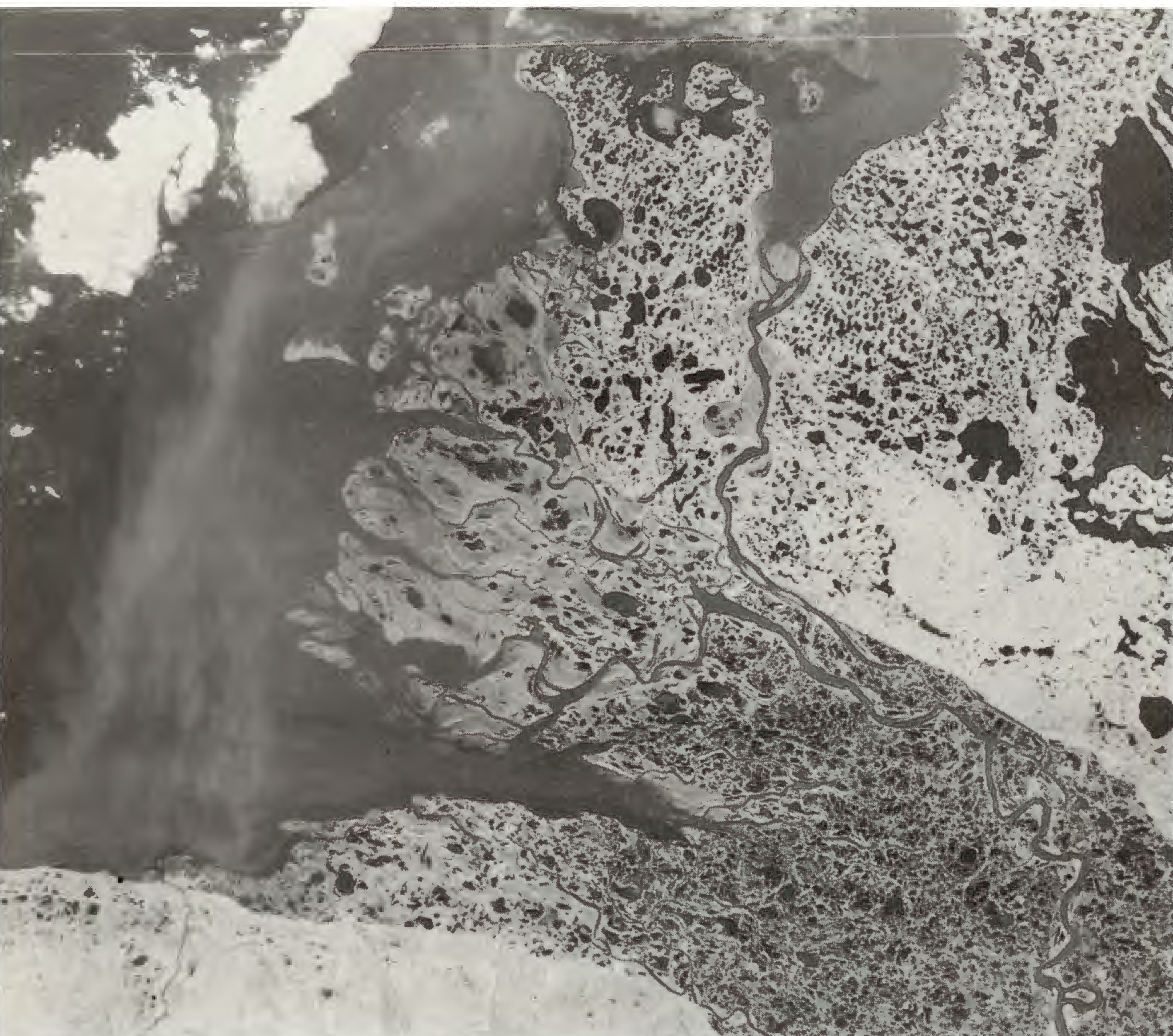
The Mackenzie River was reported frozen over at Inuvik on October 12, two days before the mean freeze-up date established for the period 1968-75 (Table 4.3).

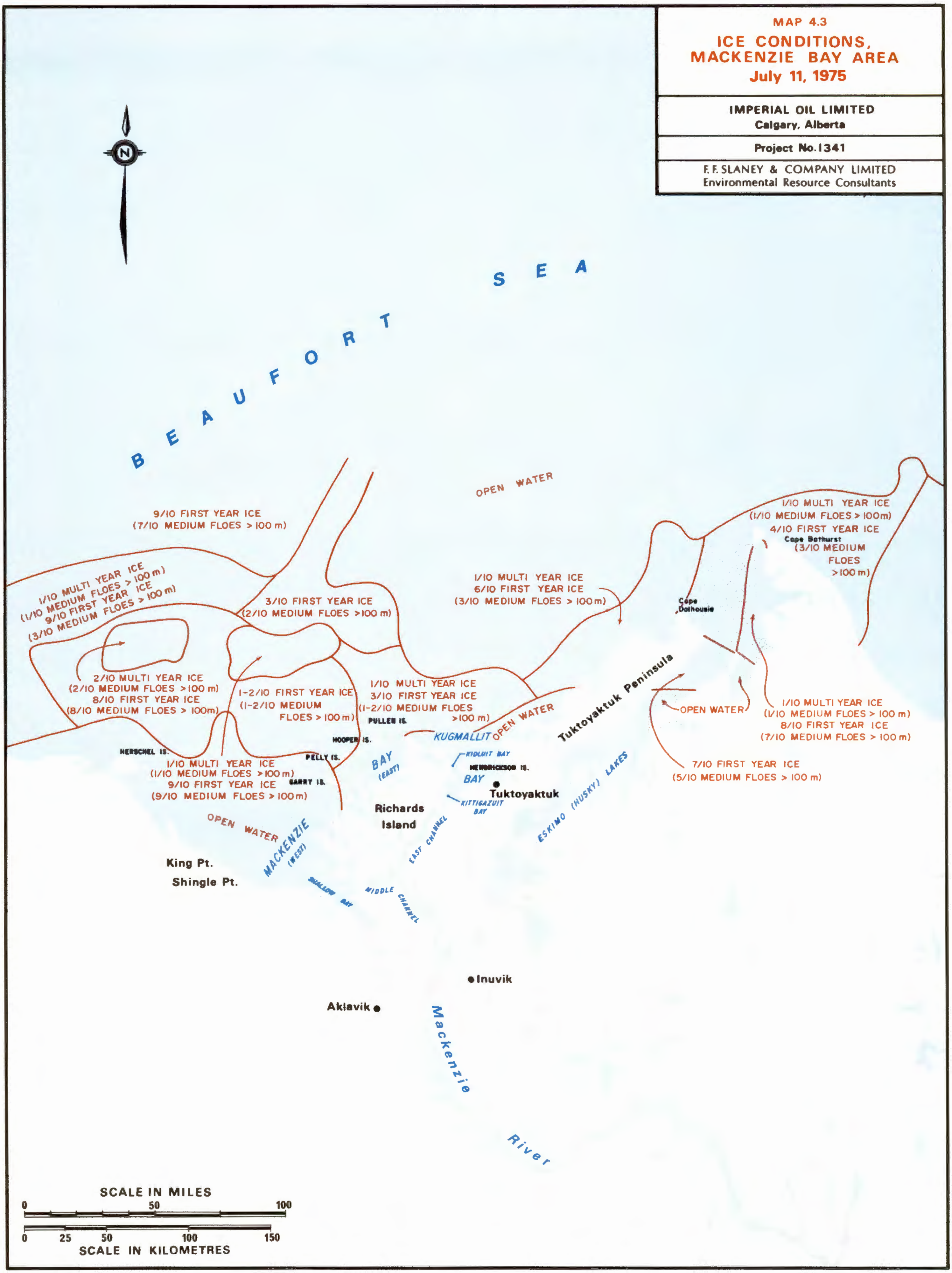
By late October, E.R.T. satellite photographs showed that nearshore freeze-up of the landfast ice was almost complete. However, large areas of open water and new ice were still evident along the shear zone. These

FIGURE 4.4

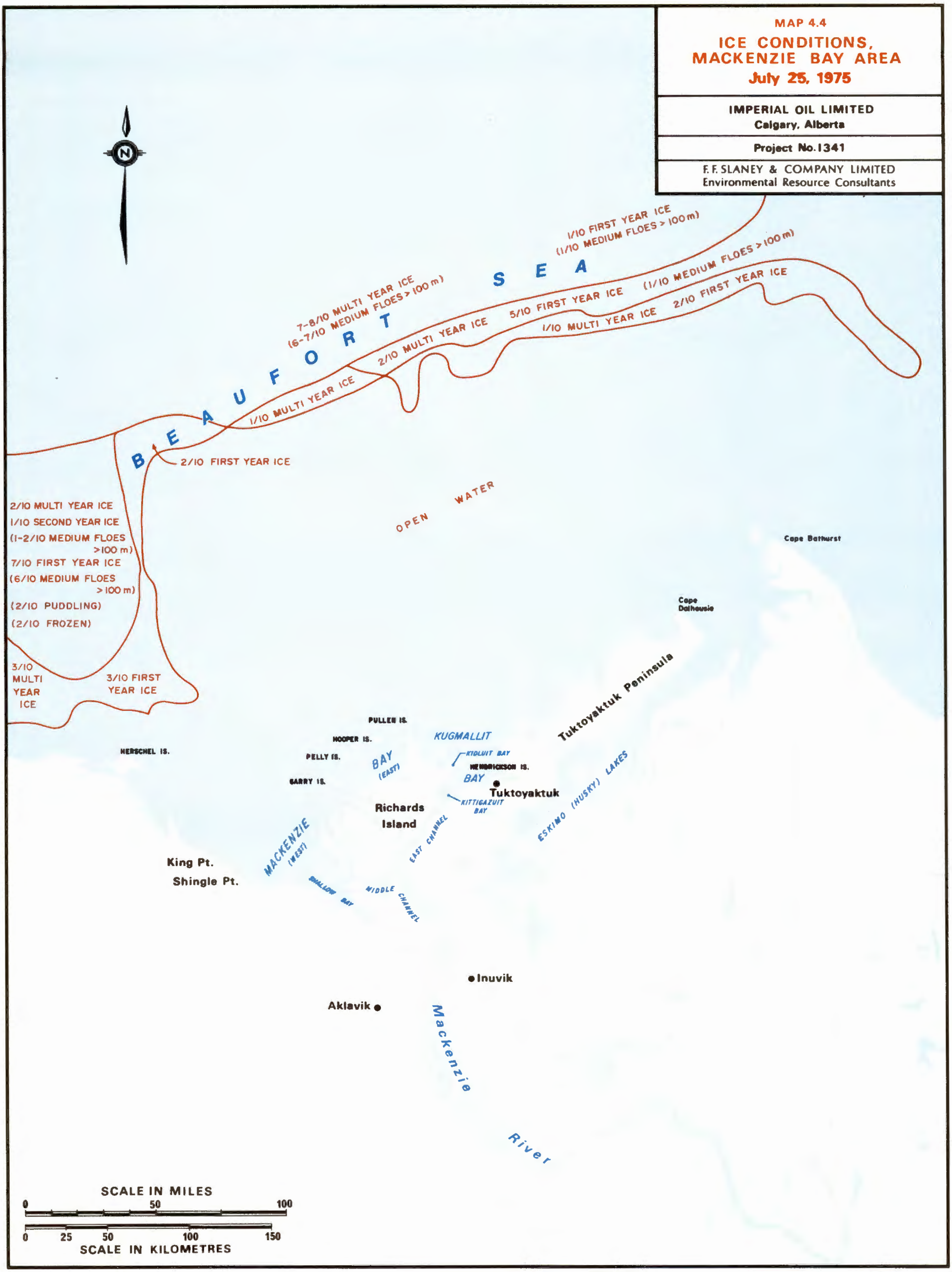
E.R.T. SATELLITE PHOTOGRAPH OF ICE CONDITIONS

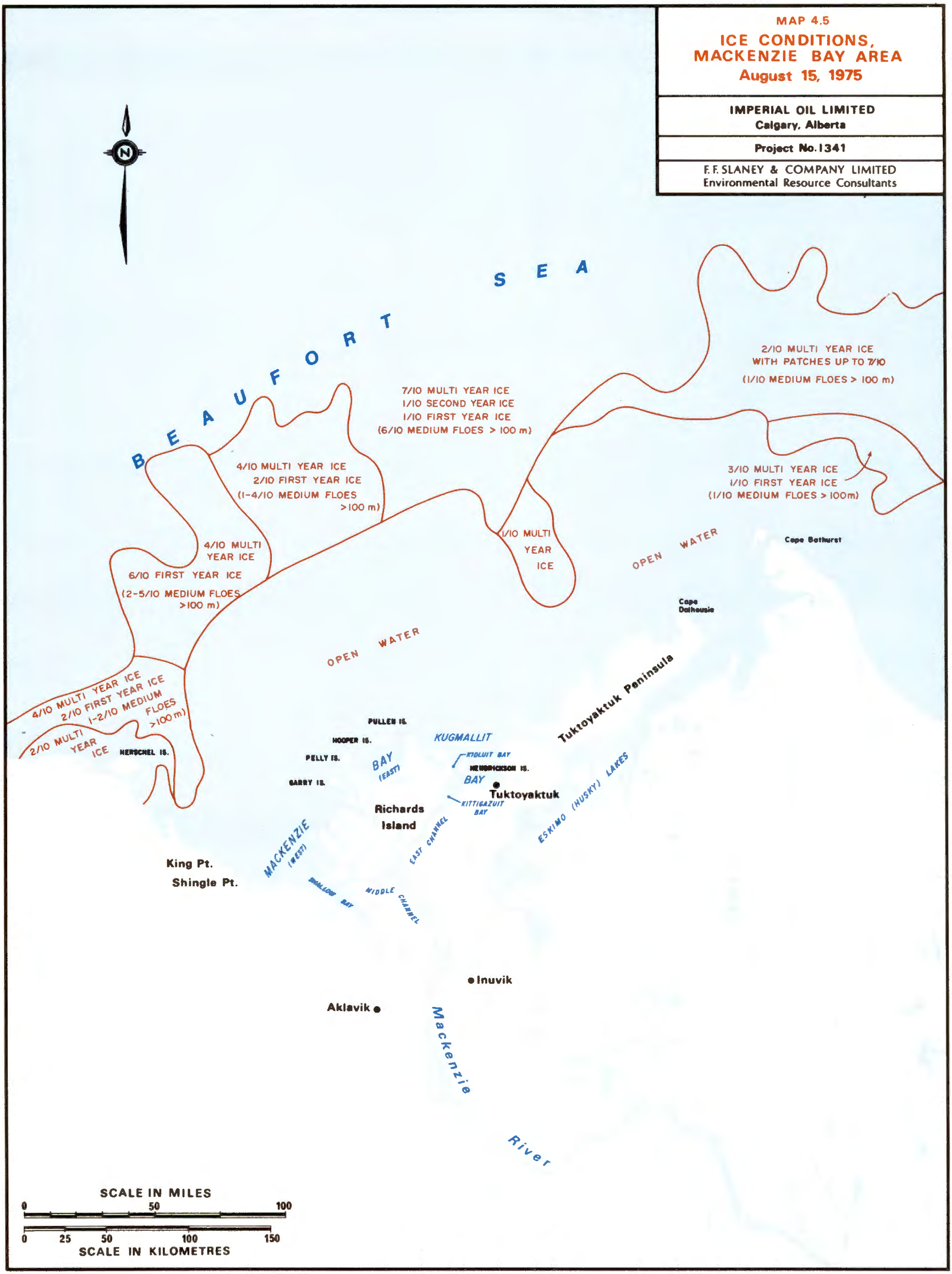
MACKENZIE BAY, JULY 7, 1975





MAP 4.3
ICE CONDITIONS, MACKENZIE BAY AREA
July 11, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No.1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
N
BEAUFORT SEA
OPEN WATER
9/10 FIRST YEAR ICE
(7/10 MEDIUM FLOES > 100 m)
1/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
9/10 FIRST YEAR ICE
(3/10 MEDIUM FLOES > 100 m)
3/10 FIRST YEAR ICE
(2/10 MEDIUM FLOES >100 m)
1/10 MULTI YEAR ICE
6/10 FIRST YEAR ICE
(3/10 MEDIUM FLOES > 100 m)
1/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES > 100m)
4/10 FIRST YEAR ICE
Cape Bathurst
(3/10 MEDIUM
FLOES
>100 m)
Cape Dalhousie
2/10 MULTI YEAR ICE
(2/10 MEDIUM FLOES >100 m)
8/10 FIRST YEAR ICE
(8/10 MEDIUM FLOES > 100m)
1-2/10 FIRST YEAR ICE
(1-2/10 MEDIUM
FLOES > 100 m)
1/10 MULTI YEAR ICE
3/10 FIRST YEAR ICE
(1-2/10 MEDIUM FLOES
>100 m)
OPEN WATER
Tuktoyaktuk Peninsula
OPEN WATER
1/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
8/10 FIRST YEAR ICE
(7/10 MEDIUM FLOES > 100 m)
PULLEN IS.
HOOPER IS.
HERSCHEL IS.
PELLY IS.
GARRY IS.
KUGMALLIT
BAY
KIDLUIT BAY
HENDRICKSON IS.
BAY
(EAST)
1/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES >100 m)
9/10 FIRST YEAR ICE
(9/10 MEDIUM FLOES > 100 m)
Tuktoyaktuk
KITTIGAZUIT BAY
ESKIMO (HUSKY) LAKES
7/10 FIRST YEAR ICE
(5/10 MEDIUM FLOES > 100 m)
Richards
Island
OPEN WATER
MACKENZIE (WEST)
EAST CHANNEL
King Pt.
Shingle Pt.
SHALLOW BAY
MIDDLE CHANNEL
Inuvik
Aklavik
Mackenzie
River
SCALE IN MILES
0 50 100
0 25 50 100 150
SCALE IN KILOMETRES


MAP 4.4
ICE CONDITIONS, MACKENZIE BAY AREA
July 25, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
N
BEAUFORT SEA
1/10 FIRST YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
7-8/10 MULTI YEAR ICE
(6-7/10 MEDIUM FLOES > 100 m)
(1/10 MEDIUM FLOES > 100 m)
2/10 FIRST YEAR ICE
5/10 FIRST YEAR ICE
1/10 MULTI YEAR ICE
2/10 MULTI YEAR ICE
1/10 MULTI YEAR ICE
2/10 FIRST YEAR ICE
2/10 MULTI YEAR ICE
1/10 SECOND YEAR ICE
(1-2/10 MEDIUM FLOES >100 m)
7/10 FIRST YEAR ICE
(6/10 MEDIUM FLOES >100 m)
(2/10 PUDDLING)
(2/10 FROZEN)
3/10 MULTI YEAR ICE
3/10 FIRST YEAR ICE
OPEN WATER
Cape Bathurst
Cape Dalhousie
Tuktoyaktuk Peninsula
PULLEN IS.
HOOPER IS.
PELLY IS.
GARRY IS.
HERSCHEL IS.
KUGMALLIT BAY
KIDLUIT BAY
HENDRICKSON IS.
Tuktoyaktuk
KITTIGAZUIT BAY
MACKENZIE BAY (EAST)
ESKIMO (HUSKY) LAKES
Richards Island
EAST CHANNEL
MACKENZIE (WEST)
King Pt.
Shingle Pt.
SHALLOW BAY
MIDDLE CHANNEL
Inuvik
Aklavik
Mackenzie River
SCALE IN MILES
0 50 100
0 25 50 100 150
SCALE IN KILOMETRES

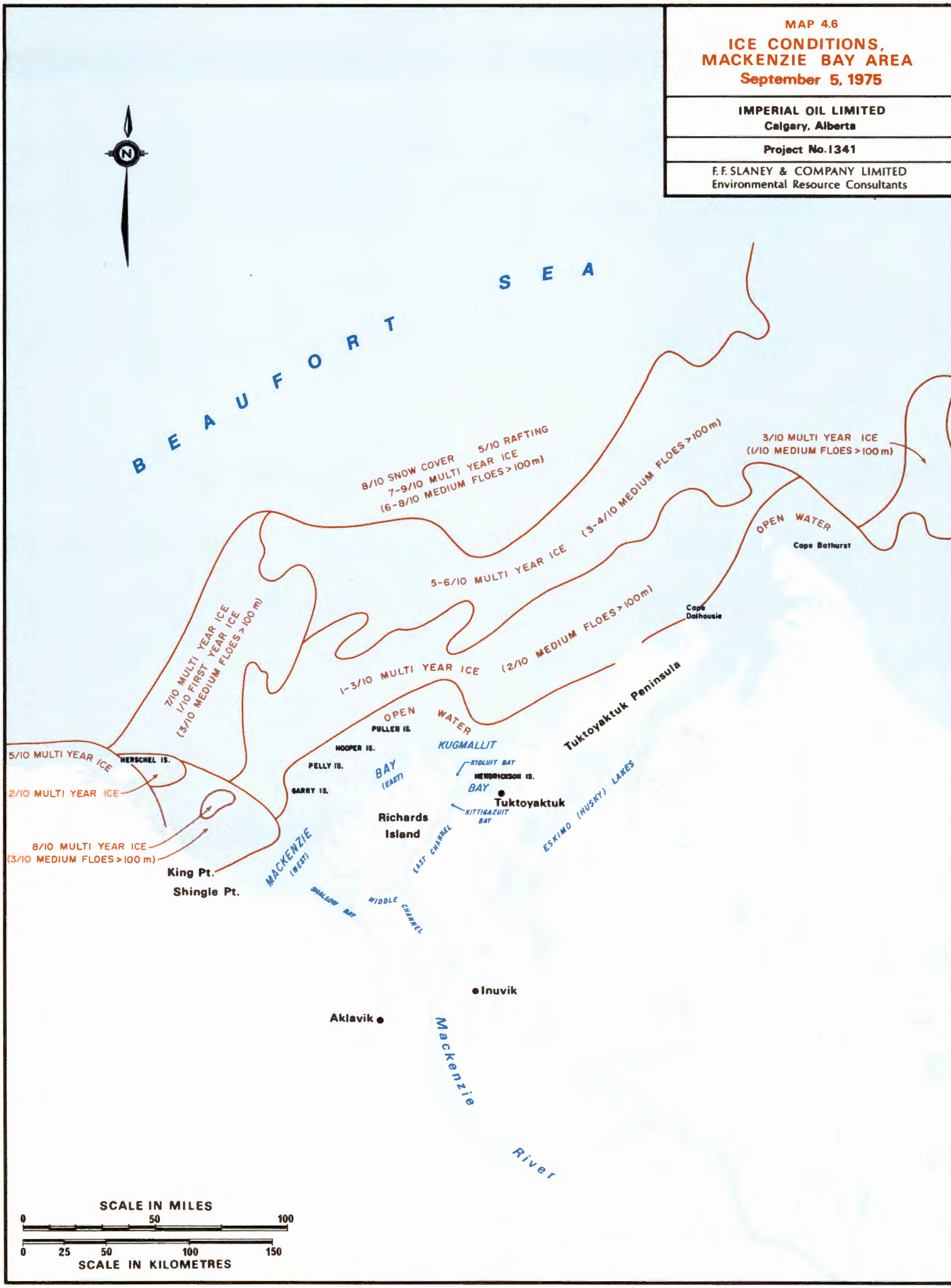


MAP 4.5
ICE CONDITIONS, MACKENZIE BAY AREA
August 15, 1975

IMPERIAL OIL LIMITED
Calgary, Alberta

Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants



MAP 4.6
ICE CONDITIONS, MACKENZIE BAY AREA
September 5, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No.1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
N
BEAUFORT SEA
8/10 SNOW COVER 5/10 RAFTING
7-9/10 MULTI YEAR ICE
(6-8/10 MEDIUM FLOES > 100 m)
(3-4/10 MEDIUM FLOES > 100 m)
5-6/10 MULTI YEAR ICE
3/10 MULTI YEAR ICE
(1/10 MEDIUM FLOES > 100 m)
OPEN WATER
Cape Bathurst
Cape Dalhousie
7/10 MULTI YEAR ICE
1/10 FIRST YEAR ICE
(3/10 MEDIUM FLOES > 100 m)
1-3/10 MULTI YEAR ICE
(2/10 MEDIUM FLOES > 100 m)
Tuktoyaktuk Peninsula
OPEN WATER
PULLEN IS.
HOOPER IS.
PELLY IS.
GARRY IS.
HERSCHEL IS.
KUGMALLIT BAY
KIDLUIT BAY
HENDRICKSON IS.
Tuktoyaktuk
KITTIGAZUIT BAY
5/10 MULTI YEAR ICE
2/10 MULTI YEAR ICE
8/10 MULTI YEAR ICE
(3/10 MEDIUM FLOES > 100 m)
BAY (EAST)
Richards Island
ESKIMO (HUSKY) LAKES
EAST CHANNEL
MACKENZIE (WEST)
King Pt.
Shingle Pt.
SHALLOW BAY
MIDDLE CHANNEL
Inuvik
Aklavik
Mackenzie River
SCALE IN MILES
0 50 100
0 25 50 100 150
SCALE IN KILOMETRES

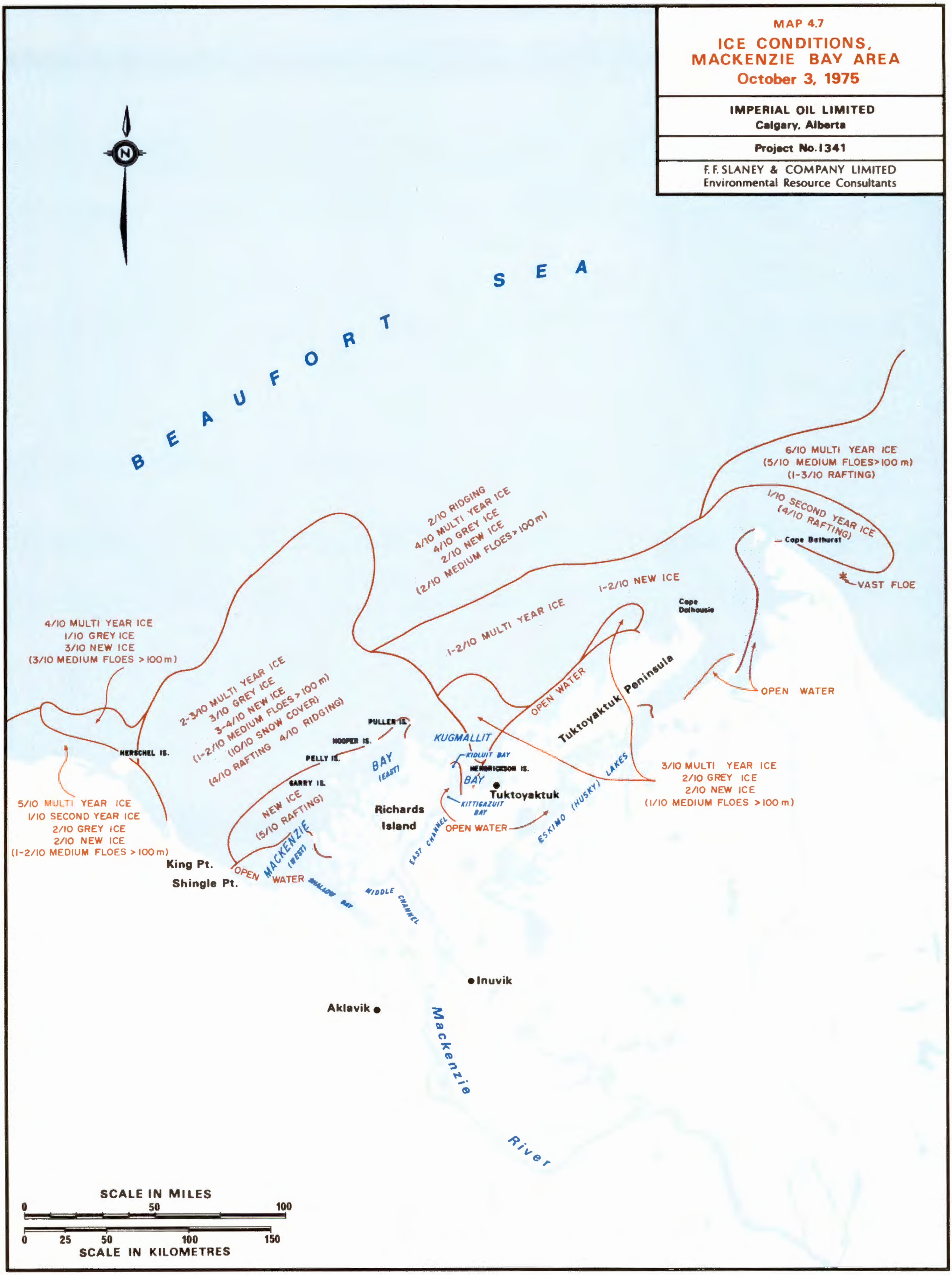

MAP 4.7
ICE CONDITIONS, MACKENZIE BAY AREA
October 3, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
N
BEAUFORT SEA
6/10 MULTI YEAR ICE
(5/10 MEDIUM FLOES>100 m)
(1-3/10 RAFTING)
1/10 SECOND YEAR ICE
(4/10 RAFTING)
Cape Bathurst
VAST FLOE
2/10 RIDGING
4/10 MULTI YEAR ICE
4/10 GREY ICE
2/10 NEW ICE
(2/10 MEDIUM FLOES>100 m)
1-2/10 NEW ICE
Cape Dalhousie
1-2/10 MULTI YEAR ICE
4/10 MULTI YEAR ICE
1/10 GREY ICE
3/10 NEW ICE
(3/10 MEDIUM FLOES >100 m)
2-3/10 MULTI YEAR ICE
3/10 GREY ICE
3-4/10 NEW ICE
(1-2/10 MEDIUM FLOES>100 m)
(10/10 SNOW COVER)
(4/10 RAFTING 4/10 RIDGING)
OPEN WATER
Tuktoyaktuk Peninsula
OPEN WATER
PULLEN IS.
HOOPER IS.
PELLY IS.
HERSCHEL IS.
GARRY IS.
KUGMALLIT BAY
(EAST)
KIDLUIT BAY
HENDRICKSON IS.
BAY
Tuktoyaktuk
KITTIGAZUIT BAY
3/10 MULTI YEAR ICE
2/10 GREY ICE
2/10 NEW ICE
(1/10 MEDIUM FLOES >100 m)
5/10 MULTI YEAR ICE
1/10 SECOND YEAR ICE
2/10 GREY ICE
2/10 NEW ICE
(1-2/10 MEDIUM FLOES >100 m)
NEW ICE
(5/10 RAFTING)
MACKENZIE (WEST)
Richards Island
OPEN WATER
ESKIMO (HUSKY) LAKES
EAST CHANNEL
King Pt.
Shingle Pt.
OPEN WATER
SHALLOW BAY
MIDDLE CHANNEL
Inuvik
Aklavik
Mackenzie River
SCALE IN MILES
0 50 100
0 25 50 100 150
SCALE IN KILOMETRES

FIGURE 4.5

E.R.T. SATELLITE PHOTOGRAPH OF ICE CONDITIONS

MACKENZIE BAY, OCT. 6, 1975

TABLE 4.3

INUVIK FREEZE-UP DATES* - MACKENZIE RIVER

Year	Date of Complete Freeze-Over
1968	October 12
1969	October 18
1970	October 15
1971	October 16
1972	October 20
1973	October 19
1974	October 2
1975	October 12
MEAN	October 14
STANDARD DEVIATION	5.8 days

*Pers. Comm. Herb Wood, Water Surveys of Canada, Inuvik.

darker-appearing areas reached widths of 20 to 30 km in places, and stretched entirely across Mackenzie Bay.

4.6.2 Winds

As detailed in Slaney (1975), coastline features near Mackenzie Bay have a governing effect on the distribution of prevailing winds. Mean annual distribution of winds at Shingle Point and at Tuktoyaktuk display significant differences due to topographical features. At Shingle Point, the highest percentage of winds come from the WNW octant, and at Tuktoyaktuk from the ESE. Usual directions for strongest winds are from the WNW at both stations. In fact, nearly all major high wind summer sessions recorded in Mackenzie Bay have occurred from between NW and NE octants.

Wind roses from the remote weather station at Taglu G-33 for the period 1972-74 (Slaney, 1975) indicated that highest frequencies of winds by direction were from northerly quadrants in the summer (the ice-free period) and from easterly quadrants in the winter.

4.6.2.1 1974 Summer Winds

The wind distribution for summer, 1974, generated one of the worst ice years in history for the southern Beaufort Sea. Recorded winds for August, 1974, at Langley Island base camp blew from the quadrant between NW and NE for 70 percent of the time (Slaney, 1975). The generally prevailing NW winds offshore kept the multi-year pack-ice close to the ten to 15 m depth contours in Mackenzie Bay throughout most of the summer.

4.6.2.2 1975 Summer Winds

During the summer of 1975, F.F. Slaney & Company took periodic measurements of wind speed and direction in conjunction with the marine sampling program in Mackenzie and Kugmallit Bays (Appendix 4.1). Wind observations were also available periodically from Shell Farewell and Garry Island (Appendix 4.1). Winds prevailed from the NW to the NE as they did in 1974, but with a much higher incidence of NE winds in 1975. As described earlier, these persistent NE winds helped clear the multi-year ice from Kugmallit and Mackenzie Bays throughout most of the summer. Much of the ice was transported to the Alaskan and northern Yukon coasts where multi-year ice was packed tightly against the shore for most of the summer.

The two highest summer wind sessions in 1975 occurred on August 10 to 11 and August 26 to 27. Winds blew from the NW during both these sessions and generated moderate storm surges on the outer Delta channels (Slaney, 1976). Winds at Inuvik were reported gusting 30 to 40 knots (55 to 74 kmh) on the evening of August 10.

4.6.3 Currents

The general circulation of waters in the Beaufort Sea is clockwise at speeds averaging 1.5 to three km per day (Slaney, 1975). The pattern is commonly called the "Beaufort Sea gyre." Associated with the major gyre area, there is a small weak anti-cyclonic gyre in Amundsen Gulf, a shear zone north of the Mackenzie Delta, and a divergence zone along the western coast of Banks Island (the source region for a large polynya).

Circulation patterns near the coast of Kugmallit and Mackenzie Bays are governed by numerous physical forces (Slaney, 1975), but are largely dependent on the prevailing wind fields, and hence the short term coastal currents are irregular and somewhat unpredictable (Healey, 1970; Beaufort Sea Project D3, 1974 and 1975).

4.6.3.1 1974 Current Measurements

In the open water season of 1974, winds from the NE to NW were most common. Current measurements during these numerous wind sessions enabled average circulation patterns to be interpreted for both NE and NW wind sessions in East Mackenzie Bay. Plotted surface current patterns are shown in Maps 21 and 22 (Slaney, 1975). Section 4.2.5.1 (Slaney, 1975) describes the actual movements.

4.6.3.2 1975 Current Measurements

In 1975, the study area was expanded to include additional oceanographic stations in Kugmallit Bay. Prevailing winds were generally from the NE, and as a result most current measurements were taken in Kugmallit and East Mackenzie Bay during wind sessions with easterly components (Appendix 4.1).

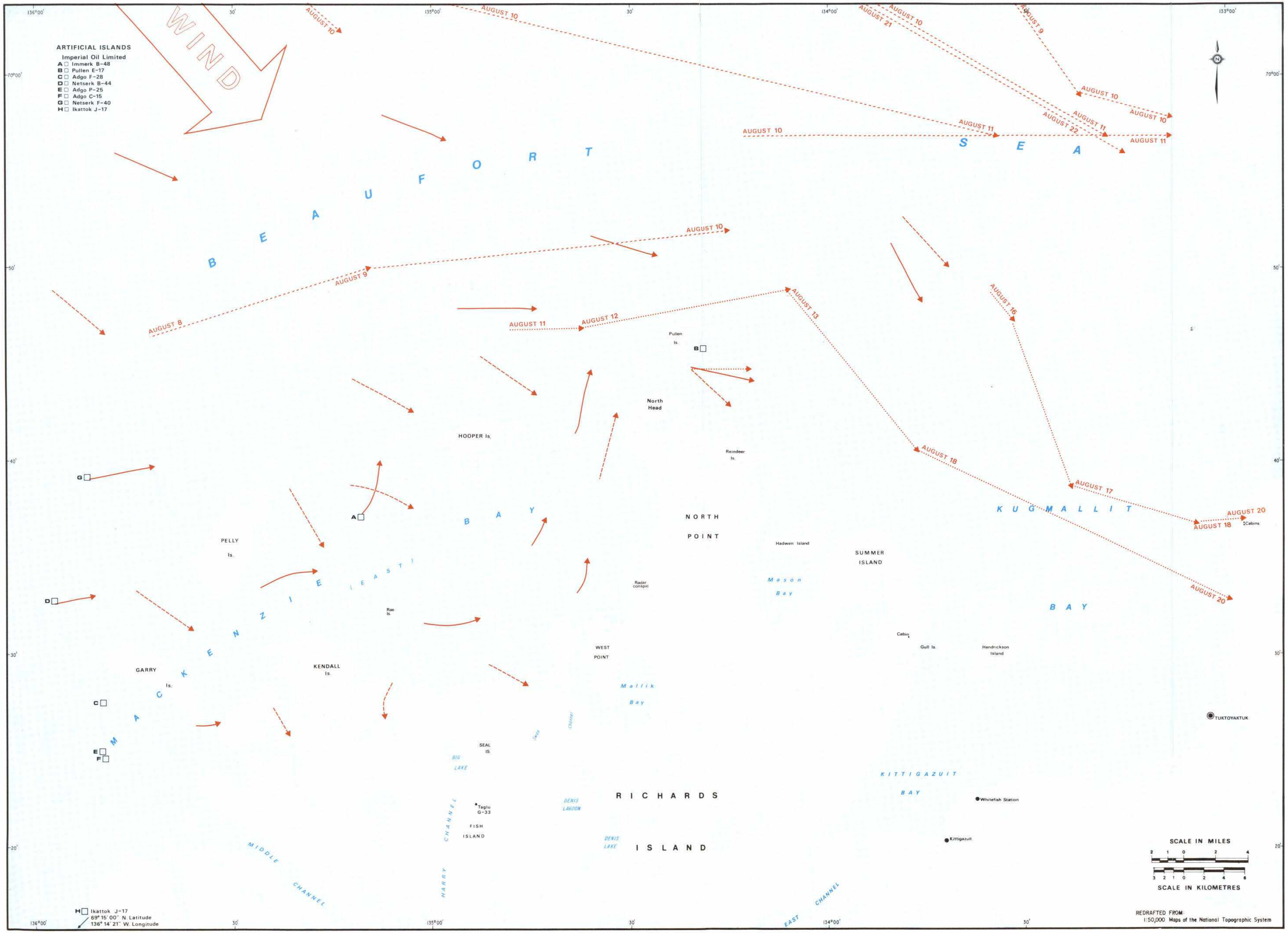
The 1974 mapping of current regimes for NE and NW winds were refined with the new data, and expanded to include areas within Kugmallit Bay (Maps 4.8 and 4.9). Also shown are drogue track observations from Beaufort Sea Project D3 (1974 and 1975) which were taken in the study area during NE or NW wind regimes.

During moderate NE winds, offshore surface currents in Mackenzie Bay (beyond the Barrier Islands) are southwesterly reflecting the NE wind stress. Longshore currents near outer edges of the Barrier Islands move in a westerly direction almost parallel to existing spits. Between Hooper and Richards Islands, a portion of the main stream is deflected southwards and split into an eastern counter-clockwise gyre which extends into the Bay. As the western gyre circulates, it further splits into a northerly component between Hooper and Pelly Islands and a westerly component between Pelly and Garry Islands. In the area west of Garry Island, the current flow is westerly and reflects both the NW hydrologic outflow from Middle Channel and the NE wind stress.

Circulation in the eastern half of Kugmallit Bay during NE winds reflects quite closely the direction of wind stress. Longshore currents are SW along the Tuktoyaktuk Peninsula. Currents in the western portion of Kugmallit Bay reflect the outflow from East Channel and the boundary constraints of Richards Island. The result is a clockwise gyre similar to that generated in East Mackenzie Bay. Longshore SW currents are deflected northwards past Mason Bay and eventually W again between Pullen Island and the North Head.

During moderate NW winds, the offshore wind-driven currents in Mackenzie Bay reflect the shoreline boundary constraints and Middle Channel hydrologic outflow. As a result, offshore currents track in an ESE direction. Longshore currents near the outer foreshore edges of the Barrier Islands are more tightly bound to shore constraints, and hence move in a slightly more easterly direction than do the offshore currents. Inside the Barrier Islands, the foreshore boundary constraints introduce more northerly components to the generally easterly moving currents. Most water enters the inner Bay from the west between Garry and Pelly Islands. Discharge of waters from the inner Bay occurs at two locations. Some water moves NE and out between Pelly and Hooper Islands, but more moves E below Hooper Island and then N between Hooper and Richards Islands. When the northerly nearshore currents meet the easterly offshore currents they become sharply deflected to the east and soon track ESE between Pullen and Richards Islands.

Drogues tracked by the Beaufort Sea Project during NW winds generally



LEGEND

- Currents averaged from F.F. Slaney & Company measurements during northwest winds ≥ 5 m.p.h. and < 20 m.p.h., 1974-75
- Estimated currents during northwest winds > 40 m.p.h.
- Drogue tracks measured by MacNeill & Garrett, 1975 during northwest winds.
- Drogue tracks measured by MacNeill & Garrett, 1974 during northwest winds.

MAP 4.8

Surface Ocean Currents During N.W. Winds

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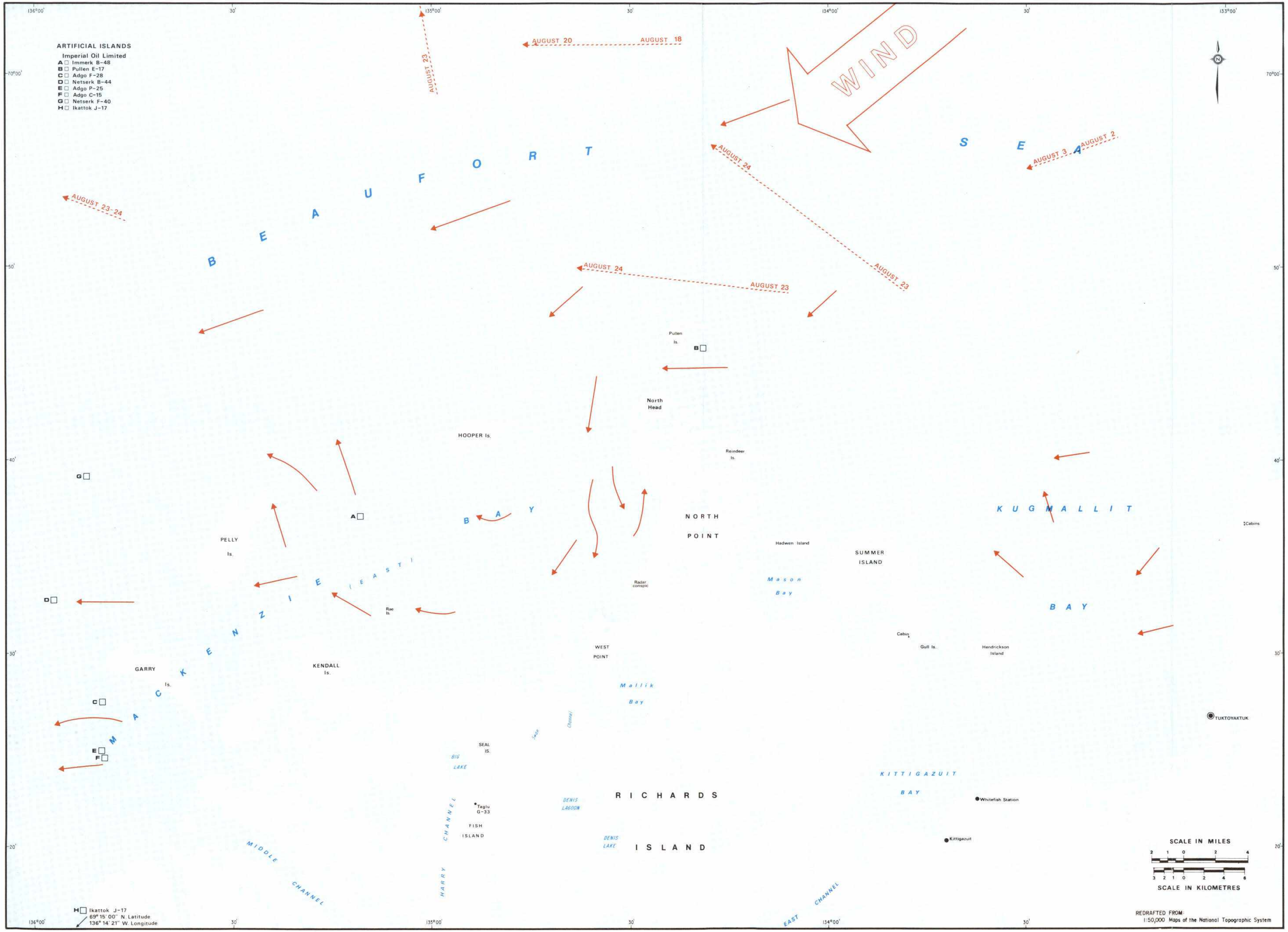


LEGEND

→ Currents averaged from F.F. Slaney & Company measurements during northeast winds ≥ 5 m.p.h. and < 20 m.p.h., 1974-75

----→ Drogue tracks measured by MacNeill & Garrett, 1974

MAP 4.9
Surface Ocean Currents During N.E. Winds

IMPERIAL OIL LIMITED
Calgary Alberta
Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants

followed the easterly longshore currents off the Barrier Islands as far as Pullen Island, and then headed SE into Kugmallit Bay. Current measurements in Kugmallit Bay during sustained NW winds were not collected in 1975. However, the eastern deflection of the drogue track August 17 to 18, 1975 suggests the presence of a slight counter-clockwise circulation with NE flow along the Tuktoyaktuk Peninsula.

Current speeds are variable in Mackenzie and Kugmallit Bays. Highest currents are usually measured in more restricted passages or during high winds. In 1975, surface currents at Station 8 (Netserk South) were measured as high as 1.7 knots (3.1 kmh) during 20 to 25 mph (32 to 40 kmh) westerly winds. These were the highest surface currents recorded in both 1974 and 1975 open water seasons.

Heavy NW winds (>40 mph (64 kmh)), and the resulting elevation of normal water levels in Mackenzie Bay, cause extensive changes in the normal current regime. The high wind stresses drive surface waters into Mackenzie Bay (Map 4.8). Foreshore boundary constraints are changed as large volumes of water are funnelled into the outer Mackenzie Delta floodplain. Mackenzie River outflow is reversed in all outer Delta channels until their banks are flooded. Offshore currents turn more southerly with the reduction of shoreward constraints and reflect more closely the true NW wind direction. Longshore currents along the Barrier Islands also turn shoreward, and with the resulting rise in water levels, flood the lowland island areas and spits. In such a situation, large amounts of sediment are transported directly across the spits rather than longitudinally around their outer edges.

A continuance of heavy winds and rising waters can push onshore current speeds in the inner Bay region to three or four times their normal magnitudes. Only when the storm finally peaks do the water levels stop rising and the currents subside. As the storm weakens and water levels begin to drop, a seaward return of the flooding waters is initiated. The return period of such waters (usually 1 to 2 days) is much longer than that for the pre-storm build-up (4 to 6 hours), so that post-storm seaward currents are probably considerably less than the onshore-moving storm currents.

4.6.4 Beaufort Sea Storms and Storm Surges

The average summer storm in Mackenzie Bay is preceded by the establishment of a low pressure system in the NW Beaufort Sea (Slaney, 1975; A.E.S., 1945 to 1970). As the low pressure center deepens, it begins to track in a SE direction. Pressure gradients intensify on the western edge and cyclonic winds soon increase in speed. The considerable temperature differences between the water surface and overlying air result in the creation of large-scale gravity winds near a cold front which develops within the system. Because of normal eastward tracking of such storms and the barrier effects of the Richardson and British Mountains, the highest winds in Mackenzie Bay are usually experienced from the N. In fact, nearly all major high wind summer session recorded in Mackenzie Bay have occurred from between NW and NE octants. Winds from NW to NE octants are also those which cause the most efficient funnelling of onshore waters and produce the largest storm surging effects.

The best documented and one of the most severe storms ever experienced in Mackenzie Bay began on September 12, 1970, and lasted 36 hours. Winds at Shingle Point reached 70 mph (113 kmh) from the NW, lasted 3 to 4 hours and then weakened to between 30 to 50 mph (48 to 80 kmh). A 4.7 m rise of water was recorded at Shingle Point, and a rise of at least 3.3 m at Tuktoyaktuk. The return period of winds of this magnitude was estimated to be greater than 25 years (Department of Public Works, (D.P.W.), 1971).

Less intensive storms of shorter duration and causing smaller surging are a more usual occurrence for Mackenzie Bay. Several such storms were measured by F.F. Slaney & Company as part of their summer survey programs from 1972 through 1975 (Table 4.4). Water level increases were not necessarily a direct reflection of the peak or average winds attained. The two most important factors seemed to be the direction and duration of the high wind sessions. In general, high NW winds of fairly long duration produce the highest water level increases.

4.6.4.1 1975 Summer Storms and Storm Surges

Only two moderate storms and associated surges occurred during the open water season of 1975 (August 10 to 11 and August 26 to 27). Summer storm statistics collected by F.F. Slaney & Company in Mackenzie Bay since 1972 are presented (Table 4.4).

On August 6, a deepening low pressure system formed in the northern reaches of the Beaufort Sea. By the evening of August 8, the gradient along the SW edge of this system had intensified so that W winds of eight to 12 knots (15 to 22 kmh) were being reported N of Richards Island. Between August 8 and August 10 the winds intensified averaging about 15 knots (28 kmh) and shifting to the NW at Garry Island.

Throughout the day on August 10, the nearshore winds at Tuktoyaktuk were reported at about 20 knots (37 kmh) from the W until about 16:00 when they shifted to the NW and averaged 20 to 25 knots (37 to 46 kmh). Periodic gusts of 30 knots (55 kmh) were reported at Inuvik, and even greater gusts were reported for the Mackenzie Bay area. A moderate storm surge of about 1.2 m was recorded near the mouths of Harry and Kumak Channels (Slaney, 1976).

These moderately high winds on August 10 continued through the night and for most of August 11. However, in the early morning of August 11, the wind direction changed to W. From August 11 to 12, the low pressure system gradually moved eastwards and winds in Mackenzie and Kugmallit Bays shifted to the SE at about eight to 12 knots (15 to 22 kmh).

A similar pattern developed for the storm of August 26 and 27. On the evening of August 25, weather records from the hourly recording station at Tuktoyaktuk showed clear skies and light (eight to ten knots (15 to 18 kmh)) winds from the SE. However, by the morning of August 26, skies had clouded and building winds had shifted to more westerly components. At noon on August 26, the winds were recorded at 25 knots (46 kmh) and gusting to 36 knots (66 kmh) from the SW. At 22:00, August 26, winds were 20 knots (37 kmh) and gusting to 28 knots (52 kmh) from the NW.

Moderate WNW winds continued through the evening of August 26 and into the morning of August 27. Between 07:00 and 10:00 on August 27, wind speeds increased from 16 knots (29 kmh) W to 32 knots (59 kmh) and gusting to 40 knots (74 kmh) from the NW. These high winds continued until 18:00 August 27, after which mean hourly winds dropped to about 16 to 18 knots (29 to 33 kmh) from the NW and gradually shifted to more southerly components during the evening of August 27 to 28.

As a result of the August 27 storm, the highest positive storm surge of the 1975 open water season was recorded by the water level recorders

TABLE 4.4

SUMMER STORM STATISTICS 1972 - 1975

Year	Date	Location	Peak Wind Speed and Direction	Average Winds	Duration	Water Level Increase From Pre-Storm Level
1972	August 20-21	Taglu G-33	40 mph W	25 mph SW	4 hours	<4.0 feet
1972	Sept. 1-2	Taglu G-33	45 mph NW	30 mph NW	6 hours	5.0 feet
1973	July 20-21	Taglu G-33	60 mph NW	35 mph NW	4 hours	3.5 feet
1974	July 6	Langley Is.	60 mph NW	35 mph NW	2 hours	2.0 feet
1974	July 19	Langley Is.	45 mph NE	30 mph NE	3 hours	1.5 feet
1974	August 19	Langley Is.	50 mph NW	35 mph NW	4 hours	3.0 feet
1975	August 10-11	Taglu D-43	40 mph NW	30 mph NW	5 hours	4.0 feet
1975	August 27	Taglu D-43	50 mph NW	35 mph NW	8 hours	5.0 feet

at the mouths of Harry and Kuluarpak Channels (Slaney, 1976). Peak level was about 15 to 30 cm higher than the surge recorded for August 10 to 11.

4.6.5 Salinity

Salinity is a reliable characteristic of sea water that can be used to map both the horizontal surface movements and vertical stratification of water bodies. Annual salinity variations also influence the types of aquatic organisms, including benthos, plankton and fish, that could be expected to occupy the region.

An estuary, by definition, constitutes a gradient from freshwater to marine conditions. The size and extent of the estuary are usually determined by physical and temporal variations of the freshwater inflow. If the source of freshwater inflow is cut or reduced, salinities in the estuary will rise due to evaporation and influx of seawater. In such cases the estuary will become typical of an embayment, with salinities approaching those of the open ocean (Odum, 1970).

The extent of estuarine area within Mackenzie Bay is not well-defined and highly variable. A combination of extensive shallow banks and heavy winter ice cover aid in significantly modifying estuarine variations.

Cameron (1953) showed that during open water conditions, a marked change in the distribution of temperature and salinity occurred seaward of the fresh Mackenzie River discharge to Kugmallit Bay. During low winds and/or westerly flow, the low salinity Mackenzie outflow moves E as a result of Coriollis and wind stress forces. During easterly winds, the low salinity outflow is NW offshore resulting in nearshore surface replacement by higher salinity waters either upwelled or advected from areas to the east. Under such conditions, surface salinities can exceed 30 $^{o}/oo$ (Barber, 1968).

In July, 1970, Healey (1971) took observations of surface currents and salinity-temperature distributions on the western side of Kugmallit Bay and a small area about 4.5 miles (72 km) from Pullen Island. In Kugmallit Bay, he found that salinities were less than 1 $^{o}/oo$ at three m depth, and 30 $^{o}/oo$ at four m depth. These data indicated a very strong halocline had occurred between two and three m depth. North of Pullen Island, the halocline was not so pronounced and was observed between depths of three to five m.

Ince (1962) indicated that the under-ice waters of Kugmallit Bay in winter were composed basically of fresh Mackenzie River water showing little salinity variation.

4.6.5.1 Salinity in East Mackenzie Bay, 1972 and 1973

Slaney (1973) found very low and consistent salinities for the shallow surface and bottom waters between the Barrier Islands and Richards Island in July, 1972. Largest variability in surface salinities were found in late August, 1972, and were attributed to the advection of surface waters during the passage of several high wind sessions (Slaney, 1973). Peak or highest surface water salinities were reported at most stations in September, 1972. Wind observations for summer 1972, at Immerk artificial island showed the prevailing winds had been from the NW for July, E and NE for August and E and W for September. The higher incidence of easterly winds in late August and September had apparently caused some upwelling and advection of more saline waters in East Mackenzie Bay. Geographically, the highest salinities of inner East Mackenzie Bay were measured along the western edge of the North Head of Richards Island.

Winter under-ice water conditions were examined near Immerk in March, 1973 (Slaney, 1974c). The results showed that near Immerk artificial island, an average 1.8 m of ice cover separated the cold air above from a shallow isothermal water layer below, and salinities were always less than 1 ^{o}/oo.

4.6.5.2 Salinity in East Mackenzie Bay, Summer, 1974

In March and April, 1974, the surface layer salinities of under-ice water in East Mackenzie Bay ranged from less than 1 ^{o}/oo at most inshore stations to 8 ^{o}/oo near the ten m depth contour northeast of Pullen Island. Bottom salinities (1974) ranged from less than 1 ^{o}/oo at most inshore stations to 25 ^{o}/oo near the 12 m contour north of the Barrier Islands.

The open water season of 1974 had some of the worst ice conditions on record. Multi-year ice was never more than 100 km from Richards Island throughout the entire summer. Proximity of this ice and the generally prevailing NW winds helped to effectively dam Mackenzie River outflow into a narrow coastline fringe of very turbid and brackish water.

Surface salinities in July 1974 (Slaney, 1975) were 1 ^{o}/oo for inner East Mackenzie Bay. Vertical profiles taken inside the Barrier Islands showed the brackish water to extend over entire depths.

In August, surface salinities seldom rose above 5 ^{o}/oo in East Mackenzie Bay, but deeper stations, north of the Barrier Islands, showed a very strong halocline (Slaney, 1975).

At Station 2, the salinity changed from 3 ^{o}/oo at 3 m depth to 20 ^{o}/oo at 6 m depth; at Station 4 the salinity changed from 5 ^{o}/oo at 5 m depth to 25 ^{o}/oo at 11 m depth; and, at Station 5 the salinity changed from less than 5 ^{o}/oo at five m depth to 20 ^{o}/oo at 15 m. A temperature drop of an average 6^{o} C over the same station depths combined to produce a very defined pycnocline, or density gradient, between the upper freshwater and lower saline water masses in these areas.

E.R.T. satellite photographs in 1974 revealed that lessening ice conditions off Cape Bathurst finally allowed this turbid freshwater surface layer to escape to the east. It took about 20 to 25 days to reach Sachs Harbour (Beaufort Sea Project D4, 1975) and the west coast of Banks Island.

Highest surface salinities for the Barrier Island region of East Mackenzie Bay were measured in late September under about 10 cm of new ice. The average surface salinities were about three to four times those recorded in August. Salinity levels of 19.0 ^{o}/oo were reported near the northern tip of Pullen Island, 14.0 ^{o}/oo near the southern tip of Pullen Island, 19.5 ^{o}/oo on the lee side of Hooper Island Spit, 26 ^{o}/oo on the seaward side of Hooper Island Spit, and 4 ^{o}/oo on the seaward side of Pelly Island.

4.6.5.3 Salinity in Kugmallit and East Mackenzie Bays - Summer, 1975

Inner East Mackenzie and Kugmallit Bays contained fresh turbid water in early July, 1975. A survey of Stations 29, 30, 57, 33, 34, 16, 12, 11, 70 and 83 (west to east across Mackenzie and Kugmallit Bays from July 8 to July 14) revealed surface salinities of less than 1 ^{o}/oo, with conductivities ranging from 105 umhos/cm at Station 29 to 700 umhos/cm at Station 11 (Appendix 4.3). High seasonal runoff from the Mackenzie River channels and a few remaining large multi-year ice floes had combined to enclose a homogeneous layer of turbid freshwater in the nearshore areas of the Mackenzie Delta. Multi-year ice floes were observed within four km of Station 16 on August 10,

1975. Of the stations sampled in early July, only Station 11 showed salinity stratification with depth. Conductivity and salinity were respectively: 700 umhos/cm and 1 ^{o}/oo at 0.5 m depth; 880 umhos/cm and 1 ^{o}/oo at three m depth; and, 6500 umhos/cm and 6.5 ^{o}/oo at 6.5 m depth on bottom (Appendix 4.3). All other stations were shallower, and showed isohaline and isothermal conditions to the bottom.

From July 15 to 18, 1975, the oceanographic sampling program in Kugmallit and Mackenzie Bays had been designed to coincide with the E.R.T. satellite fly-pass of the study area. Unfortunately, adverse weather conditions caused the termination of the program after only one sampling day in Kugmallit Bay. Results of surface salinity measurements are shown (Figure 4.6). Station salinities and direction of surface currents have been superimposed on an E.R.T. satellite photo of Kugmallit and Mackenzie Bay for July 15, 1975 (Figure 4.6). Except for Station 73, all surface salinities during these NE winds were near 0 ^{o}/oo. A marked change in surface turbidity can be observed near Station 73, indicative of an important change in water type. The darker-appearing areas are the generally clear more saline, oceanic water that has been advected west with the NE winds. This water replaces the lighter-appearing brackish water from Mackenzie River channels. Primary surface isohalines are approximated for Kugmallit Bay (Figure 4.6).

During this period, sampling of the vertical water column at each station revealed that only Station 77 was homogeneous with depth. The vertical salinity and temperature structuring of Stations 73, 74, 75 and 78 is shown (Figure 4.7). Depth of the halocline (maximum vertical salinity gradient) increased shorewards from Station 73, probably the result of close proximity to East Channel outflow and increased wave activity. At Station 73, the halocline was at 1.6 m depth; at Station 74 at 2.2 m depth; at Station 78 at 2.6 m depth, and, at

Station 75 at 3.9 m depth. Bottom salinities at most stations were 13 to 15 ^{o}/oo, significantly higher than their surface values. Station 78, with bottom salinities of only about 8 ^{o}/oo, represented the horizontal transition zone between saline bottom areas offshore and the brackish well-mixed onshore waters as illustrated by the vertical homogeneity at Station 77.

The NE wind flow from July 15 to 17, 1975, carried the Mackenzie River plume westwards and also forced the multi-year ice pack well offshore. As a result, surface salinities measured near Pullen Island on July 17 and 18, 1975, were relatively high. The surface salinity at Station 2 was 17 ^{o}/oo (Figure 4.6) and 6 ^{o}/oo at Station 26. Bottom salinities were 25 ^{o}/oo and 30 ^{o}/oo, respectively. However, salinities measured near Kendall Island in East Mackenzie Bay (Station 58) were still extremely low (Appendix 4.3) reflecting the close proximity of heavy summer channel flow from Kumak Channel.

From July 28 to 31, 1975, the winds in East Mackenzie Bay were generally from the NW. As a result, a west-east sampling of Stations 8, 7, 16, 12, 1 and 11 during this period revealed relatively high surface salinities for the entire East Mackenzie Bay area. Lowest surface salinities (6 ^{o}/oo) were measured at Station 16 and highest (15 ^{o}/oo) at Station 1. Very little vertical structuring was observed at the nearshore Stations 8, 16, 12 and 11. Water columns were nearly homogeneous at these stations, indicating much larger salt volumes in Mackenzie Bay during summer, 1975, as compared to summer, 1974. In 1974, the proximity of multi-year ice had effectively pooled and concentrated the Mackenzie River freshwater outflow into nearshore Mackenzie Delta areas for most of the summer (Slaney, 1975). The 1975 offshore Stations 7 and 1 showed significant vertical structuring in late July, 1975, especially Station 7 (Figure 4.6). The upper

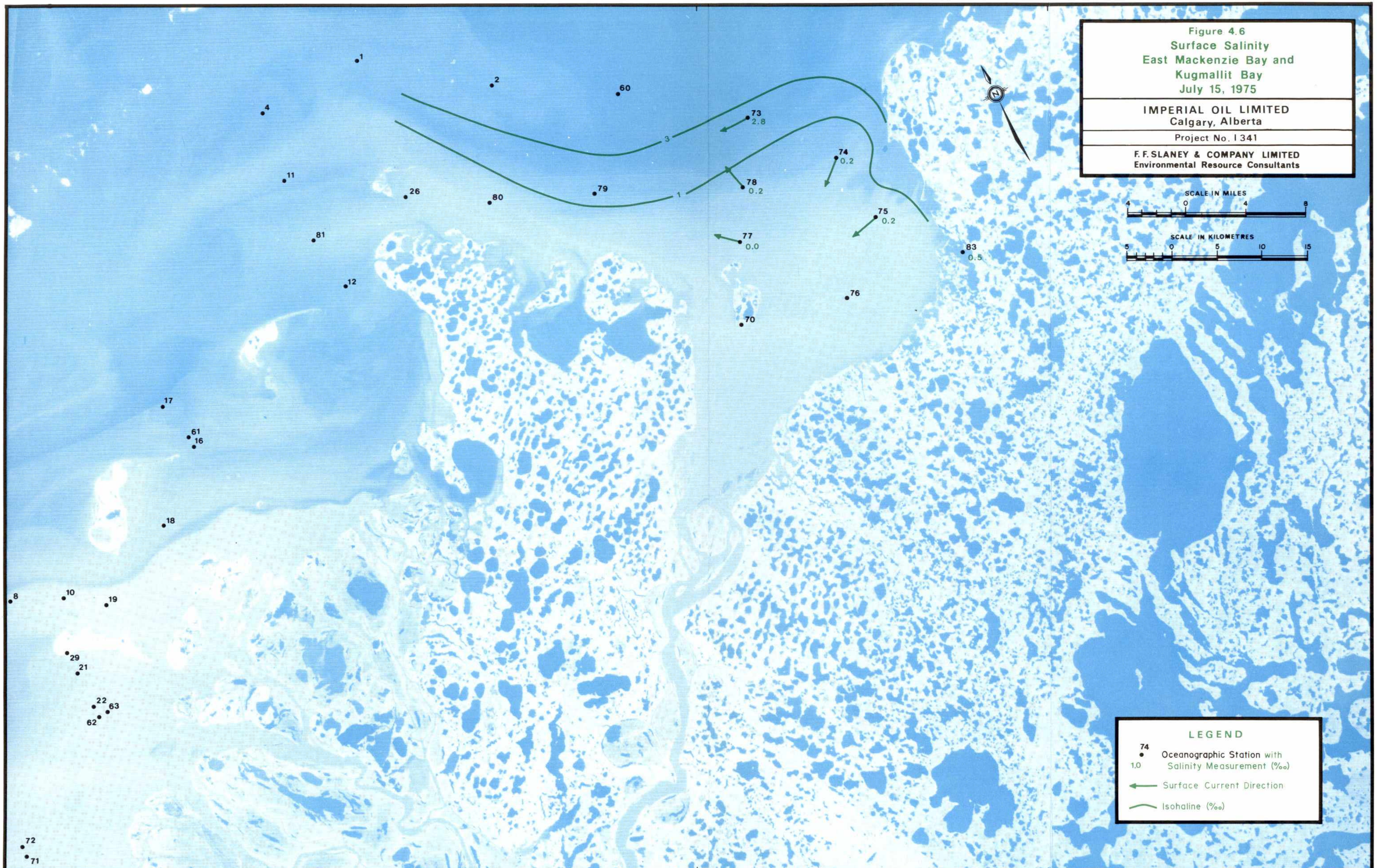


Figure 4.6
Surface Salinity
East Mackenzie Bay and
Kugmallit Bay
July 15, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
SCALE IN MILES
4 0 4 8
SCALE IN KILOMETRES
5 0 5 10 15
N
1
2
60
4
73
2.8
3
74
0.2
11
78
0.2
26
80
79
1
75
0.2
81
77
0.0
83
0.5
12
76
70
17
61
16
18
8
10
19
29
21
22
63
62
72
71
LEGEND
74
1.0
Oceanographic Station with
Salinity Measurement (‰)
Surface Current Direction
Isohaline (‰)

FIGURE 4.7 page 1

SALINITY - TEMPERATURE PROFILES
JULY 15, 1975

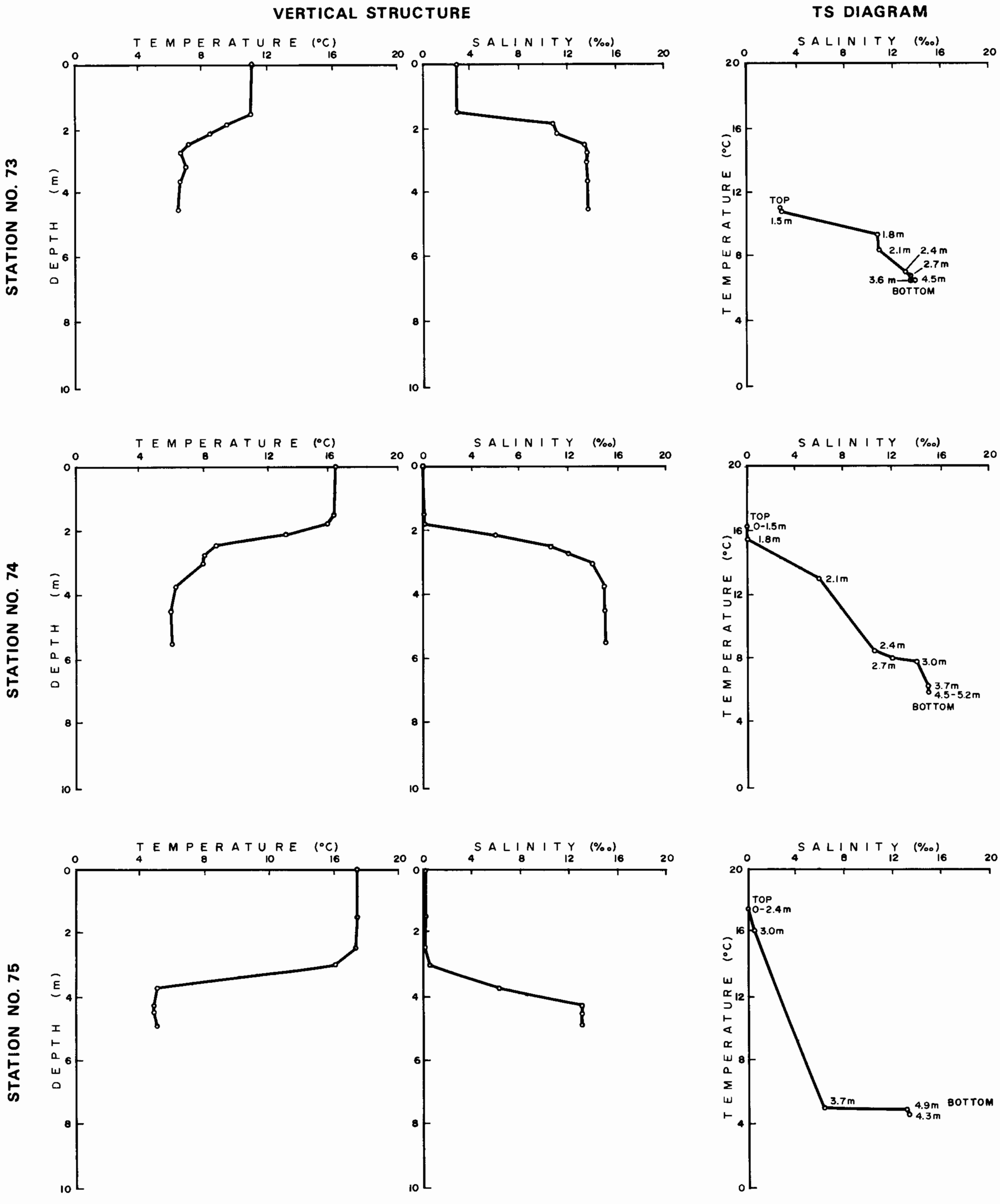
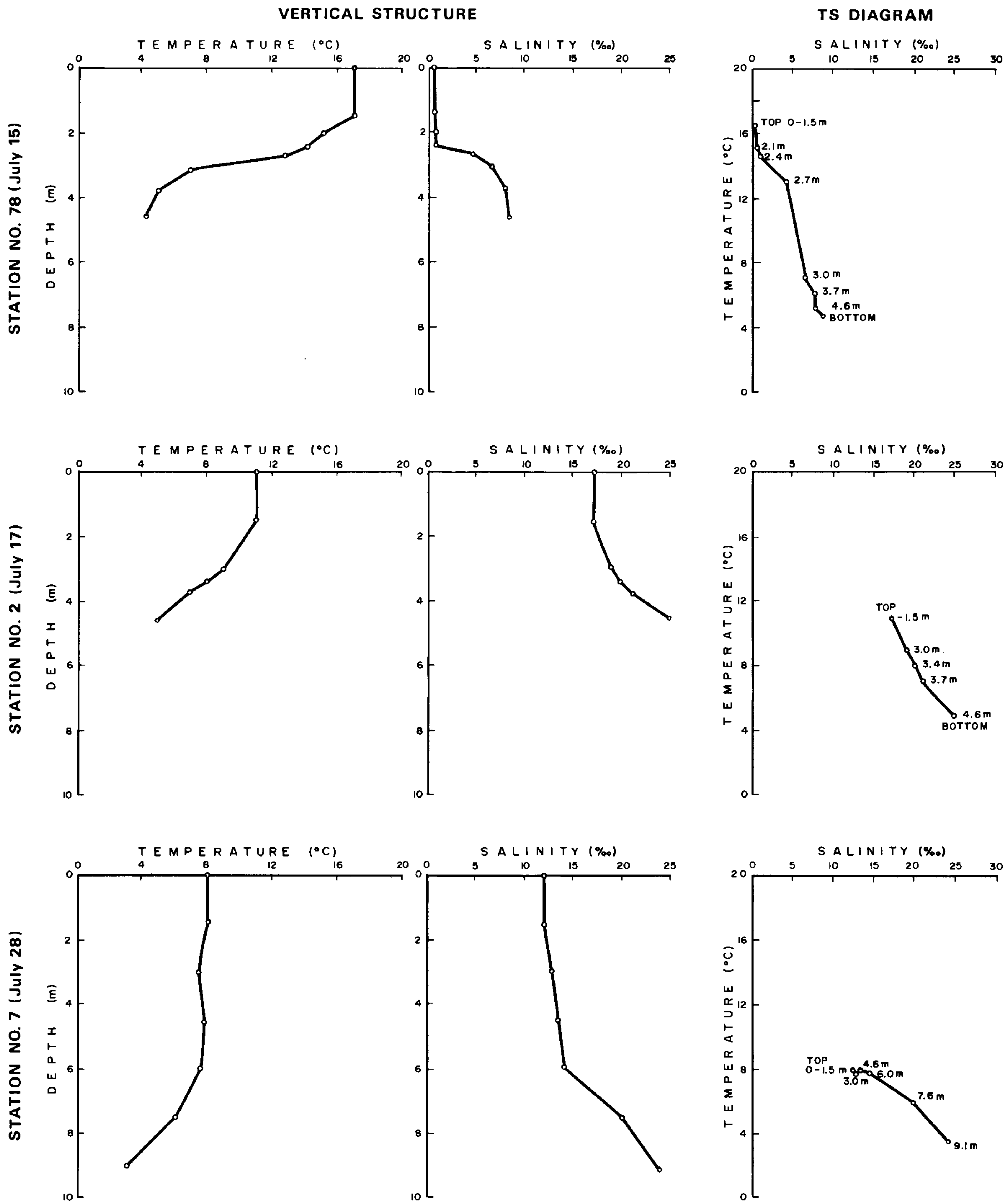


FIGURE 4.7 page 2

SALINITY - TEMPERATURE PROFILES

JULY 15-28, 1975



five m were well-mixed, but between the depths of six and nine m, salinity changed from about 14 to 24 $^{o}/oo$. A strong pycnocline (maximum vertical density gradient) resulted from the strong halocline and associated thermocline which were present, and prevented any natural mixing of the water column. As a result, the salinity changes that occurred at outer stations were probably associated with advection processes which are tied to the surface winds and freshwater outflows.

From August 2 to 4, 1975, the Wilson III surveyed Kugmallit and Mackenzie Bays during the second E.R.T. satellite fly-pass of the area. Horizontal salinity distributions are shown (Map 4.10). Cloud cover obscured most E.R.T. satellite imagery during this period, with only moderate clearing on August 4 (Figure 4.8).

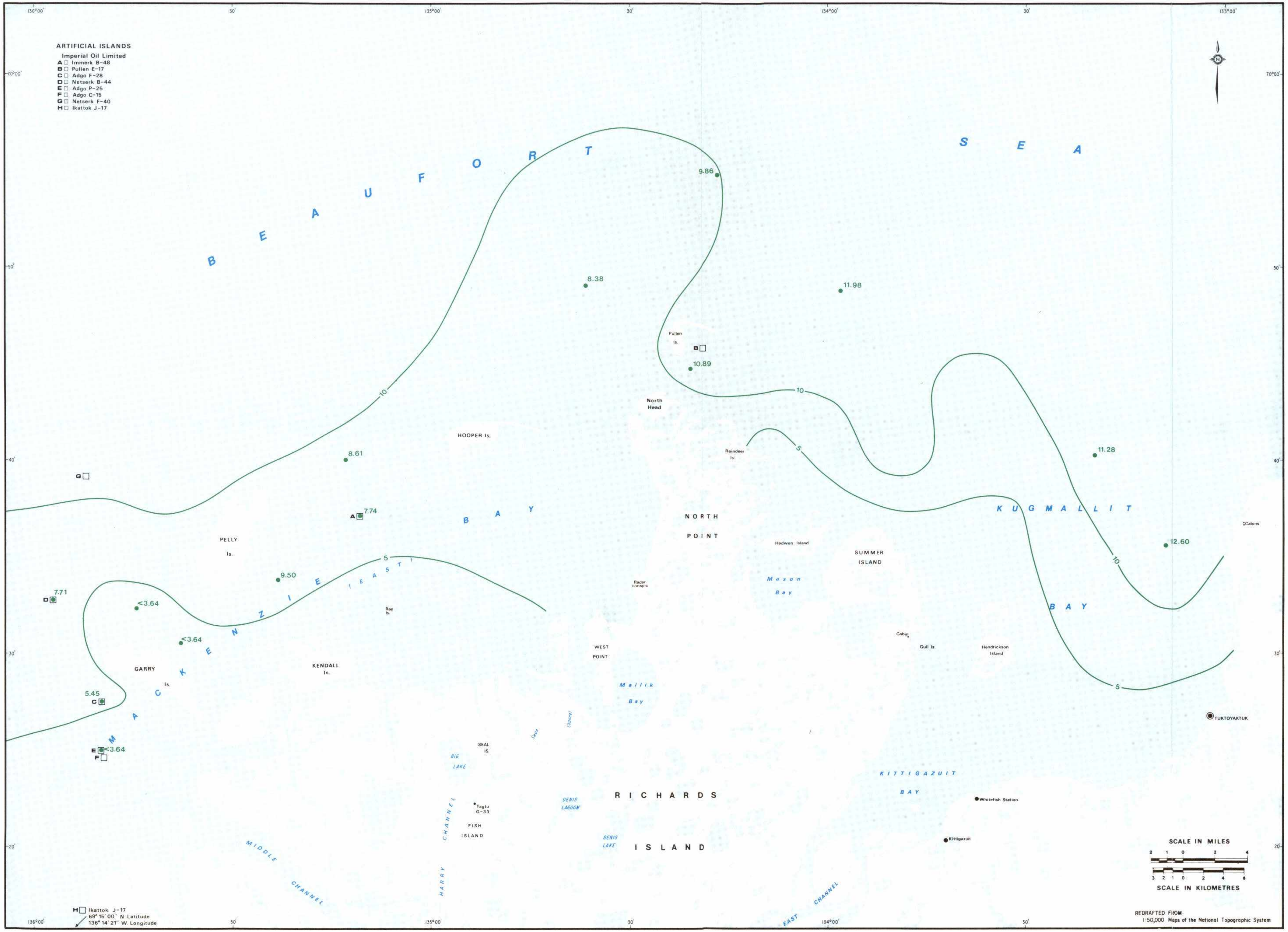
As revealed by the isohalines, a broad tongue of saline water extended into Kugmallit Bay along the Tuktoyaktuk coast (Map 4.10). Winds were prevailing northeasterly. East Channel outflows were diverted westwards around and seawards from the North Head of Richards Island. Surface salinities of 10 $^{o}/oo$ were common in the nearshore areas east and southeast of Pullen Island along the North Head. In East Mackenzie Bay, the 10 $^{o}/oo$ isohaline roughly paralleled the Barrier Islands with a large band of 5 - 10 $^{o}/oo$ water within the inner Bay. Detailed records of vertical salinity profiles in East Mackenzie Bay were lost with the Wilson III; however, laboratory analyses of preserved top and bottom water samples enabled some comparison of structuring in Kugmallit Bay (Appendix 4.3). Vertical salinity differences at sampled stations in Kugmallit Bay are shown (Table 4.5).

TABLE 4.5

VERTICAL SALINITY DIFFERENCES, KUGMALLIT BAY, AUGUST 2, 1975

	STATION						
	2	60	73	74	78	79	26
Depth (m)	4.6	5.3	5.0	5.2	4.6	4.3	3.9
Surface Salinity (°/oo)	11.98	10.47	11.28	12.60	7.01	12.78	10.89
Bottom Salinity (°/oo)	14.85	19.20	17.65	14.97	12.39	14.28	16.63
Vertical Salinity Difference (Surface to bottom)	2.87	8.73	6.37	2.37	5.38	1.50	5.74
Vertical Salinity Gradient (Surface to bottom in °/oo/m)	0.63	1.65	1.27	0.46	1.17	0.35	1.47

With the exception of the high bottom salinity value at Station 26 near Pullen Island, the highest bottom salinities were recorded at the deeper offshore stations. The largest salinity gradient (top to bottom) was measured at Station 60. The relatively high salinities at all depths for all stations indicates there is general replacement of the turbid, brackish Mackenzie River water with clear, more saline arctic marine water during sustained NE winds. Such high surface salinities may provide mechanisms for the earlier-than-predicted exchange of Tuktoyaktuk Harbour waters (Barber, 1968) during NE winds.



LEGEND

- 12.6 Oceanographic Station with Salinity Measurement (‰)
- Isohaline (‰)

MAP 4.10

Surface Salinity, East Mackenzie Bay and Kugmallit Bay, August 2-4, 1975

IMPERIAL OIL LIMITED
Calgary Alberta

Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants

FIGURE 4.8

E.R.T. SATELLITE PHOTOGRAPH,

MACKENZIE BAY, AUGUST 4, 1975

Periodic sampling in East Mackenzie Bay from August 5 to 19, 1975, indicated generally low salinity water of 3 $^{o}/oo$ for inner East Mackenzie Bay, south of Stations 8, 32 and 16 (Appendix 4.3). Stations along the NE spit of Pelly Island showed salinities of 6 $^{o}/oo$ on occasion, which would suggest periodic higher salinity intrusion to at least the edge of the Barrier Islands during early August, 1975. Station 71 was bounded by freshwater on August 18, 1975. However, as indicated by the vertical structuring at Netserk Stations 8 and 9 on August 16, a tongue of deeper saline water lay only a few km offshore (Figure 4.9).

Figure 4.10 shows the E.R.T. satellite photograph of surface conditions on August 20, 1975. Ship measurements of surface currents and salinities in Kugmallit Bay on August 20 are also displayed on the photo, as are selected primary isohalines. Planned sampling in inner Mackenzie Bay was not possible because of mechanical problems with the research vessel.

Winds were light and generally from south to east (Appendix 4.1) on August 20. Currents in Kugmallit Bay were weak and poorly defined. Highest surface salinities were measured at Stations 79 and 90, between Summer and Pullen Islands. Flow of the East Channel plume was generally eastwards along nearshore areas off Tuktoyaktuk Harbour. Measurements of vertical structure at each sampled station are shown (Figure 4.9). Stations 75 and 76, which lay directly in the shallow outflow from East Channel, maintained considerable stratification. The halocline was at about two m. Bottom salinities at these two stations were 5.5 and 5.8 $^{o}/oo$, respectively. Stations 79, 80, 26 and 2, which showed the greatest surface salinities, had the least vertical structuring. Evidently, mixing from continued wave action in these areas had helped to modify the salinity distributions with depth.

4.6.6 Water Temperature

The thermal budget is an important control of the physical, chemical and biological interactions occurring in water. It is also an important determinant of the percent saturation of dissolved oxygen which is crucial to all biological activity.

The water temperatures of East Mackenzie Bay are primarily controlled by the extreme arctic climate and the Mackenzie River outflow. Cameron (1953) described the effects of the fresh, turbid Mackenzie River on the vertical distribution of temperature and salinity in Mackenzie Bay. The high turbidity of the fresh surface layer impedes the normal transfer of heat to deeper layers, and allows the surface waters to heat considerably on calm, clear days. This surface heating helps to intensify the stability of the water column which is already high because of a strong halocline. The high stability impedes any vertical movements in the water column.

Water temperatures normally decrease with depth, but on some occasions a temperature inversion may develop. When the surface waters are exposed to cold northerly winds, the convective and conductive heat losses overcome the radiative heat gain and the temperature of surface waters decreases to levels below that of the water at deeper levels. Advection of melting ice into the Bay can cause the same kind of effect.

Surface water temperatures in Mackenzie Bay during open water conditions in 1972 ranged from $5^{o}C$ to $18^{o}C$, depending on the proximity of ice, the weather and the extent of turbid surface waters (Slaney, 1973). Bottom temperatures frequently approached the freezing temperature of the water (dictated by its salinity).

Slaney (1974c, 1974d) examined under-ice water temperatures near the Barrier Islands in March 1973 and March-April, 1974. Isothermal conditions

FIGURE 4.9 page 1

SALINITY - TEMPERATURE PROFILES
AUGUST 16 & 20, 1975

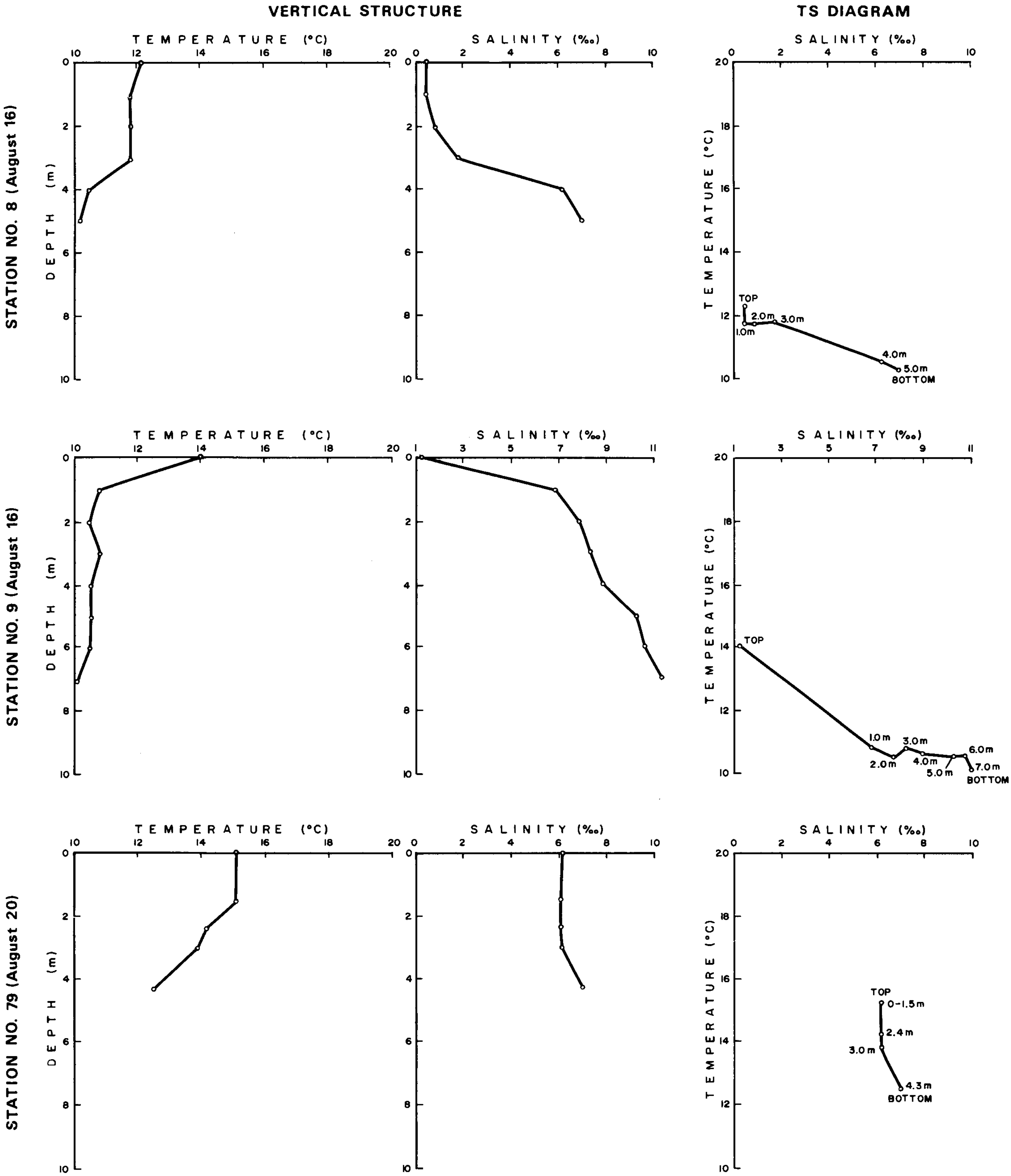


FIGURE 4.9 page 2

SALINITY – TEMPERATURE PROFILES
AUGUST 20, 1975

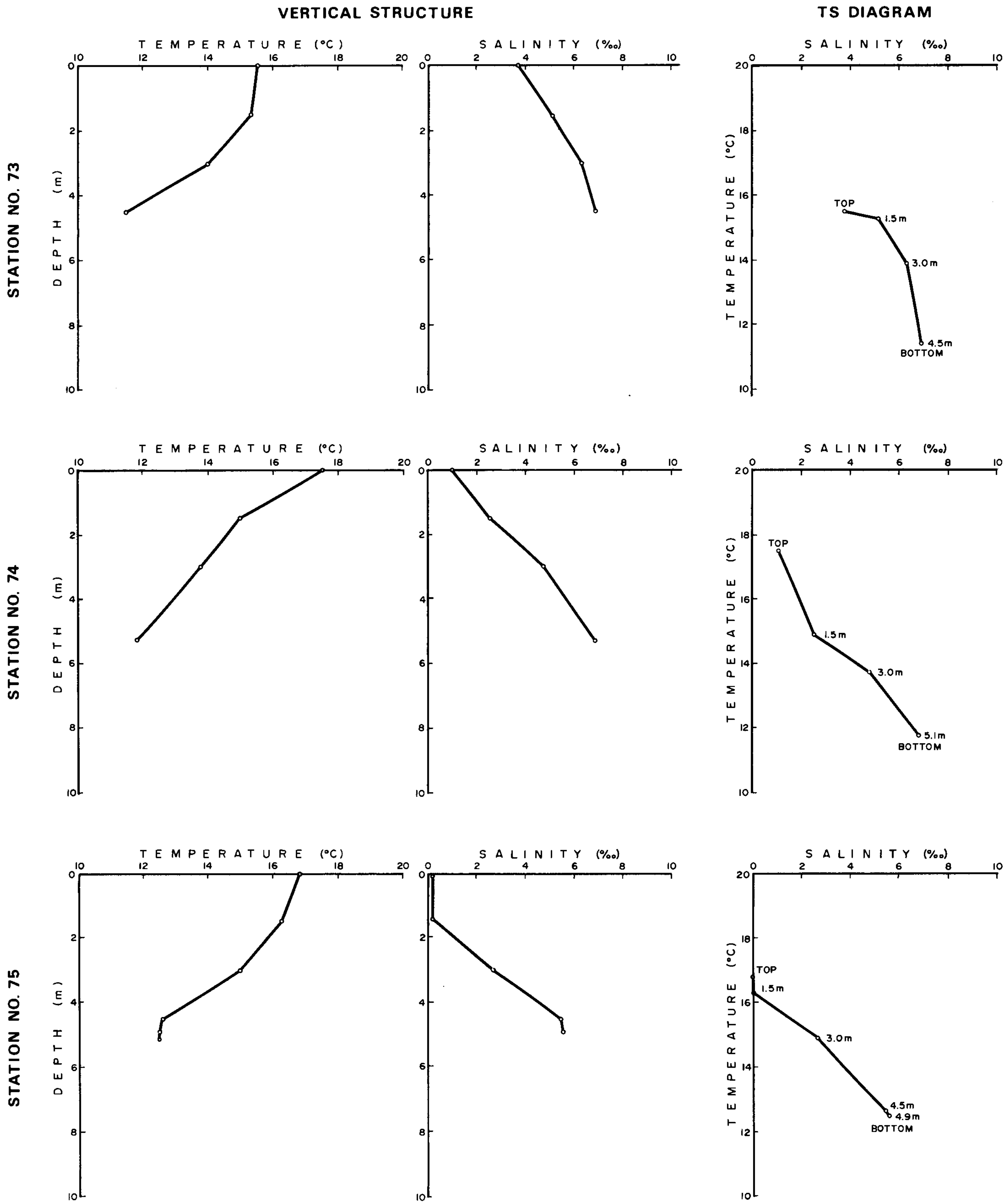


FIGURE 4.9 page 3

SALINITY – TEMPERATURE PROFILES
AUGUST 20, 1975

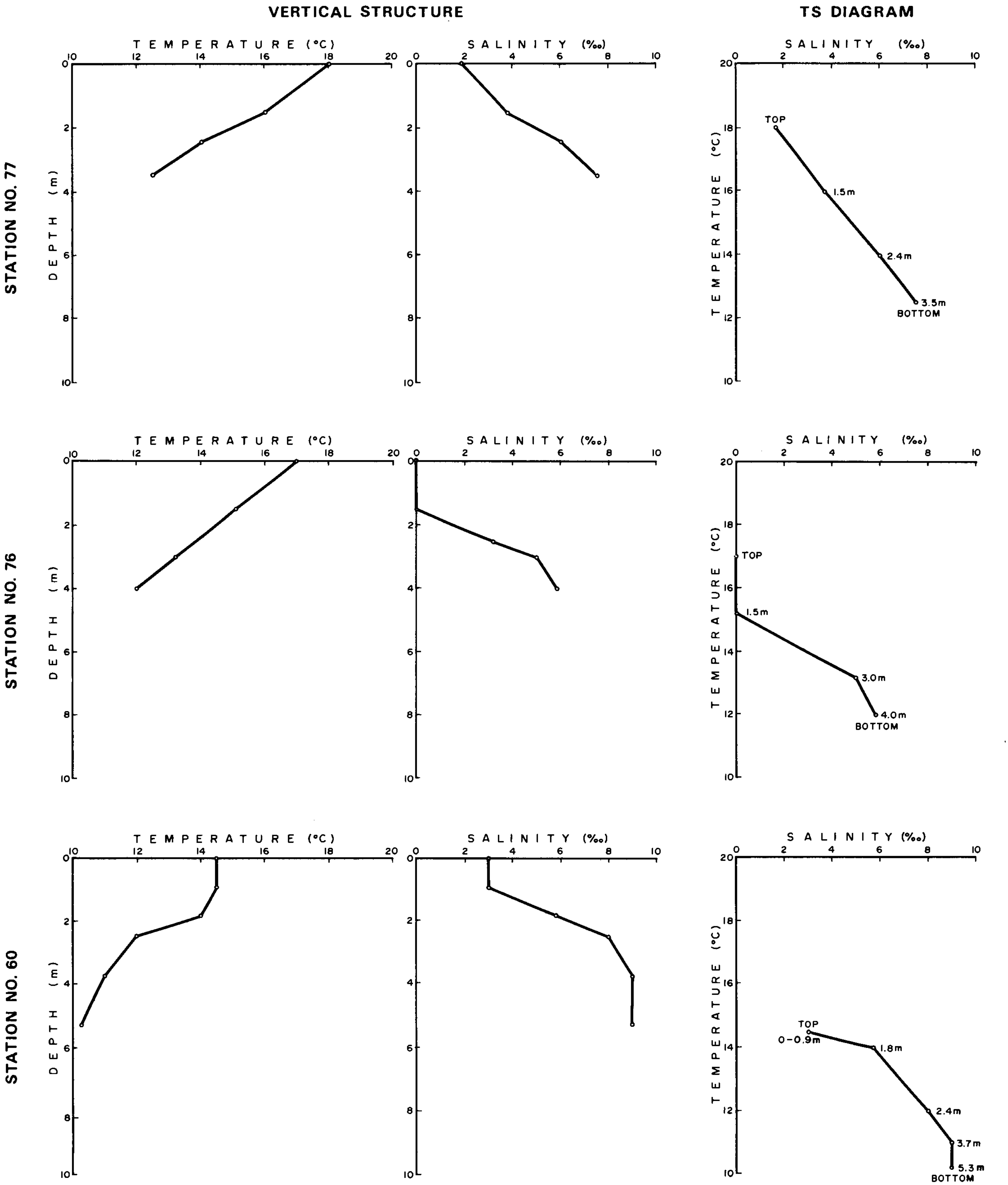
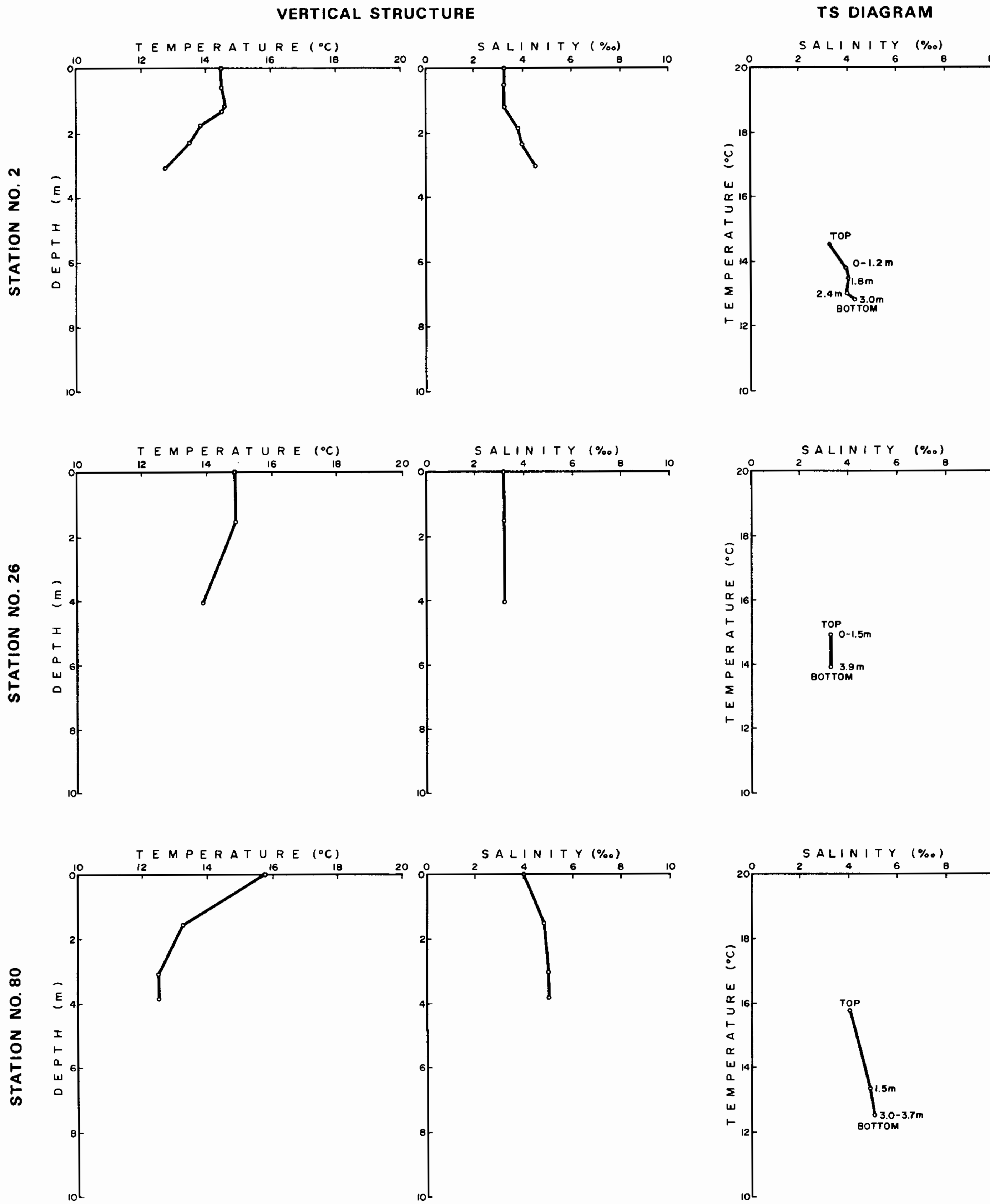


FIGURE 4.9 page 4

SALINITY – TEMPERATURE PROFILES
AUGUST 20, 1975



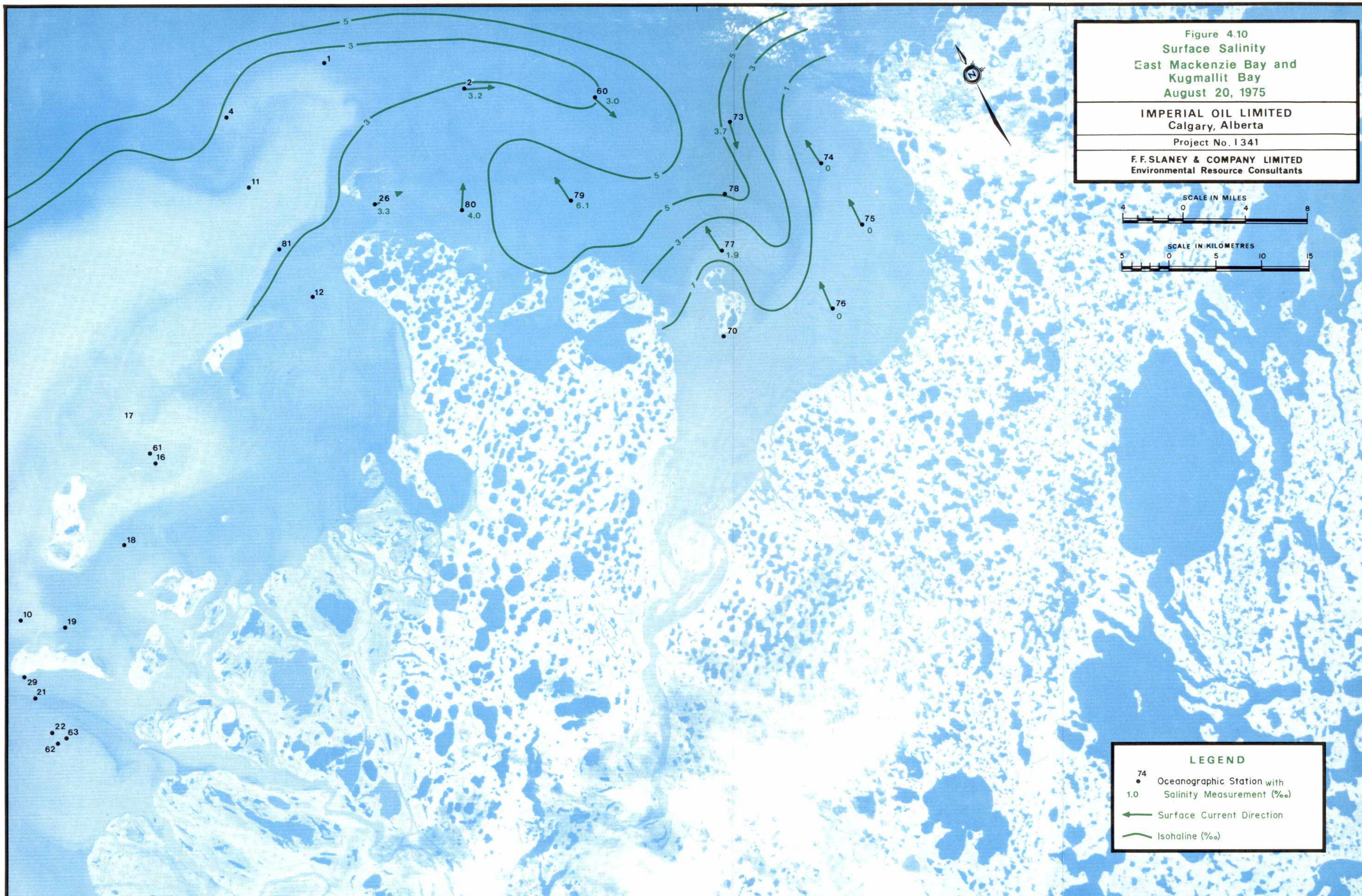


Figure 4.10
Surface Salinity
East Mackenzie Bay and
Kugmallit Bay
August 20, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
SCALE IN MILES
4 0 4 8
SCALE IN KILOMETRES
5 0 5 10 15
LEGEND
74
Oceanographic Station with
1.0 Salinity Measurement (‰)
Surface Current Direction
Isohaline (‰)
1
2
3.2
60
3.0
4
73
3.7
74
0
11
26
3.3
80
4.0
79
6.1
78
75
0
81
77
1.9
12
76
0
70
17
61
16
18
10
19
29
21
22
63
62
5
3
1

generally prevailed in the under-ice water column. The temperature difference between surface and bottom layers was 1.0^{o}C or less. Temperatures were all near the freezing temperature of the water. Greatest vertical temperature differences occurred where bottom waters were saline.

4.6.6.1 Water Temperature in East Mackenzie Bay, Summer, 1974

In 1974, the late break-up of ice conditions in Mackenzie Bay kept June water temperatures in the nearshore areas of East Mackenzie Bay colder than normal. In fact, the close proximity of melting ice floes and the predominance of cold northerly winds helped reduce sea surface temperatures below normal throughout most of the summer in Mackenzie Bay.

In July, water temperatures near the mouth of Middle Channel in Mackenzie Bay ranged from 9.0^{o}C to 17.0^{o}C. Surface temperatures north of the Barrier Islands were kept to 2 to 3^{o}C by the strong influence of melting floe ice which was never more than 100 km from the Barrier Islands at any time during the summer.

On July 21, 1974, an E.R.T. satellite fly-pass showed that a 4/10 concentration of first year floe ice was still fast along the northern edge of Hooper and Pullen Islands. The temperature of the freshwater outflow from Middle Channel was approximately 16^{o}C. Most of the inner Bay area was enclosed by the 12^{o}C isotherm, except in the NE where it appeared that a SW current between Hooper and Richards Island had carried cold water into the Bay. Very little vertical temperature stratification was apparent in the shallow waters sampled.

By August 8, 1974, the ice had moved about 20 km offshore. Warmest waters (15.5^{o}C) were in the vicinity of Mackenzie River discharge from

Middle Channel and coldest (5.8^{O}C) at Station 5 close to the edge of 3/10 first year ice. Offshore stations indicated a strong thermocline at about 3 to 5 m depth, and bottom temperatures approached the freezing level. Nearshore shallow areas showed little temperature stratification.

On August 26, 1974, the areas of highest temperature were at the mouth of Middle Channel (11^{O}C), off the mouth of Harry Channel (10.5^{O}C) and in a turbid layer of water near Station 13 (10.5^{O}C). Coldest measured areas were near Stations 11 and 12 (approximately 5^{O}C) where colder water was moving onshore from the northern ice covered areas. At most offshore stations a strong thermocline occurred at 3 to 5 m depth, and bottom temperatures at the deeper stations approached the freezing level. Station 6, near the ice edge, showed a more gradual stratification with a thermocline between eight to 12 m depth.

The close proximity of broken floe ice to the shore continued into September, 1974, and kept the surface temperatures generally low. As a result, the cooling of surface layers to near freezing temperatures occurred quickly when air temperatures began dropping in September. New ice formation was well underway by the third week of September. Field observations near the Barrier Island spits, September 27 to 29, revealed freezing water temperatures and an average 13 cm of new ice.

4.6.6.2 Water Temperatures in Kugmallit and East Mackenzie Bays - Summer, 1975

Water temperatures in the surface layer of outer Kugmallit and Mackenzie Bays in 1975 were usually higher than in 1974. The high frequency of N and NW winds in summer 1974 had maintained melting floe ice in close proximity to Mackenzie Bay for much of the summer. As a result, 1974 surface water temperatures near the ice were significantly reduced, especially those along the outer edge of the Barrier Islands.

In 1975, generally prevailing NE winds helped to clear Kugmallit and Mackenzie Bays of ice early in the summer and produced generally warmer water temperatures. The only 1974 oceanographic stations with consistent temperatures similar to those measured in 1975 were those located near and warmed by the outflows of major Mackenzie River channels (Stations 58, 21 and 22). The horizontal distribution of 1975 water temperatures was probably very similar to that measured by Cameron (1952) for the 1951 open water season. Ice conditions were considered good for both these years in Kugmallit and Mackenzie Bays.

In early June, 1975, inner East Mackenzie Bay contained warm turbid water. A survey of Stations 29, 30, 57, 33, 34, 16, 12, 11, 70 and 83 (west to east across Mackenzie and Kugmallit Bays from July 8 to 14) showed water temperatures averaging 12.5 to 15^{o}C (Appendix 4.3), excepting Station 11 and Station 83. Station 11, the furthest offshore, was also the coldest at 10.5^{o}C and the only station to show vertical temperature stratification. Its bottom temperature was 3.5^{o}C, with a thermocline at about four m. Station 83, inside Tuktoyaktuk Harbour, was the warmest at 16.0^{o}C.

The surface conditions of Kugmallit and Mackenzie Bays on July 15, 1975, are shown (Figure 4.11). Surface currents and water temperatures are shown from the marine survey of the Wilson III on the same day. Temperatures were relatively uniform in Kugmallit Bay, ranging from 16 to 18^{o} C for all stations except Station 73 where prevailing NE winds and longshore westerly currents had transported colder more saline waters.

Vertical structuring measured at Stations 73, 74, 75 and 78 is shown (Figure 4.7). Depth of the thermocline at each station increased shorewards and bottom temperatures decreased slightly. At Station 73, the bottom temperature was 6.4^{o}C and the thermocline was at 2 m. At nearshore Station 75, the bottom temperature was 5.0^{o}C and the thermocline was at 3.5 m.

From July 28 to 31, 1975, the winds in East Mackenzie Bay were generally from the NW. As a result, a west-east sampling of Stations 8, 7, 16, 12, 1 and 11 during this period revealed cool saline waters along the outer Barrier Islands. Coldest surface temperatures were measured at stations furthest offshore (Stations 7 and 1). Very little vertical structuring was observed at nearshore Stations 8, 16, 12 and 11 indicating considerable wave activity. The vertical temperature profile at offshore Station 7 is shown (Figure 4.6). Surface temperatures near 8^{o}C dropped to 3^{o}C at the bottom, with the thermocline located at about 7.5 m. Offshore Station 1 showed only an 0.5^{o}C temperature drop top to bottom (Appendix 4.3).

From August 2 to 4, 1975, the Wilson III surveyed Kugmallit and Mackenzie Bays during the E.R.T. satellite fly-pass. Considerable water temperature data were collected, but all the records were lost with the vessel on August 8, 1975.

Surface water temperatures in East Mackenzie Bay from August 5 to 12, 1975, ranged between 8 to 12^{o}C (Appendix 4.3). Weather conditions were generally overcast, and air temperatures were cool during this period (Appendix 4.2). Such conditions reduced the radiative and conductive heat transport to the surface layers and lowered surface temperatures.

During cloudless days, a combination of high insolation and generally high turbidities concentrate heat absorption in the shallow surface layer. From August 13 to 19, 1975, weather conditions improved and measured surface water temperatures were slightly higher (Appenix 4.3). Water temperatures ranged from 12.2^{o}C at Station 8 on August 16 to 18.0^{o}C at Station 21 on August 16. Through all weather conditions, the warmest temperatures were generally measured in the nearshore

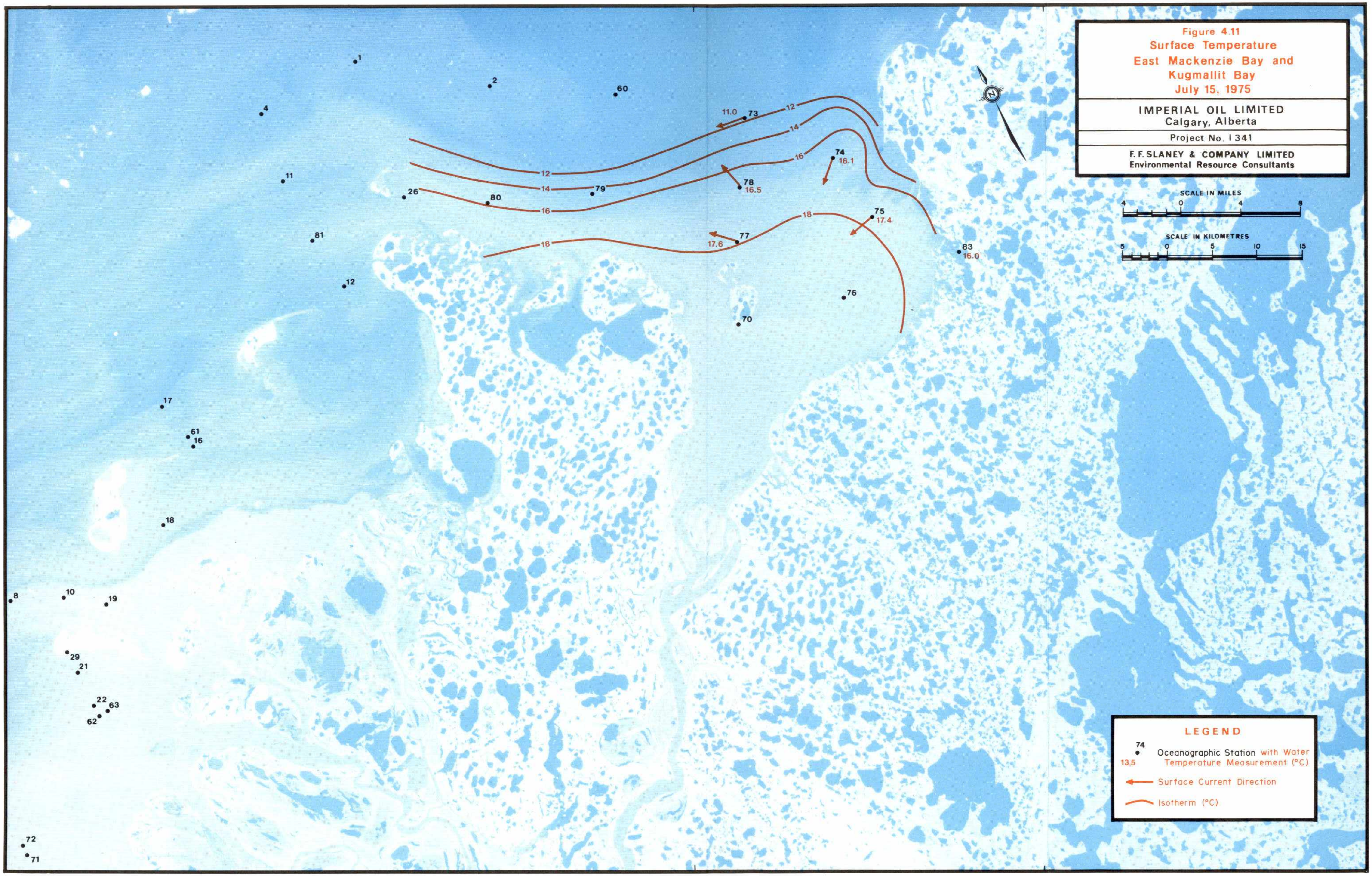


Figure 4.11
Surface Temperature
East Mackenzie Bay and
Kugmallit Bay
July 15, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
SCALE IN MILES
4 0 4 8
SCALE IN KILOMETRES
5 0 5 10 15
LEGEND
74
13.5
Oceanographic Station with Water Temperature Measurement (°C)
Surface Current Direction
Isotherm (°C)
12
14
16
18
11.0
16.1
16.5
17.4
17.6
16.0
1
2
4
8
10
11
12
16
17
18
19
21
22
26
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83

areas of inner East Mackenzie Bay where warmer turbid Mackenzie River outflow provided additional thermal input. Very little vertical temperature stratification was observed in the nearshore Mackenzie Bay, indicative of shallow, homogeneous and well-mixed waters. Temperature profiles for Netserk South (Station 8) and Netserk North (Station 9) on August 16 are shown (Figure 4.9). The thermocline depth at the more offshore Station 9 was very shallow (about 1 m), with a bottom temperature of 10.1°C. The thermocline at Station 8 was at approximately 3.5 m with a bottom temperature of 10.2°C.

E.R.T. satellite photographs of Kugmallit and Mackenzie Bays on August 20, 1975, are shown (Figure 4.12). Primary isotherms and measured surface currents are also shown. Winds were light from the south to east. Skies were generally clear and air temperatures ranged from 14 to 20°C. A small cool tongue of clearer water extended SW into Kugmallit Bay, but in general, surface water temperatures were warm at 17 to 18°C. Coldest water was observed near the clearer waters off Pullen Island.

Salinity/temperature profiles at each station are shown (Figure 4.9). Stations 2 and 26 showed the least evidence of thermal stratification with differences in top to bottom temperatures of only 1 to 1.5°C. Shallow inshore stations in Kugmallit Bay showed considerable stratification with a marked thermocline at about two m. Solar heating effects in this turbid water were apparently restricted to the upper meter.

4.6.7 Turbidity and Settleable Materials

Turbidity and suspended solids are a measure of the transparency of the water. Settleable materials identify the rate of settling of the suspended matter under static conditions. Phytoplankton and other aquatic plants are the base of the food web and depend on light energy to photosynthesize. Increased turbidity reduces light penetration and may limit photo-chemical productivity. Artificially increased turbidities may also result in depleted levels of dissolved oxygen through the introduction of oxygen consuming organic detrital material.

The annual variation of suspended materials in the Mackenzie River is large. Peak loads usually occur shortly after freshet in the upper reaches of the Mackenzie River, but suspended materials may not peak in the Mackenzie Estuary until as late as mid-August because of the long transit time from the upper tributaries to the Mackenzie mouth. Mackay (1963) reported East Channel suspended loads during 1958 of: July 1, 25 ppm; July 15, 23 ppm; August 1, 128 ppm; August 15, 210 ppm; and, August 31, 31 ppm. He also estimated that the lower Mackenzie River can transport over 9.1 x 10^7 kg (100,000 tons) of sediment per day. Slaney (1973) recorded 1972 average August value of turbidity in East Mackenzie Bay as 70.4 ppm with peaks of 110+ ppm.

During winter conditions, the water beneath the ice in East Mackenzie Bay clears in conjunction with reduced discharges and sediment loads from the Mackenzie River. Slaney (1974c) reported March, 1973, bottom turbidities near Immerk artificial island that ranged from 5.8 ppm to 13.6 ppm. During March and April, 1974, turbidities ranged from 0.7 ppm at Station 8 (Netserk South) to 22.0 ppm at Immerk artificial island. Total suspended solids in March and April, 1974, ranged from 1.6 to 104.0 ppm

4.6.7.1 Turbidity and Settleable Materials in East Mackenzie Bay - Summer, 1974

Natural levels of turbidity, suspended solids and settleable materials were highly variable during the 1974 open water season in East Mackenzie Bay. Ranges in natural turbidity were extremely large (800 ppm at Station 13, August 14, to 5 ppm at Station 54, September 28; Appendix 4.4). Mean turbidities at most stations were greater than

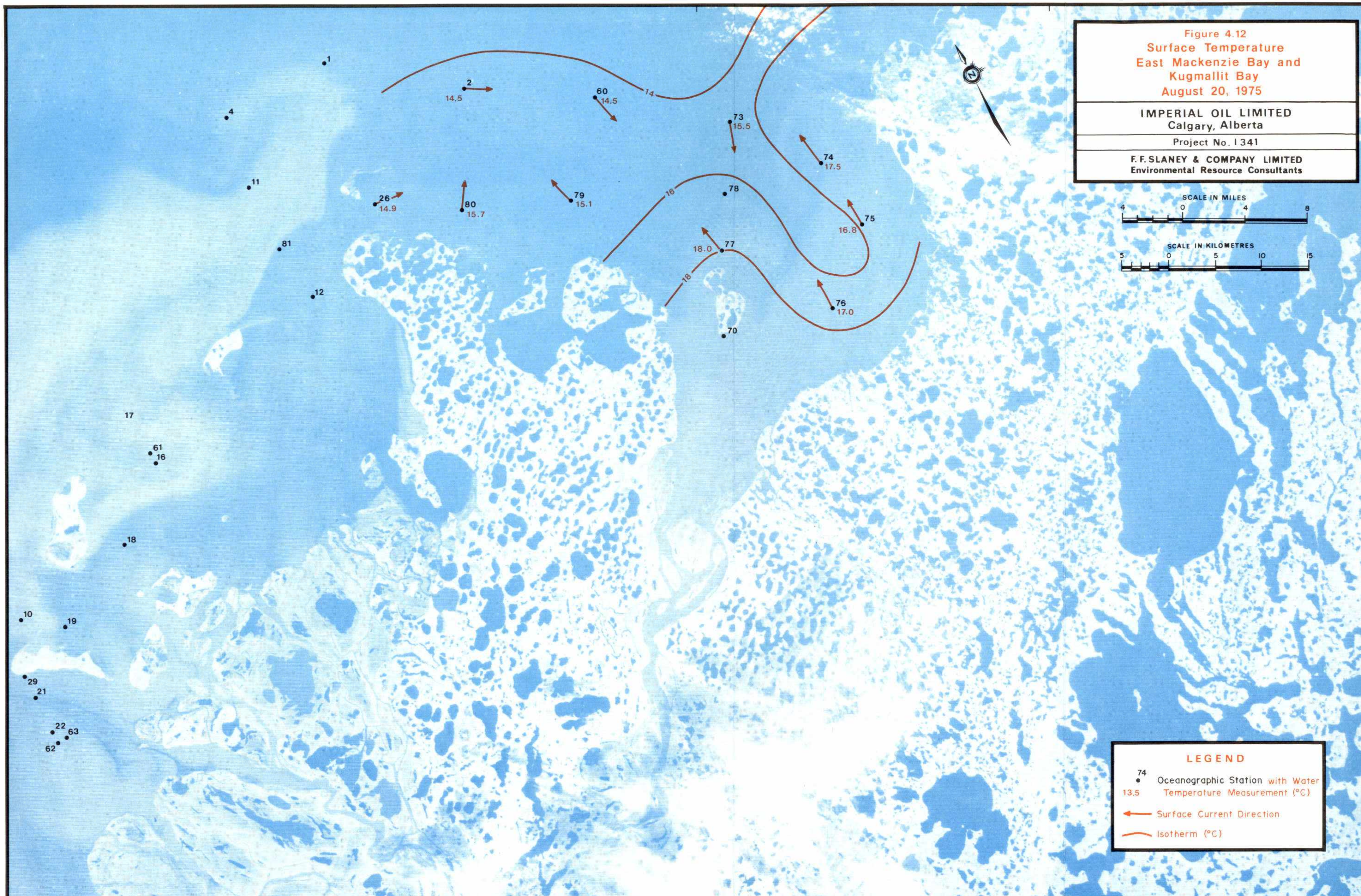


Figure 4.12
Surface Temperature
East Mackenzie Bay and
Kugmallit Bay
August 20, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
SCALE IN MILES
4 0 4 8
SCALE IN KILOMETRES
5 0 5 10 15
LEGEND
74
13.5
Oceanographic Station with Water Temperature Measurement (°C)
Surface Current Direction
Isotherm (°C)
1
2
14.5
60
14.5
14
4
73
15.5
74
17.5
11
26
14.9
80
15.7
79
15.1
16
78
75
16.8
81
77
18.0
18
12
76
17.0
70
17
61
16
18
10
19
29
21
22
63
62

320 ppm for approximately half of the sampling period. Levels of suspended solids and settleable materials were equally as variable. The highest recorded suspended load was 966.3 ppm at Station 23 on August 4. Amounts of settleable materials were not always related directly to the levels of turbidity or suspended solids. Largest amounts of settleable material were measured at 2.5 ml/l at Station 49 near an operating tugboat.

The naturally high turbidities and suspended loads are a combined result of the estimated 9.1×10^7 kg of silt deposited per day by the Mackenzie River (Mackay, 1963), the nature of Mackenzie Bay substrates and the frequency of strong winds. Construction activities, especially near dredges, caused small increases in the usually high natural levels of sediment. Settleable materials showed the most pronounced changes, but usually because of localized operations. Substrates of the inner Bay have been shown to consist of approximately 60 percent clay and 40 percent sand (Slaney, 1973). During storms with high winds, clay, sand and organic components are put into suspension by heavy wave agitation. The amount and composition of sediments in suspension depended on duration of peak winds which dictate the wave energy.

In mid-July, a homogeneous layer of fresh turbid water was contained in East Mackenzie Bay, and turbidities ranged from 80 to 250 ppm throughout the area. During the same period, the Mackenzie River outflow at Arctic Red River was high and ranged from 1.90×10^4 to 2.36×10^4 kls (6.75×10^5 to 8.41×10^5 cfs) (Water Survey of Canada, 1971).

A Beaufort Sea storm on July 31, 1974, combined with increasing river loads, helped raise turbidities at several inner Bay stations to 600 ppm or higher.

A sample collected August 7 on the Pelly spit during 48 kmh winds, contained 2.2 ml/l of settleable material which stratified into 0.2 ml silt, 0.2 ml sand, and 1.8 ml organic matter.

A second sample, taken during 16 to 24 kmh winds in open water near the SW tip of Garry Island, contained 0.4 ml/l suspended materials.

Although heavier fractions settle rapidly, colloidal particles can remain in suspension from one to three weeks under quiescent conditions. As a result, the residual turbidities may remain high without further wind agitation, and contain relatively little settleable material.

The turbidity of Mackenzie River waters had increased to about 400 ppm in early August, 1974, associated with heavier than normal precipitation in upstream areas during late July.

In September, 1974, discharges from the Mackenzie River channels had dropped as did sediment loads in Mackenzie Bay. Turbidity levels ranged from five to 45 ppm in late September. Settleable materials were less than 0.01 ml/l.

4.6.7.2 Turbidity and Settleable Materials in Kugmallit and Mackenzie Bays - Summer, 1975

The extremes and absolute levels of turbidity, suspended solids and settleable materials in 1975 were considerably less than those of summer, 1974 (Appendix 4.4). The early clearing of landfast ice in 1975 had allowed wider-spread movement and dilution of the turbid outflow from Mackenzie Bay than in 1974, when heavy near-shore ice cover had effectively dammed and restricted the brackish surface water movements.

Surface distribution of turbidities measured from the Wilson III on July 15, 1975, in Kugmallit Bay are shown on an E.R.T. satellite photo of surface conditions on July 15, 1975 (Figure 4.13). As a result of high NE winds and increased cloud cover after July 15, 1975, no further ship measurements or E.R.T. satellite photos were available for this period in East Mackenzie Bay.

Turbidities in Kugmallit Bay on July 15 ranged from a minimum of 30 ppm at Station 73 to a maximum of 88 ppm at Station 77. As shown by changes in colouration on the E.R.T. satellite photograph, a significant decrease in surface transparency (lighter-appearing areas) in Kugmallit Bay marked the high sediment load of East Channel outflow as it was being transported by the NE wind stress around the North Head of Richards Island and into Mackenzie Bay.

Mason Bay appeared dark on the E.R.T. satellite photo indicating sediment-free water. Measurements in Mason Bay on July 13 showed a surface turbidity of 13 ppm and settleable materials of less than 0.01 ml/l. Areas along the Tuktoyaktuk Peninsula had received clearer sediment-free water from the east. Bottom turbidities in Kugmallit Bay were all significantly less than at the surface, except at Station 77 (Appendix 4.3). The turbidicline (maximum vertical turbidity gradient) was probably located at or near the halocline at each station, differentiating the transition zone between turbid freshwater at the surface and clearer more saline water at the bottom. The halocline was located at about 1.6 m at Station 73, 2.2 m at Station 74 and 3.9 m at Station 75 (Section 4.6.5.2). Station 77 was isohaline over all depths. Considerable mixing from the higher surface currents and wave activity at Station 77 had apparently elevated settleable materials to 0.1 ml/l and also increased bottom turbidity to 98 ppm. Settleable material at all other stations was not measurable at less than 0.1 ml/l.

Visual interpretation of the E.R.T. satellite photo of East Mackenzie Bay for July 15 indicated that the turbid discharges from Harry, Kuluarpak and Middle Channels were also carried westwards by the NE wind stress. As a result, only a small area south of a line drawn from the mouth of Harry Channel west past Kendall Island and out between Pelly and Garry Islands would probably exhibit turbidities higher than the 88 ppm measured at Station 77. North of this line and west of Pelly and Hooper Islands, clearer more saline waters had replaced the turbid, brackish waters. Turbidities were probably all less than 50 ppm in this zone.

Turbidity measurements at Station 2 and 26 on July 17 and 18, respectively, indicated that the transition between higher turbidities in the westward-moving East Channel plume and the lower turbidity in clear saline waters offshore still existed. Surface and bottom turbidities at offshore Station 2 were 5 and 6 ppm respectively, whereas surface and bottom turbidities at nearshore Station 26 were 65 and 32 ppm, respectively.

A west to east survey from July 26 to 30, 1975, of East Mackenzie Bay Stations 21, 8, 16 and 12 revealed considerable variation in turbidity levels. Highest surface and bottom turbidity was measured at Station 16. Considerable barge and boat traffic near Immerk artificial island on July 30, 1975, had apparently caused some localized increases in sediment loading. Turbidity at the surface was about 90 ppm, but at three m depth it was up to 210 ppm. This variation was large when compared to the 43 ppm surface turbidity and the 46 ppm bottom turbidity measured at nearby Station 12 a few hours later. Bottom turbidities were all greater than at the surface for stations within East Mackenzie Bay during this period, contrary to the condition monitored in Kugmallit Bay. This was probably the result of considerable wave-mixing which had occured in the typically shallow waters of East Mackenzie Bay.

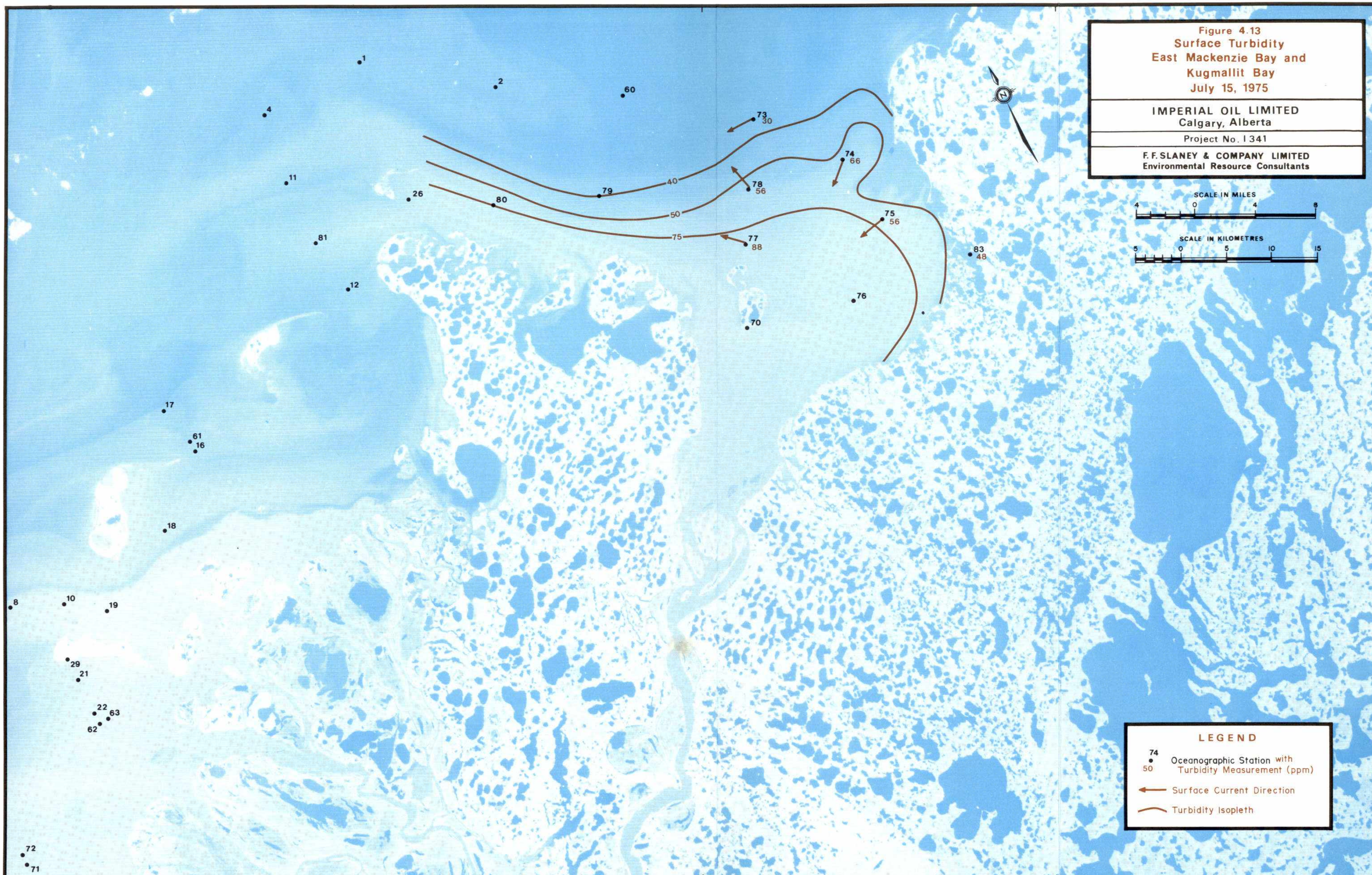


Figure 4.13
Surface Turbidity
East Mackenzie Bay and
Kugmallit Bay
July 15, 1975

On July 28, 1975, at Station 8, winds were westerly at 20 to 25 mph (32 to 40 kmh). Currents were 1.7 knots (3.1 kmh) at the surface and 1.25 knots (2.3 kmh) at the bottom. Settleable materials were the highest measured in 1974-75 (2.55 ml/l at the bottom). Wave activity around Station 8 (Nerserk South) had apparently uplifted high sediment loads. Turbidities were 78 ppm at the surface and 120 ppm at the bottom.

Surface turbidity interpretations for Kugmallit and East Mackenzie Bays during the E.R.T. satellite fly-pass of August 2, 3 and 4 are shown (Map 4.11). Unfortunately, extensive cloud cover obscured the sea surface from the E.R.T. satellite during August 2 and 3 of this period, and on August 4 only Mackenzie Bay could be seen. Winds were prevailing northeasterly.

In Kugmallit Bay, surface turbidities at all sampled stations were low (less than 10 ppm), and bottom turbidities slightly higher. This reflected the gradual replacement which had occurred of clearer saline water from the east. East Channel outflow was deflected NW along the North Head of Richards Island. Settleable materials were all less than 0.01 ml/l.

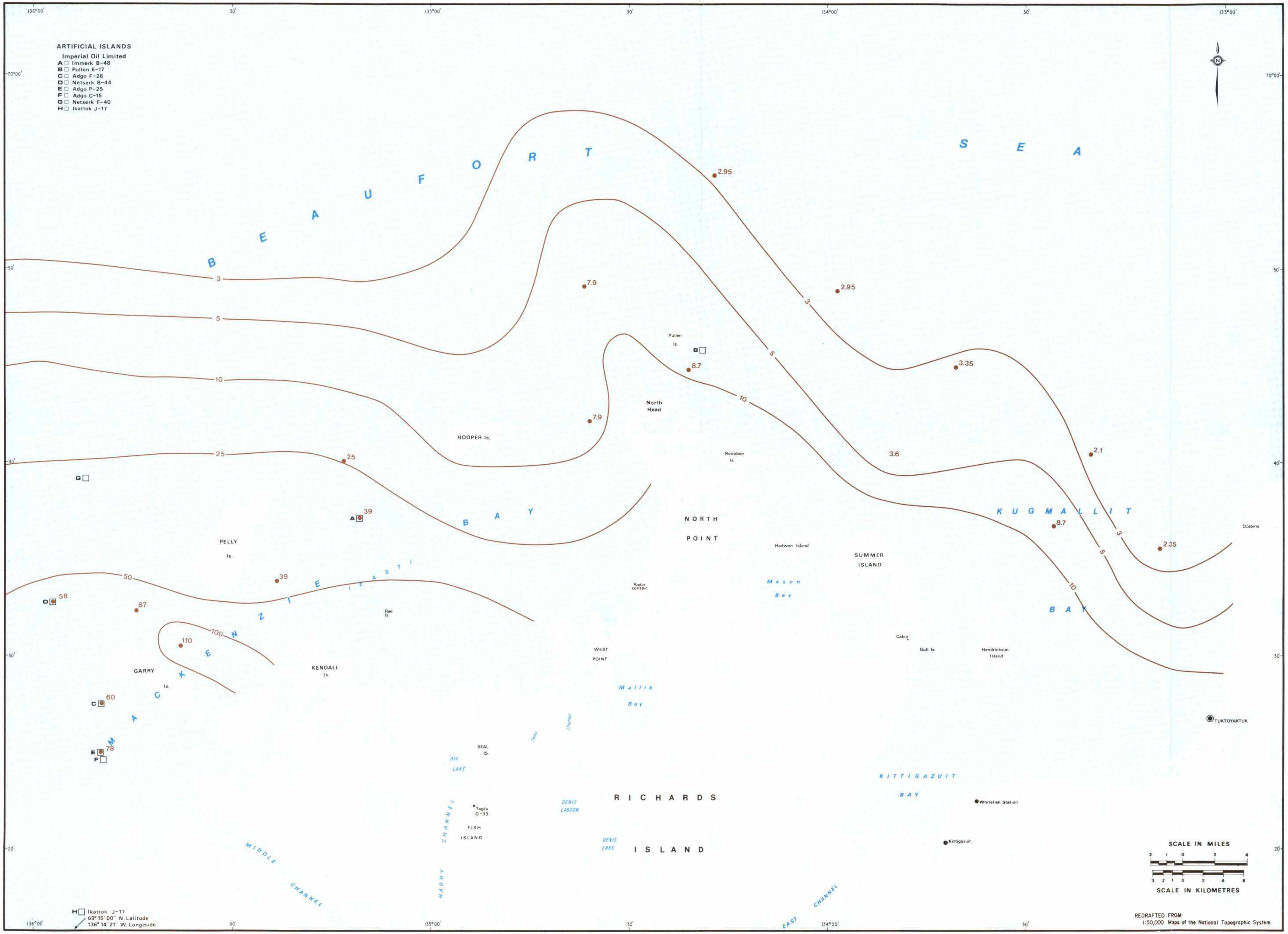
In East Mackenzie Bay, turbidity levels were generally higher with most falling in the range of 30 to 80 ppm. Settleable material were less than 0.10 ml/l. Stations 19 and 10 were the major exceptions, however, as surface turbidities were 110 and 87 ppm and settleable materials 0.6 and 0.3 ml/l, respectively. Ocean currents were westerly near Station 19 where a dredge was in operation nearby. It is suspected that a plume of uplifted sediments from these dredging operations extended to the west towards Station 10 during the measurements. Also, the turbid discharge from the mouth of Kanguk Channel may have extended west past Stations 19 and 10, sustaining high natural turbidity levels. The high settleable material content in the samples collected at Stations 19 and 10 is probably a direct result of the dredging activity, but the elevated turbidities at both stations are probably not much different to that which was already being generated naturally from Kanguk Channel.

Southwest of Garry Island, surface turbidities were slightly less. At Stations 21 and 22 (Adgo North and South) surface turbidity was 60 and 78 ppm, respectively. Station 22 was highest because of its close proximity to Middle Channel outflow.

From August 4 to 29, 1975, turbidity measurements were not possible in Mackenzie Bay because of the loss of the field turbidimeter with the Wilson III. However, during the E.R.T. satellite fly-pass on August 20, 21 and 22, water samples were collected, frozen and transported immediately for laboratory analyses in Vancouver. The results of these analyses and turbidipleth analysis are shown on an E.R.T. satellite photo of Mackenzie and Kugmallit Bays, August 20 (Figure 4.14). Surface measurements were not taken in inner Mackenzie Bay because of a motor breakdown on the Arcticus at Pullen Island.

On August 20, 1975, surface currents in Kugmallit Bay were generally higher than they had been earlier in August. As shown by the lighter appearing plume, East Channel outflow extended eastward along the Tuktoyaktuk Peninsula. A large curling eddy was also apparent around Hendrickson Island and near Toker Point. Surface turbidities were 21 and 15.5 ppm at Stations 76 and 75 inside the East Channel plume, while bottom turbidities were 58 and 90 ppm, respectively.

Outside the Barrier Islands in East Mackenzie Bay, a very turbid (lighter-appearing) water mass was observed moving eastward towards



LEGEND

3.6 Oceanographic Station with Turbidity Measurement (‰)

Turbidity Isopleth (ppm)

MAP 4.11

Surface Turbidity, East Mackenzie Bay and Kugmallit Bay, August 2-4, 1975

IMPERIAL OIL LIMITED
Calgary Alberta

Project No. 1341

F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants

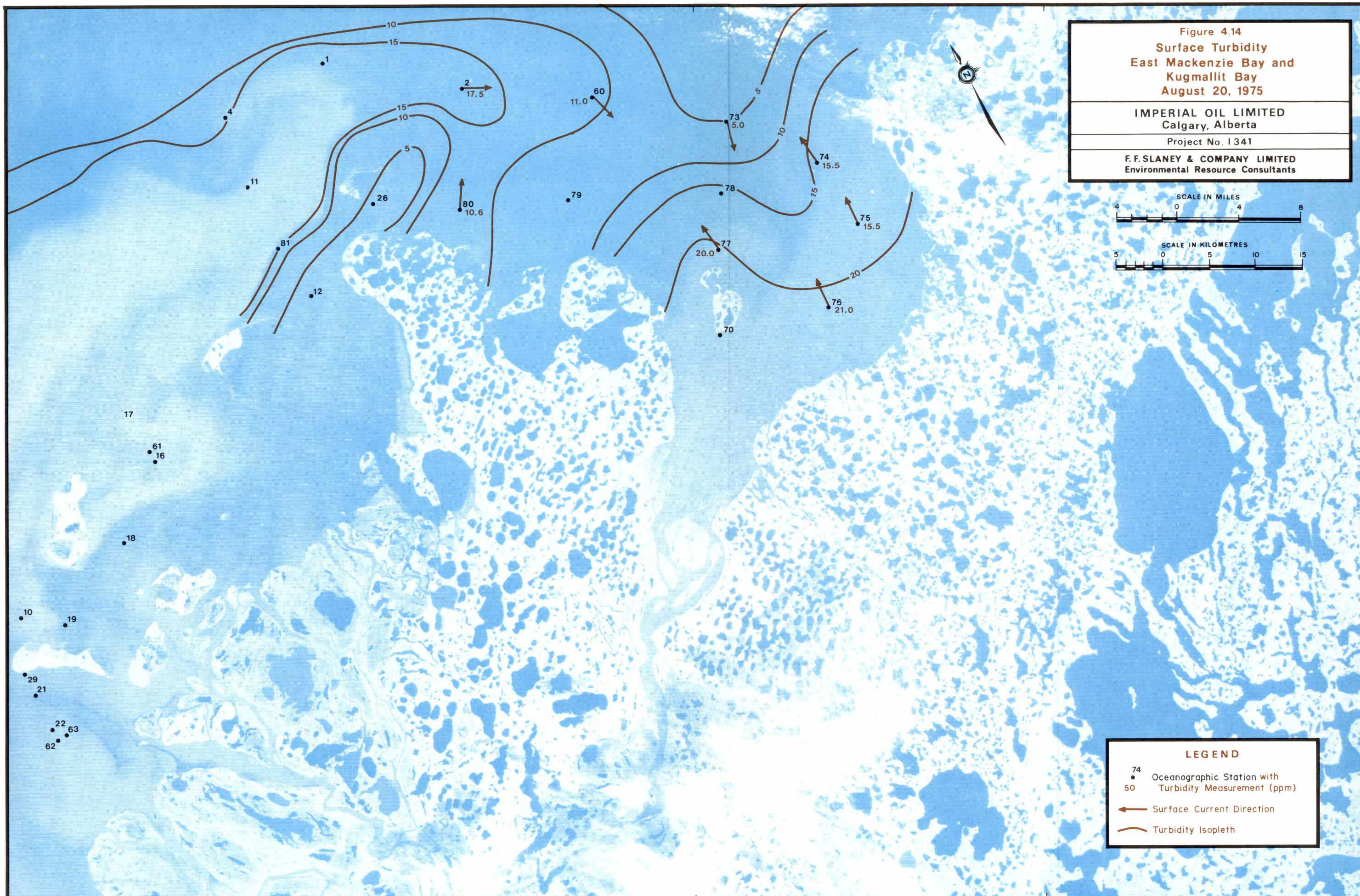


Figure 4.14
Surface Turbidity
East Mackenzie Bay and
Kugmallit Bay
August 20, 1975
IMPERIAL OIL LIMITED
Calgary, Alberta
Project No. 1341
F. F. SLANEY & COMPANY LIMITED
Environmental Resource Consultants
SCALE IN MILES
4 0 4 8
SCALE IN KILOMETRES
5 0 5 10 15
LEGEND
74
50
Oceanographic Station with Turbidity Measurement (ppm)
Surface Current Direction
Turbidity Isopleth
10
15
5
20
1
2
17.5
4
60
11.0
73
5.0
74
15.5
11
26
80
10.6
79
78
75
15.5
81
77
20.0
12
76
21.0
70
17
61
16
18
10
19
29
21
22
63
62

Pullen Island. Measurements at Station 2 in the clearer area (darker-appearing) to the east of this turbid water showed surface turbidities of 17.5 ppm top and bottom, so that it is suspected that turbidities in the turbid water mass outside the Barrier Islands were in excess of 50 ppm. Most areas inside the Barrier Islands had the same surface colouration as the area near Station 2, so that turbidities were probably near 20 ppm.

4.6.8 Dissolved Oxygen

The percent saturation of dissolved oxygen (D.O.) is a parameter affecting the biological productivity of a water body. Temporary reductions of a naturally high concentration of D.O. can have deleterious effects upon the aquatic resources in a given area.

The capacity of a water body to hold dissolved oxygen is a function of the temperature and to a lesser extent the salinity. Cold fresh-water can contain more dissolved oxygen than warm saline water.

Available measurements of dissolved oxygen concentrations relevant to Mackenzie Bay area (Slaney, 1973; Slaney, 1974b; Slaney, 1974c; Grainger, 1974; and Wong et al, 1974) indicate D.O. levels are generally high in both open water and under-ice conditions. Slaney (1974b), reported under-ice concentrations ranging from 11.4 to 15 mg/l. Slaney (1973), reported open water surface concentrations of dissolved oxygen ranging from eight to 13 mg/l with most measurements in excess of ten mg/l.

4.6.8.1 Dissolved Oxygen in East Mackenzie Bay - Summer, 1974

Dissolved oxygen ranged from five to 13 mg/l in the study area in 1974, which represented a range of 48 to 112 percent saturation.

Differences in absolute levels of dissolved oxygen with depth were, in most cases, small. However, percent saturation at the lower depths was reduced because of cooler temperatures.

Surface oxygen concentrations were lowest in mid to late July, and remained in the seven to ten mg/l range until mid-August, at which time an average increase to 11 mg/l occurred. The variability in oxygen concentration was inversely related to water temperature change. The rapid increase of water temperatures in mid-July apparently resulted in lower concentrations of dissolved oxygen, with maximum concentrations not exceeding ten mg/l.

Colder water temperatures in mid-September allowed higher dissolved oxygen concentrations. Mean concentrations were about 11 mg/l with maxima of 13 mg/l.

Mean oxygen levels were lowest at nearshore stations (Stations 28, 29 and 19), where temperatures were slightly warmer, and at sites located on lee sides of islands where mixing from wave activities had been reduced (Stations 34 and 27). Highest oxygen levels were generally measured in the more exposed areas (Stations 4, 5 and 11) where considerable wave mixing and colder surface waters were common. Some evidence of an east-west gradient in dissolved oxygen levels was also apparent. Dissolved oxygen was about 0.5 to 1.0 mg/l lower in the SW as compared to NE portions of Inner East Mackenzie Bay. The general east to west positive temperature gradient across East Mackenzie Bay had apparently affected the oxygen carrying capacity of the surface waters. Percent saturation remained high in all areas.

4.6.8.2 Dissolved Oxygen in East Mackenzie and Kugmallit Bays - Summer, 1975

In July, 1975, surface water temperatures at most stations were, in general, slightly higher than those measured in 1974. However, surface dissolved oxygen levels were similar to those measured in 1974.

The intrusions of cold saline bottom water, which occurred frequently in 1975, contained near identical amounts of dissolved oxygen as did the surface waters. However, because of their lower temperatures, the bottom waters had lower percent saturation of dissolved oxygen.

On July 28, 1975, winds were 20 to 25 mph (32 to 40 kmh) from the west. At Station 8, the lowest concentration of dissolved oxygen measured during two years of study was recorded. Surface D.O. was 11 mg/l and bottom D.O. was two mg/l, representing only about 20 percent saturation at the bottom. This low D.O. may have been an indirect effect of high bio-chemical oxygen demanding (B.O.D.) organics being uplifted by breaking waves around Station 8 (Netserk South) and transported by high bottom currents to the area of sampling. Low oxygen concentrations at the bottom (4 mg/l and 35 percent saturation) were also recorded at Station 7 on the same date. Because of in situ salinity and temperature, surface waters commonly contained nine to ten mg/l dissolved oxygen in this region and averaged 80 to 100 percent saturation.

Dissolved oxygen levels measured from August 2 to 11, 1975, were lost with the Wilson III. However, during the remainder of August, surface oxygen concentrations ranged from nine to 11 mg/l and 77 to 105 percent saturation. Bottom waters were generally saline during this period and resulted in lower oxygen saturations. Stations offshore and greater than three m in depth frequently had surface oxygen saturations greater than 100 percent.

Measurements of dissolved oxygen during 1975 had a wider range of absolute levels and percent saturation than did measurements in 1974 (Appendix 4.4). Surface means of these parameters were fairly similar over the two seasons.

4.6.9 Hardness, Alkalinity and pH

Hardness, alkalinity and pH are characteristic parameters of a water body which can be used as indicators of any changes or effects resulting from addition of contaminants or the intrusion of other water bodies. Hardness may be defined as the total concentration of calcium and magnesium ions, and other hardness producing metallic ions when they are present. Alkalinity and pH are a measure of the water's capacity to accept protons.

Previous measurements of hardness and alkalinity in Mackenzie Bay (Slaney, 1973, 1974 and 1975) indicate that levels of total alkalinity and total hardness slowly increase from July through September, and are associated with the general increase in surface salinities.

4.6.9.1 Hardness, Alkalinity and pH in 1974

Offshore ice and NW winds in 1974 caused Mackenzie River water to pool within Mackenzie Bay preventing intrusion of saline waters. The confined river water resulted in generally low alkalinity and hardness levels within Mackenzie Bay throughout the entire 1974 open water period (Slaney, 1975).

The maximum ranges of alkalinity, hardness and pH measured in 1974 were: 103 to 188 mg/l alkalinity; 103 to 1027 mg/l hardness; and, 7.5 to 9.0 pH (Slaney, 1975). Concentration of calcium and magnesium ions did not exceed 164 ppm during the same period. Highest levels of alkalinity, hardness and pH were reported at the most offshore stations in August and September, 1974, when more saline Beaufort Sea water had finally begun to move into the Mackenzie River estuary.

4.6.9.2 Hardness, Alkalinity and pH in 1975

In early June, 1975, inner East Mackenzie Bay and Kugmallit Bay contained primarily fresh Mackenzie River water, which had characteristically low alkalinity and hardness. Maximum July hardness in Kugmallit Bay (2,466.8 ppm) was measured on July 16, 1975, at Station 73 during an intrusion of saline bottom water. Surface alkalinity reached its highest level (>684 ppm) in East Mackenzie Bay during the later half of July.

Considerable variations in water body characteristics occurred in August, 1975. From August 2 to 4, a broad tongue of saline water extended into Kugmallit Bay. The resulting hardness, alkalinity, calcium and magnesium values at Station 60 were the highest measured during the 1975 summer period (Appendix 4.4). Minimum values of these parameters were measured during August at stations where surface waters were predominantly fresh Mackenzie River water.

The 1975 pH range was similar to that reported in 1974, but the maximum value 9.5 was 0.5 pH units higher. Alkalinity, hardness, calcium and magnesium ranges were generally greater in 1975 due to the greater frequency of saline water intrusion in 1975.

4.6.10 Nutrients

Nutrients are an important regulator in the growth of algal populations, which are the basis of the aquatic food web. Changes in the usual ambient levels of the macro nutrients, such as phosphates, nitrates, silica and carbon, could result in a chain reaction affecting all components of the food web. Data from recent studies, including Slaney (1975), Wong et al (1974), Brunskill et al (1973) and Grainger (1974) suggest that nutrients in East Mackenzie Bay during the open water period are generally low when compared to concentrations in temperate regions.

Nutrient concentrations are expected to be generally lower in summer when primary productivity is greatest, and higher in winter when ice cover is permanent and productivity is least. Brunskill et al (1973) sampled Mackenzie Bay between 1971 and 1972 and found concentrations of phosphorous, nitrogen and silicon to range between 0.23 to 1.5 m Moles m^{-3}; 7.3 to 5.5 m Moles m^{-3}; and, 26 to 107 m Moles m^{-3}, respectively.

4.6.10.1 Nutrients in East Mackenzie Bay - Summer, 1974

Values of three dissolved nutrients in East Mackenzie Bay were measured in March, 1974 (Slaney, 1974c). Silicate levels ranged from 1.4 to 4.8 ppm; nitrate levels ranged from 0.1 to 0.11 ppm; and all orthophosphate levels were $\leq$ 0.01 ppm.

During summer, 1974, nutrient analyses for East Mackenzie Bay waters indicated relatively small variability between stations. The ranges of nitrate nitrogen (NO_3), orthophosphate (PO_4), and silica (SiO_2) concentrations were less than 0.1 to 1.02 ppm, less than 0.2 ppm; and, 2.0 to 4.6 ppm, respectively.

4.6.10.2 Nutrients in East Mackenzie Bay - Summer, 1975

Nutrient analyses for silica, orthophosphate, carbon, and nitrates indicated relatively low values at all stations throughout the

1975 summer (Appendix 4.3). Previously, highest nutrient concentrations had been found in the deeper saline waters offshore from the Mackenzie Delta (Wong et al, 1974).

In 1975, phosphate and nitrates did not occur in measurable amounts in any of the samples, with phosphates being less than 0.01 ppm and nitrates being less than 0.1 ppm. Slaney (1975) found a wider range in levels of orthophosphate and nitrates in East Mackenzie Bay during 1974. Maximum concentrations reported in 1974 were 0.2 ppm orthophosphate and 1.02 ppm nitrates.

Silica concentrations ranged from 2.8 to 5.5 ppm in 1975, which is similar to the 2.0 to 4.6 ppm range reported in 1974 by Slaney (1975). Bottom samples were generally lower in silica than surface samples, and did not exceed 4.0 ppm silica. Surface values of silica showed no general increase throughout the summer nor did any area have consistently high concentrations.

Carbon concentrations in 1975 were low, with a range of 13 to 38 ppm. Slaney (1974c) reported a similar range of total organic carbon (T.O.C.) in East Mackenzie Bay in 1972. Parsons and Takahashi (1973) note that carbon in open ocean surface water may range from 100 to 500 ppm. Therefore, the carbon concentration in East Mackenzie Bay is lower than the usual range found in temperate zone surface waters. Inorganic carbon accounted for the largest portion of the total carbon content in all the 1975 samples.

4.6.11 Heavy Metals

Estuaries have been described by Astor and Chester (1973) and Krauskopf (1956) as playing a significant role in final concentrations of metal ions in sea water. Hydrous oxides which are formed in estuaries act as absorptors of trace metals removing them from solution. Hence, concentrations of trace metals in solution in Mackenzie Bay are likely to be lower than those in Mackenzie River.

Natural levels of trace metals need to be established to provide a basis against which any effects of hydrocarbon exploration and development can be monitored.

4.6.11.1 Heavy Metals in East Mackenzie - Summer, 1974

Most of the 1974 heavy metal concentrations measured in East Mackenzie Bay were below the minimum detection limits of atomic absorption spectroscopy. The lead and nickel concentrations in 1974 were within the same range as observed by Brunskill et al (1973) for Mackenzie Bay during 1971 to 1972.

4.6.11.2 Heavy Metals in East Mackenzie Bay - Summer, 1975

Concentrations of the heavy metals, nickel, cadmium, chromium and lead in East Mackenzie Bay were frequently below the minimum detection limits of 0.001 ppm of atomic absorption spectroscopy. The maximum variation of measurable metal concentrations was 0.005 ppm for nickel. Chromium concentrations did not show any measurable change during the sampling period, and were always less than 0.005 ppm. Concentrations of lead ranged from less than 0.001 ppm to 0.003 ppm. Cadmium concentrations varied from less than 0.001 ppm to 0.002 ppm. Maximum values for trace metals were recorded more frequently in August than July, probably due, however, to a lower sampling frequency during July.

During 1974, Slaney (1975) reported concentrations of heavy metals within these same ranges, with the exception of nickel which reached a maximum of 0.009 ppm on one occasion. Few studies have measured the concentrations of heavy metals in the Beaufort Sea.

4.7 POSSIBLE ENVIRONMENTAL EFFECTS

The results of the 1974 and 1975 physical oceanography and water chemistry surveys have been presented in Section 4.6. The following section summarizes the observed general and specific effects of dredging and other island-building activities on the existing physical oceanography and water chemistry regime of the Mackenzie River Estuary.

4.7.1 Physical Effects

The effects of construction and presence of artificial drilling islands on the natural physical processes which occur in East Mackenzie Bay appear small and localized. Most abandoned island sites should revert back to conditions similar to pre-construction after being subjected to a few years of heavy weathering forces which are characteristic of Mackenzie Bay.

The physical presence of an artificial island in Mackenzie Bay or Kugmallit Bay tends to obstruct the natural movements of ice, water and to some degree the winds in the local vicinity. Old established artificial islands such as Immerk have been observed to cause slight additional melting of winter ice and snow in the early spring. The extent of melting is primarily dependent on both the degree of change in surface albedo around the island, which in turn affects heat absorption, and the changes in ice texture which have occurred because of abnormal ice movements around the islands. Offshore ice movements near Station 8 (Netserk South) in early winter, 1975, caused the ice surface to buckle and fold in a NW-SE direction, upstream of the island, with considerable fracturing around the edges. A series of small pressure ridges, each approximately 15 m long, extended for a few hundred meters upstream of the island site (pers. comm. G. Mainland and K. Crogsdale, Imperial Oil Limited). Most pressure ridges were groundfast with some reaching elevations of five m above the ice surface.

Local winds and ocean currents are deflected around, and, in the case of winds, over each island site. The affected areas are small (usually less than a few thousand meters in diameter), and predominantly downstream of each island site.

The effect of shallowing waters in the vicinity of artificial islands focuses the incoming wave fields onto their shorelines. Considerable energy is expended by these waves as they peak and break along the beaches. The additional turbulent energy, which is added to the surf zones around each island, can cause local increases in suspended sediment levels.

There is also a slight sheltering effect due to presence of artificial islands. Leeward winds are reduced in the immediate vicinity of each island and, because of lost energy, waves of smaller magnitude extend downstream from each island site for several hundred meters.

High weathering forces are characteristic in Mackenzie and Kugmallit Bays during the open water season. As a result, the removal of protective structures and eventual abandonment of the artificial islands should return physical conditions similar to that which existed in the preconstruction state. Ice scour will help to eliminate any shallows, especially in late fall.

4.7.2 Chemical Effects

No significant potential for long-term effects on the water chemistry of Kugmallit and Mackenzie Bays was observed as a result of 1974-75 artificial island construction, gravel dredging and associated activities. Short-term water chemistry effects observed in both sampling years are described in the following sections and summarized in Appendix 4.4. Most effects were caused by suction dredging and/or wave effects around each island. However, because of the high natural variability of most water chemistry parameters over short time periods in Kugmallit and Mackenzie Bays, the effects were usually very short-term.

4.7.2.1 1974 Observations of Island Construction Effects

Gravel dredging and construction activities affected natural turbidity levels, settleable solid loads and water depths at three stations during 1974.

Suction dredge operation near Garry Island maintained turbidity levels in the 305 to 370 ppm range. Natural turbidity levels at nearby control stations ranged 140 to 180 ppm. The effects of this increase in turbidity were probably minimal in the long-term, however, as sustained natural turbidities caused by wave action reached the 400 to 600 ppm range in unaffected areas nearby only a few days after the dredging operations had commenced.

Increased silt loads were also observed during dredging at the Garry Island and Pelly Island borrow sites. Settleable solid concentrations were maintained in the 0.15 to 0.25 ml/l range as compared to a natural mean of 0.09 ml/l at nearby control stations. Periodic reductions in the dissolved oxygen content of bottom waters were also observed near the operating dredges, possibly due to increased B.O.D. of the uplifted organic materials.

Clamshell operations at Station 8 (Netserk South) during late August, 1974, maintained turbidities slightly higher than those measured at control stations at the same time. Turbidity levels created by clamshell operations were in the 305 to 364 ppm range which is equivalent to those caused by suction dredging.

Suction dredging increased water depths by 3.6 meters at the Garry Island borrow site. The specific effects to aquatic resources of this type of habitat alteration would be influenced by the unit area dredged, depth of excavation, and specific location of borrow site. Substrates of potential sites in the lee of islands may be more important to aquatic fauna than those of more exposed sites.

Suction dredge operations near Pelly Island increased natural turbidity levels from approximately ten ppm (0.01 ml/l settleable materials) to 480 ppm (2.5 ml/l settleable materials) in late September. Although the turbidity plume was localized, the increase was significant.

4.7.2.2 1975 Observations of Island Construction Effects

In summer, 1975, artificial islands were constructed at Station 9 (Netserk F-40) and Stations 71 and 72 (Ikattok J-17). Dredging operations took place at a borrow location north of the Pelly Island spit (Map 2). Stockpiles of Yaya Lakes gravel were located on the north tip of a spit adjacent to Garry Island and at the original Adgo F-28 site, and were removed for the construction of Netserk F-40 and Ikattok J-17, respectively. Immerk, Langley Camp 16 and a floating camp at the Garry Island mooring basin were used as support camps with considerable boat and barge traffic between these bases.

During the 1975 field season, intensive sampling in the activity areas was not conducted. Rather, the program focused on the continuation of the broad scale measurements of natural physical and chemical variability which occurred in Mackenzie Bay, and was expanded to include areas in Kugmallit Bay.

A composite description of 1974 and 1975 natural variabilities of water chemistry parameters was presented in Section 4.6. Site-specific water chemistry effects, presented below, are those which were observed in conjunction with the broad-scale sampling and, which were either directly or indirectly attributed to artificial island construction or presence. Most observed 1975 effects were either consequences of dredging operations north of Garry Island, and/or consequences of increased wave activities around artificial islands.

On July 20, 1975, high surface and bottom turbidity was measured at Station 16. Considerable barge and boat traffic near Immerk artificial island caused localized increases in sediment loading. Turbidity at the surface was about 90 ppm, but at three m depth was up to 210 ppm. This variation was large when compared to the 43 ppm surface turbidity and the 46 ppm bottom turbidity measured at nearby Station 12 a few hours later.

On July 28, 1975, at Station 8 on the north side of Netserk B-44, winds were measured at 18 to 25 mph (29 to 40 kmh) from the west. Wave activity was considerable, with some peak wave heights about 1.5 m. Ocean currents were to the NNE with speeds of 1.7 knots (3.1 kmh) at the surface and 1.2 knots (2.2 kmh) at the bottom. Dissolved oxygen concentration was 11 mg/l at the surface (super-saturated) and only two mg/l at the bottom (20 percent saturation). Turbidity and settleable materials were 78 ppm and 1.95 mg/l respectively at the surface, and 120 ppm and 2.5 ml/l respectively at the bottom. The levels of settleable materials corresponded quite closely with those observed in the downstream plume from dredging operations at Garry Island in September, 1974.

The high breaking waves at Station 8 (Netserk B-44) on July 28 were focused on the shallower slopes of the artificial island and were uplifting large amounts of sediments. Judging by the low dissolved oxygen levels at depths of three m offshore, the heavier components of this uplifted material partially settled out as they were carried away from the island, and must have maintained a high B.O.D. Organic material in areas undisturbed from island construction are usually located at depths beyond the major effects of most intense wave activity, so that little is naturally uplifted, and accumulations may occur. However, uplifted base materials around Netserk B-44 may have been a composite of organics with high B.O.D. because of the source of fill materials (i.e. from surface dredging). The ocean currents and levels of settleable materials were the highest measured in the two years of study.

Surface measurements at Station 8 in early August showed much lower settleable materials (< 0.1 ml/l) than on July 28. It is suspected that the levels of high settleable material and low dissolved oxygen measured on July 28 did not last much longer than the actual high wind session. Continual flushing by the usual slow-moving ocean currents in the area would soon carry away and dilute most affected waters.

On July 28, 1975, at Station 7, the same wind and wave conditions as described for Station 8 produced a slightly reduced effect. Dissolved oxygen levels measured at the surface were ten mg/l (100 percent saturated) and those measured near the nine m bottom were four mg/l (38 percent saturated). Sediment data were not collected.

On August 3, 1975, at Station 19, surface turbidities were 110 ppm and settleable materials 0.60 ml/l downstream from an operating dredge off the north tip of Garry Island. Since turbidities and settleable material at other stations sampled in this period were typically < 40 ppm and < 0.1 ml/l respectively, the surface levels at Station 19 represented significant increases. Records of absolute levels of dissolved oxygen were lost with the Wilson III, but it is recollected that all surface D.O. measured that day ranged between nine to ten mg/l. Total affected area would be dependent on period of operation of the dredge and frequency of previous current speeds and directions. In several flights over the operating dredge previously, a small sinuous darker-appearing surface plume was observed to extend a maximum of a few hundred meters downstream from the dredge.

4.8 SUMMARY OF IMPORTANT POINTS

4.8.1 Ice

4.8.1.1 Break-Up

In comparison to ice conditions in 1974, the break-up pattern in May, 1975, was further advanced. By late May, 1975, melt water was evident along the shores of most channels in the delta and extended some 12 km into Mackenzie Bay from the mouth of Kanguk Channel. The Mackenzie River at Inuvik had broken up and was clear of ice by June 4. Harry Channel, in the outer Mackenzie Delta, broke up June 7, 1975. By June 20, 1975, open water extended from Shallow Bay to Mallik Bay, however, landfast ice was still adhered to the seaward shores of the Barrier Islands. By July 7, 1975, large multi-year ice floes lay 5 to ten km off Pelly Island, and open water now extended around Richards Island into Kugmallit Bay. By August 15, 1975, open water extended 130 km north of Hooper Island, whereas, during 1974, the edge of the ice floes receded a maximum of about 50 km off Hooper Island.

4.8.1.2 Freeze-Up

During September, 1975, ice conditions off the Mackenzie Delta and Tuktoyaktuk Peninsula were heavy and resembled conditions described by Burns (1974) for most September ice cover observed between 1964 to 1969. Most outer Delta lakes were ice-covered by late September. Freeze-up had advanced about two weeks ahead of normal. At Inuvik, the Mackenzie River was reported frozen over on October 12, two days before the mean freeze-up date established for the period between 1968 to 1975. By late October, nearshore freeze-up of the landfast ice was almost complete.

4.8.2 Winds

Usual directions for strongest winds are from the WNW at Tuktoyaktuk and Shingle Point. Winds through summer, 1975, prevailed from the NW to the NE as they did in 1974, with a much higher incidence of northeasterly winds. These persistent NE winds helped clear the multiyear ice from Kugmallit and Mackenzie Bays throughout most of the summer.

The two highest summer wind sessions in 1975 occurred on August 10 to 11 and August 26 to 27. Winds blew from the NW during both these sessions and generated moderate storm surges on the outer Delta channels.

4.8.3 Currents

The general circulation of waters in the Beaufort Sea is clockwise at speeds averaging 1.5 to three km per day (Slaney, 1975). Circulation patterns near the coast of Kugmallit and Mackenzie Bays are governed by numerous physical forces (Slaney, 1975), but are largely dependent on the prevailing wind fields.

In 1975, prevailing winds were generally from the NE. During moderate NE winds, offshore currents in Mackenzie Bay (beyond the Barrier Islands) followed quite closely the true NE wind direction. Currents in the western portion of Kugmallit Bay were influenced by the outflow from East Channel and the boundary constraints of Richards Island.

During moderate NW winds, offshore surface currents tracked in an ESE direction. In East Mackenzie Bay, currents were deflected north by boundary constraints causing slight counter-clockwise circulation; while in Kugmallit Bay, the flow regime was more southerly with SE flow along the Tuktoyaktuk Peninsula.

Heavy NW winds (>40 mph) result in abnormal elevation of water levels in Mackenzie Bay, and extensive changes in the normal current regime. Large volumes of water are funnelled into the outer Mackenzie Delta floodplain, and Mackenzie River outflow is reversed in all outer Delta channels. Offshore and longshore currents along the Barrier Islands turn more southerly, and only after the storm finally peaks do the water levels recede and currents reverse.

4.8.4 Beaufort Sea Storms

The average summer storm in Mackenzie Bay is preceded by the establishment of a low pressure system in the NW Beaufort Sea. Nearly all major high wind summer sessions recorded in Mackenzie Bay have occurred from between NW and NE octants. Winds from these octants are also those which cause the most efficient funnelling of onshore waters and produce the largest storm surging effects.

Only two moderate storms and associated surges occurred during the open water season of 1975 (August 10 to 11 and August 26 to 27). On the evening of August 10, winds shifted to the NW and averaged 20 to 25 knots (37 to 46 kmh) at Tuktoyaktuk, with periodic gusts as high as 40 knots (74 kmh) reported at Inuvik. As a result, a moderate storm surge of about 1.2 m was recorded near the mouths of Harry and Kumak Channels (Slaney, 1976).

A similar pattern developed for the storm of August 26 to 27 at Tuktoyaktuk, which resulted in a slightly larger rise in Delta water levels. The highest positive storm surge of the 1975 open water season was recorded by the water level recorders at the mouths of Harry and Kuluarpak Channels on August 10 to 11 (Slaney, 1976), and resulted in increases of 1.4 to 1.5 m.

4.8.5 Salinity

The extent of the estuarine area off Mackenzie Bay is not well-defined and highly variable. During low winds and/or westerly flow, the low salinity Mackenzie outflow moves eastward as a result of Coriollis and wind stress forces. During easterly winds, the low salinity outflow moves northwesterly offshore, resulting in nearshore surface replacement by higher salinity waters either upwelled or advected from areas to the east.

In 1975, high seasonal run-off from the Mackenzie River channels and a few remaining large multi-year ice floes combined to enclose a homogeneous layer of turbid freshwater in the nearshore areas of the Mackenzie Delta. Of the stations sampled in early July, 1975, only Station 11 showed salinity stratification with depth. All other stations were shallower and showed isohaline and isothermal conditions.

From July 15 to 18, 1975, the winds were from the NE and surface salinities in Kugmallit and Mackenzie Bays were near 0 $^{o}/oo$. Bottom salinities at most stations were 13 to 15 $^{o}/oo$, indicating significant vertical structuring.

From July 28 to 31, 1975, the winds were generally from the NW. Surface salinities were relatively high. Very little vertical structuring was observed at the nearshore stations, indicating the much larger salt volumes in Mackenzie Bay during 1975 as compared to summer, 1974. Offshore Stations 7 and 1 showed significant vertical structuring. A strong pycnocline (maximum vertical density gradient) resulted from the strong halocline and associated thermocline which were present.

From August 2 to 4, 1975, a broad tongue of saline water extended into Kugmallit Bay along the Tuktoyaktuk coast. Surface salinities of 10 $^{o}/oo$ were common in the nearshore areas. In East Mackenzie Bay, the 10 $^{o}/oo$ isohaline roughly paralleled the Barrier Islands with a large band of 5 to 10 $^{o}/oo$ water within the inner Bay. The relatively high salinities at all levels for all stations indicated a general replacement of the turbid brackish Mackenzie River water with clear more saline arctic surface water during sustained NE winds. From August 5 to 19, salinity in East Mackenzie Bay was relatively low; however, strong vertical structuring at Netserk Stations 8 and 9 on August 16 indicated a tongue of deeper saline water lay a few kilometers offshore.

On August 20, winds and currents in Kugmallit Bay were weak and not well-defined. Offshore stations had the greatest surface salinities with inner stations having well-mixed waters and lower salinities.

4.8.6 Temperature

The water temperature of East Mackenzie Bay is primarily controlled by the extreme arctic climate and the Mackenzie River outflow. In 1975, generally prevailing NE winds helped to clear Kugmallit and Mackenzie Bays of ice early in the summer and produced generally warmer water temperatures than in 1974.

In early July, 1975, inner East Mackenzie Bay contained warm turbid water. Station 11, the furthest offshore station sampled, was the coldest at 10.5^{o} C and the only station to show vertical temperature stratification. Temperatures were relatively uniform in Kugmallit Bay, ranging from 16 to 18^{o} C.

From July 28 to 31, 1975, very little vertical structuring was measured at the nearshore stations, indicating considerable wave mixing, and a well-established brackish layer from Mackenzie River outflow.

Weather conditions in August, 1975, were generally overcast, and air temperatures were cool. This reduced the radiative and conductive heat transport to the surface layers, hence surface water temperatures were lower. The warmest temperatures were generally measured in the areas of inner East Mackenzie Bay where warmer Mackenzie River outflow provided additional thermal input.

4.8.7 Turbidity and Settleable Materials

The annual variation of suspended materials in the Mackenzie River is large. Peak load usually occurs shortly after freshet in the upper reaches of the Mackenzie River, but suspended materials may not peak in the Mackenzie Delta until as late as mid-August. During the 1974 open water season, mean turbidities at most stations were greater than 320 ppm for approximately half of the sampling period. Amounts of settleable materials were not always directly related to the levels of turbidity or suspended solids. Construction activities, especially near dredges, caused some small increases in the usually high natural levels of sediment.

The extremes and absolute levels of turbidity, suspended solids and settleable materials in 1975 were considerably less than those of summer 1974. The early clearing of landfast ice in 1975 had allowed wider-spread movement and dilution of the turbid outflow from the Mackenzie Channels. Surface turbidities in Kugmallit Bay on July

15 ranged from 30 to 80 ppm at stations sampled. Bottom turbidities were all significantly less than at the surface. The turbidicline (maximum vertical turbidity gradient) was probably located at or near the halocline at each station.

From July 26 to 30, 1975, measured bottom turbidities in East Mackenzie Bay were all greater than at the surface, contrary to conditions measured earlier in Kugmallit Bay. This was probably the result of considerable wave-mixing which had occurred in the typically shallow waters of East Mackenzie Bay.

On August 20, 1975, surface turbidities in Kugmallit Bay were generally higher than in early August. Outside the Barrier Islands, a very turbid water mass was observed moving eastward towards Pullen Island. Turbidities inside the Barrier Islands were probably ≤ 20 ppm.

4.8.8 Dissolved Oxygen

The capacity of a waterbody to hold dissolved oxygen is a function of the temperature and to a lesser extent the salinity. In 1975, surface water temperatures at most stations were slightly higher than those measured in 1974, and surface dissolved oxygen levels were about the same. The intrusions of cold saline bottom waters, which occurred frequently in 1975, contained near identical amounts of dissolved oxygen as did surface waters.

At Station 8, July 28, 1975, the lowest bottom concentration of dissolved oxygen (2 mg/l) was recorded during the two years of measurements. Winds were 20 to 25 mph (37 to 46 kmh) from the NW with considerable wave activity. Oxygen saturation was about 20 percent.

In general, measurements of dissolved oxygen during 1975 had a wider range of both absolute levels and percent saturation than did measurements in 1974.

4.8.9 Alkalinity, Hardness and pH

Previous measurements of hardness and alkalinity in Mackenzie Bay indicate that levels of total alkalinity and total hardness slowly increase from July through September. The 1975 pH range was similar to that reported in 1974, but the maximum value 9.5 was 0.5 pH units higher. Alkalinity, hardness, calcium and magnesium ranges were generally greater in 1975 due to the greater intrusion and frequency occurrence of saline water in 1975.

4.8.10 Nutrients

Nutrient concentrations are generally expected to be lower in summer when primary productivity is greatest, and higher in winter when ice cover is permanent and productivity is least. In 1975, phosphate and nitrates did not occur in measureable amounts in any of the samples. Bottom samples were generally lower in silica than surface samples and did not exceed 4.0 ppm silica. Carbon concentrations in 1975 were low. Inorganic carbon accounted for the largest portion of the total carbon content in all the 1975 samples.

4.8.11 Heavy Metals

Concentrations of the heavy metals, nickel, cadmium, chromium and lead in East Mackenzie Bay were frequently below the minimum detection limits of 0.001 ppm of atomic absorption spectroscopy. The maximum variation of measurable metal concenrtrations was 0.005 ppm for nickel. During 1974, Slaney (1975) reported concentrations of heavy metals within these same ranges, with the exception of nickel which reached a maximum of 0.009 ppm on one occasion.

4.8.12 Possible Environmental Effects

4.8.12.1 Physical Effects

The effects of construction and presence of artificial drilling islands on the natural physical processes which occur in East Mackenzie Bay appear small and localized.

The physical presence of an artificial island in Mackenzie Bay or Kugmallit Bay tends to obstruct the natural movements of ice, water and to some degree winds in the local vicinity. There is also a slight sheltering effect due to presence of artificial islands.

4.8.12.2 Chemical Effects

Most chemical effects observed in 1975 were either consequences of dredging operations north of Garry Island or consequences of increased wave activities around artificial islands.

On July 28, 1975, ocean currents and settleable materials at Station 8 were the highest measured and the dissolved oxygen the lowest measured in the previous two years of study. High waves were focused on the shallower slopes of the artificial islands and were breaking and uplifting large amounts of sediments which must have maintained a high B.O.D.

Considerable barge and boat traffic near Immerk artificial island caused some localized increases in sediment loading.

The operating dredge at Garry Island resulted in surface turbidities of 110 ppm and settleable materials of 0.60 ml/l.

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APPENDIX 4.1

1975 OCEAN CURRENT MEASUREMENTS
EAST MACKENZIE BAY AND KUGMALLIT BAY

DATE	TIME	STATION	WIND SPEED (mph)	WIND DIRECTION (° TRUE)	DEPTH (m)	CURRENT SPEED (KNOTS)	CURRENT DIRECTION (° TRUE)
10/7	2000	16	5	360	0	0.45	330
					3.0	0.33	355
11/7	1130	12	5	110	0	0.28	020
					4.0	0.15	205
13/7	0900	11	5	040	0	0.30	320
					3.0	0.60	220
					6.5	0.20	170
15/7	1020	73	14	060	0	0.70	265
					4.5	0.60	265
15/7	0930	74	8-10	040	0	0.50	220
					5.2	0.30	155
15/7	0825	75	8-10	055	0	0.50	265
					4.9	0.55	265
15/7	1215	77	15	020	0	0.85	320
					3.5	0.45	310
15/7	1130	78	16	040	0	0.80	355
					4.6	0.60	310
17/7	1800	2	5	040	0	0.30	220
					4.6	0.25	310
18/7	1600	26	25	340	0	0.75	210
					1.5	0.70	290
26/7	1945	62	15	095	0	0.75	265
28/7	1250	8	18-25	310	0	1.70	020
					1.0	1.70	020
					2.0	1.70	020
					3.0	1.20	020

APPENDIX 4.1(page 2)

DATE	TIME	STATION	WIND SPEED (mph)	WIND DIRECTION (o TRUE)	DEPTH (m)	CURRENT SPEED (KNOTS)	CURRENT DIRECTION (o TRUE)
28/7	1330	7	18-22	250	0	0.92	360
					1.9	0.80	040
					3.0	0.80	040
					5.0	0.70	095
					7.0	0.70	095
					9.0	0.40	095
					11.0	0.40	095
30/7	1130	16	8	350	0	0.72	315
					3.0	0.45	265
30/7	1500	12	10	310	0	0.45	280
					2.0	0.32	245
					4.0	0.25	260
31/7	1630	1	6	360	0	0.72	030
					3.0	0.75	0 0
					5.0	0.16	160
					7.0	0.16	130
					10.0	0.18	090
31/7	1900	11	4	310	0	0.32	265
					3.0	0.45	220
					5.0	0.45	220
16/8	1630	21	3	080	0	0.57	120
					2.0	0.55	040
16/8	1525	8	8	070	0	0.76	-
					5.0	0.60	-
					10.0	0.23	-
16/8	1355	9	5	060	0	0.30	-
					1.0	0.35	-
					2.0	0.15	-
					3.0	0.15	-
					4.0	0.25	-
					5.0	0.30	-

APPENDIX 4.1(page 3)

DATE	TIME	STATION	WIND SPEED (mph)	WIND DIRECTION (° TRUE)	DEPTH (m)	CURRENT SPEED (KNOTS)	CURRENT DIRECTION (° TRUE)
18/8	1510	71	5	360	0	0.35	340
					2.0	0.35	-
20/8	1130	2	4	190	0	0.60	120
					4.6	0.30	-
20/8	1240	60	2	160	0	0.95	158
					5.3	0.15	-
20/8	1415	73	2	160	0	0.40	190
					4.5	0.20	-
20/8	1525	74	-	-	0	0.65	350
					5.2	0.10	-
20/8	1630	75	2	060	0	0.60	360
					4.9	0.10	-
20/8	1730	76	3	070	0	0.40	360
					4.0	0.10	-
20/8	1825	77	5	160	0	0.50	350
					3.5	0.15	-
20/8	1930	79	5	100	0	0.55	350
					4.3	0.10	-
20/8	2030	80	5	110	0	0.30	030
					3.7	0.20	-
20/8	2120	26	5	130	0	0.65	090
					1.5	0.40	-

APPENDIX 4.2

1975 WEATHER RECORD
GARRY ISLAND AND SHELL FAREWELL

A. SHELL FAREWELL STATION

DATE	TIME	DIRECTION (° TRUE)	WIND SPEED (mph)	TEMP. °C	CONDITION
July 8	08:00	270-280	4-7	-	clear
	20:00	270	1-3	-	clear
July 9	08:00	260-270	8-12	17	clear
	20:00	260-010	8-12	15	clear
July 10	08:00	170-180	8-12	19	clear
	20:00	270	4-7	19	clear
July 11	08:00	350	4-7	17	clear
	20:00	350	4-7	18	clear
July 12	08:00	010	1-3	14	drizzle
	20:00	040	4-7	16	overcast
July 13	08:00	040	1-3	15	scattered cloud
	20:00	060	4-7	19	clear
July 14	08:00	060	4-7	17	clear
	20:00	060	4-7	19	clear
July 15	08:00	060	4-12	17	clear
	20:00	040	8-18	17	clear
July 16	08:00	040	8-12	9	overcast
	20:00	020	4-7	11	scattered cloud
July 17	08:00	010	4-7	15	scattered cloud
	20:00	050	4-7	16	scattered cloud
July 18	08:00	030	4-7	10	overcast
	20:00	330	4-7	10	overcast
July 19	08:00	320-330	4-12	6	overcast
	20:00	350	4-12	7	drizzle
July 20	08:00	350	4-7	4	overcast
	20:00	350	4-7	6	overcast
July 21	08:00	290-300	4-7	7	overcast
	20:00	300	4-7	9	overcast

B. GARRY ISLAND STATION

DATE	TIME	WIND DIRECTION (° TRUE)	WIND SPEED (mph)	TEMP. °C	CONDITION
July 20	08:00	350	4-7	4	overcast
	20:00	350	1	6	overcast
July 21	08:00	290-300	4-12	7	overcast
	12:00	300	19-20	8	overcast
July 30	15:00	355	8-12	-	scattered cloud
	20:00	010	4-7	-	scattered cloud
July 31	08:00	005	1-3	-	scattered cloud
	14:00	0	1-3	-	overcast
	20:00	345	1-3	9-15	scattered cloud
August 1	08:00	040	8-12	7	scattered cloud
	14:00	010	13-18	-	overcast/rain
	20:00	330	8-12	-	overcast
August 2	08:00	320-330	4-7	-	overcast
	14:00	020	4-7	-	overcast
	20:00	010	4-7	-	scattered cloud
August 3	08:00	040	8-12	-	overcast
	14:00	040	8-12	-	overcast
	20:00	030	13-18	-	overcast
August 4	08:00	020	8-12	6	scattered cloud
	14:00	120	13-20	-	scattered cloud
	20:00	115	13-18	-	scattered cloud
August 5	08:00	150	8-12	-	clear
	14:00	200	8-12	-	scattered cloud
	20:00	010	4-7	-	scattered cloud
August 6	08:00	300-310	25-30	-	rain
	14:00	300-310	20-25	-	rain
	20:00	330	20-25	-	rain
August 7	08:00	320	4-7	2	rain
	14:00	310	8-12	-	overcast
	20:00	300	4-12	-	overcast
August 8	08:00	160	13-18	4	overcast
	14:00	240	13-18	-	overcast
	20:00	270	8-12	-	overcast
August 9	08:00	210-220	19-20	9	overcast
	14:00	220	20-36	-	overcast
	20:00	290	20-25	-	drizzle
August 10	08:00	290	25-33	-	overcast
	13:00	300	25-30	-	overcast

WATER CHEMISTRY IN EAST MACKENZIE BAY AND KUGMALLIT BAY, JULY 8 TO AUGUST 20, 1975

Stn.	Stn. Depth m	Date	Air Temp. °C	Sampling Depth m	Salinity ‰	Cond. umhos/cm	Water Temp. °C	D.O. mg/l	% O_2 Sat.	CO_2 mg/l	pH	Alkalinity ppm Total	Alkalinity ppm HCO_3	Alkalinity ppm CO_3	Alkalinity ppm OH	Hardness ppm	Turbidity ppm	Turbidity JTU	Set. Mat. ml/l	Suspended Solids ppm Total	Suspended Solids ppm Fixed	Suspended Solids ppm Vol.	Dissolved Solids ppm Total	Dissolved Solids ppm Fixed	Dissolved Solids ppm Vol.	Cl ppm	Phosphate ppm	Nitrates ppm	Ca ppm	Mg ppm	Cr ppm	Cd ppm	Pb ppm	Ni ppm	SiO_2 ppm	Carbon ppm Total	Carbon ppm Organic	Carbon ppm Inorganic
1	10.3	Jul. 31	4.2	0.5	15.0	17000	8.5	10.0	93	-	9.5	103	-	-	-	>684.0	-	-	-																			
				3.0	15.2	17500	8.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.0	17.0	19000	8.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				7.0	17.6	19600	7.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				10.0	20.1	22000	8.0	9.0	96	-	-	-	-	-	-	-	-	-	-																			
		Aug. 3	-	0.5	9.86	16400	-	-	-	-	8.35	-	110.6	2.6	0	1900.7	2.95	4.3	<0.50	13.6	9.5	4.1	11386	8596	2790	5480.0	<0.01	<0.1	133.0	486.9	<0.005	<0.001	<0.001	<0.001	4.0	34	12	22
2	4.6	Jul. 17	9.4	0.5	17.0	20000	11.0	11.0	125	20	9.1	137	-	-	-	>760	5.0	-	0																			
				1.5	17.0	20000	11.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	19.0	20000	9.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.4	20.0	21500	8.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	21.0	21500	7.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.6	25.0	24000	5.0	10.0	100	-	-	-	-	-	-	-	6	-	0																			
		Aug. 2	-	0.5	11.98	20500	-	-	-	-	7.9	-	96.9	0	0	2234.3	2.95	3.4	< .05	9.7	8.0	1.7	13848	11152	2696	6670.0	<0.01	<0.1	150.0	572.4	<0.005	0.001	0.001	<0.001	3.4	22	5	17
				4.6	14.85	26200	-	-	-	-	8.0	-	117.9	0	0	798.7	3.35	3.6	< .05	11.1	9.0	2.1	18812	14524	4288	8290.0	<0.01	<0.1	189.0	204.6	<0.005	<0.001	0.001	0.001	3.0	29	3	26
		Aug. 20	12.0	0.5	3.2	4000	14.5	9.0	87	-	7.9	-	71.9	0	0	456.9	17.5	22.0	<0.05	27.0	22.4	4.6	2484	1936	548	1190.0	<0.01	<0.1	41.3	117.0	<0.005	<0.001	<0.001	<0.001	3.8	21	8	13
				0.6	3.2	4000	14.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				1.2	3.2	4000	14.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				1.8	3.9	4900	13.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	4.0	5500	13.5																															
				3.0	4.2	5500	12.8	10.0	99	-	7.95	-	79.3	0	0	596.5	17.5	18.0	<0.05	25.0	20.0	5.0	3244	2694	550	1590.0	<0.01	<0.1	52.4	152.8	<0.005	<0.001	0.001	0.001	4.1	25	7	18
7	11.2	Jul. 28	6.1	0.5	12.3	14300	8.0	10.0	100	-	9.0	>684	-	-	-	103.0	-	-	-																			
				1.5	12.4	14100	8.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	12.8	14200	7.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.6	13.2	15000	7.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				6.0	14.5	16000	7.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				7.6	20.0	20500	6.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				9.1	24.1	23100	3.5	4.0	38	-	-	-	-	-	-	-	-	-	-																			
8	5.0	Jul. 28	7.2	0.5	10.8	12200	9.0	11.0	112	-	9.0	>684	-	-	-	170.0	78.0	-	1.95																			
				1.0	10.7	12200	8.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	10.8	12300	8.8	2.0	20	-	-	-	-	-	-	-	120.0	-	2.55																			
		Aug. 4	-	0.5	7.76	13600	-	-	-	-	8.3	-	108.4	1.2	0	1526.6	58.0	38.0	0.1	60.2	50.4	9.8	8344	6562	1782	4300.0	<0.01	<0.1	111.0	391.1	<0.005	<0.001	<0.001	<0.001	3.9	27	8	19
		Aug. 16	18.5	0.5	0.5	610	12.2	9.0	83	-	9.0	154	-	-	-	103.0	-	-	<0.1																			
				1.0	0.5	620	11.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.0	0.9	1190	11.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	1.8	2510	11.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.0	6.2	7400	10.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.0	7.0	8500	10.2	-	-	-	-	-	-	-	-	-	-	-	-																			
9	7.5	Aug. 16	19.0	0.5	1.3	1950	14.0	11.0	106	-	9.0	>684	-	-	-	103.0	-	-	-																			
				1.0	6.8	9100	10.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.0	7.8	9400	10.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	8.3	10100	10.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.0	8.9	10700	10.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.0	10.3	12600	10.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				6.0	10.6	12800	10.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				7.0	10.8	12900	10.1	-	-	-	-	-	-	-	-	-	-	-	-																			
10	2.7	Aug. 3	-	0.5	<3.64	2100	-	-	-	-	8.0	-	87.8	0	0	257.8	87.0	81.0	0.3	130.2	110.0	20.2	1224	818	406	542.0	<0.01	<0.1	34.3	66.0	<0.005	<0.001	<0.001	<0.001	4.7	38	13	25
11	6.5	Jul. 13	9.0	0.5	<1.0	700	10.5	12.8	111	-	8.5	274	-	-	-	103.0	64.0	-	-																			
				3.0	<1.0	880	9.5	14.2	121	-	-	-	-	-	-	-	-	-	-																			
				6.5	6.5	6500	3.6	15.0	113	-	8.5	>684	-	-	-	103.0	22.0	-	-																			

Stn.	Stn. Depth m	Date	Air Temp. °C	Sampling Depth m	Salinity ‰	Cond. umhos/cm	Water Temp. °C	D.O. mg/l	% O_2 Sat.	CO_2 mg/l	pH	Alkalinity ppm Total	Alkalinity ppm HCO_3	Alkalinity ppm CO_3	Alkalinity ppm OH	Hardness ppm	Turbidity ppm	Turbidity JTU	Set. Mat. ml/l	Suspended Solids ppm Total	Suspended Solids ppm Fixed	Suspended Solids ppm Vol.	Dissolved Solids ppm Total	Dissolved Solids ppm Fixed	Dissolved Solids ppm Vol.	Cl ppm	Phosphate ppm	Nitrates ppm	Ca ppm	Mg ppm	Cr ppm	Cd ppm	Pb ppm	Ni ppm	SiO_2 ppm	Carbon ppm Total	Carbon ppm Organic	Carbon ppm Inorgan
11		Jul. 31	5.0	0.5	<1.0	159	9.5	10.0	87	-	9.0	>684	-	-	-	103.0	-	-	-																			
				3.0	<1.0	163	8.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.0	1.0	168	8.8	10.0	36	-	-	-	-	-	-	-	-	-	-																			
		Aug. 3	-	0.5	8.38	15300	-	-	-	-	7.9	-	82.9	0	0	1587.3	7.9	8.8	<0.05	20.2	14.4	5.8	9320	7884	1436	4650.0	<0.01	<0.1	108.0	406.6	<0.005	<0.001	<0.001	0.002	3.3	20	3	17
12	4.0	Jul. 11	14.7	0.5	<1.0	203	13.9	10.2	98	-	9.0	154	-	-	-	137.0	10.0	-	-																			
				3.0	<1.0	217	13.9	11.2	108	-	-	-	-	-	-	-	-	-	-																			
		Jul. 30	6.9	0.5	<1.0	93	10.1	13.0	115	-	9.0	>684	-	-	-	103.0	43.0	-	<0.1																			
				1.0	<1.0	109	9.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.0	<1.0	119	9.9	13.0	115	-	-	-	-	-	-	-	46.0	-	<0.1																			
		Aug. 3	-	0.5	7.31	13700	-	-	-	-	7.7	-	79.3	0	0	1385.1	17.5	17.5	<0.05	27.8	20.2	7.6	8320	6719	1601	4050.0	<0.01	<0.1	96.1	354.8	<0.005	<0.001	<0.001	0.001	3.2	17	2	15
14	2.0	Aug. 3	-	-	9.50	15700	-	-	-	-	8.25	-	115.0	1.2	0	1880.5	39.0	33.0	0.1	78.8	67.8	11.0	10998	8402	2596	5280.0	<0.01	<0.1	138.0	481.7	<0.005	<0.001	<0.001	<0.001	4.3	34	11	23
		Aug. 15	-	0.5	<1.0	870	13.8	10.0	96	-	9.0	170	-	-	-	103.0	-	-	-																			
				1.0	<1.0	870	13.2	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.0	4.8	4980	11.5	-	-	-	-	-	-	-	-	-	-	-	-																			
16	3.0	Jul. 10	16.5	0.5	<1.0	245	15.0	13.0	127	-	8.5	137	-	-	-	103.0	-	-	-																			
				1.0	<1.0	245	15.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	<1.0	245	15.0	13.0	127	-	-	-	-	-	-	-	-	-	-																			
		Jul. 30	6.6	0.5	6.0	7500	9.3	10.0	99	-	9.0	>684	-	-	-	103.0	90.0	-	<0.1																			
				2.0	6.3	7800	9.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	6.9	8100	9.5	10.0	97	-	-	-	-	-	-	-	210.0	-	0.1																			
		Aug. 3	-	0.5	7.74	14100	-	-	-	-	8.1	-	105.5	0	0	1506.4	30.0	38.0	<0.05	57.0	44.0	13.0	9042	7224	1818	4290.0	<0.01	<0.1	112.0	385.9	<0.005	<0.001	<0.001	< 0.001	3.8	27	6	21
17	4.5	Aug. 3	-	0.5	8.61	15500	-	-	-	-	8.15	-	107.3	0.91	0	1668.2	25.0	27.0	<0.05	40.8	28.8	12.0	10038	7898	2140	4780.0	0.01	<0.1	122.0	427.3	<0.005	<0.001	<0.001	0.001	3.3	29	5	24
19	1.9	Aug. 3	-	0.5	<3.64	-	-	-	-	-	7.95	-	89.3	0	0	95.0	110.0	100.0	0.6	348.4	311.4	37.0	184	124	60	23.6	<0.01	<0.1	24.6	24.3	<0.005	<0.001	<0.001	0.001	5.2	38	10	28
21	2.0	Aug. 4	-	0.5	5.45	9600	-	-	-	-	8.15	-	102.6	0.3	0	1081.7	60.0	44.0	0.1	70.4	58.8	11.6	6366	5004	1362	3010.0	<0.01	<0.1	50.0	277.1	<0.005	<0.001	<0.001	<0.001	4.5	25	5	20
		Aug. 16	19.5	0.5	0	231	18.0	-	-	-	8.5	154	-	-	-	108.0	-	-	-																			
				1.0	0	231	17.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.0	0	232	17.5	-	-	-	-	-	-	-	-	-	-	-	-																			
22	1.7	Aug. 4	-	0.5	<3.64	210	-	-	-	-	8.12	-	90.4	0.2	0	98.6	78.0	72.0	0.2	137.8	121.6	16.2	166	116	50	23.6	<0.01	<0.1	24.6	25.3	<0.005	<0.001	<0.001	<0.001	5.5	30	10	20
26	3.9	Jul. 18	6.6	0.5	6.0	7000	11.0	11.0	111	-	-	>684	-	-	-	86.0	32.0	-	0																			
				1.5	30.0	25000	1.5	12.0	110	-	-	-	-	-	-	-	65.0	-	0																			
		Aug. 2	-	0.5	10.89	18500	-	-	-	-	8.10	-	121.9	0	0	2092.7	8.7	15.0	<0.05	33.0	23.0	10.0	12720	9912	2808	6060.0	<0.01	<0.1	147.0	536.1	<0.005	<0.001	<0.001	0.005	4.5	27	10	17
				3.9	16.63	28100	-	-	-	-	8.05	-	125.6	0	0	3184.6	78.0	67.0	0.2	193.2	163.2	30.0	18712	15854	2858	9300.0	<0.01	<0.1	210.0	815.8	<0.005	<0.001	<0.001	0.005	3.0	30	5	25
		Aug. 3	-	0.5	10.63	17900	-	-	-	-	8.10	-	109.8	0	0	2022.0	17.5	23.0	<0.05	45.2	33.2	12.0	11774	9940	1834	5910.0	<0.01	<0.1	145.0	331.5	<0.005	<0.001	<0.001	<0.001	5.2	24	3	21
				3.9	11.30	19600	-	-	-	-	8.10	-	117.7	0	0	2193.8	15.5	23.0	<0.05	42.6	32.6	10.0	12274	9960	2314	6290.0	<0.01	<0.1	142.0	518.0	<0.005	<0.001	<0.001	0.001	3.7	30	8	22
		Aug. 20	16.0	0.5	3.3	4100	14.9	10.0	103	-	-	599	-	-	-	103.0	-	-	-																			
				1.5	3.3	4100	14.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.9	3.3	4150	13.9	-	-	-	-	-	-	-	-	-	-	-	-																			
29	6.0	Jul. 8	-	0.5	0.1	105	13.3	10.0	94	-	8.5	120	-	-	-	103.0	-	-	-																			
		Aug. 7	-	0.5	0.7	400	10.0	-	-	-	8.5	86	-	-	-	427.5	-	-	-																			
30	3.0	Jul. 8	15.0	0.5	0.3	178	17.5	9.4	98	-	8.5	103	-	-	-	119.7	-	-	-																			
		Aug. 11	-	0.5	0.5	700	8.0	-	-	-	7.5	34	-	-	-	376.2	-	-	-																			
				3.0	0.9	1150	8.0	-	-	-	-	-	-	-	-	-	-	-	-																			

Stn.	Stn. Depth m	Date	Air Temp. °C	Sampling Depth m	Salinity ‰	Cond. umhos/cm	Water Temp. °C	D.O. mg/l	% O_2 Sat.	CO_2 mg/l	pH	Alkalinity ppm Total	HCO_3	CO_3	OH	Hardness ppm	Turbidity ppm	JTU	Set. Mat. ml/l	Suspended Solids ppm Total	Fixed	Vol.	Dissolved Solids ppm Total	Fixed	Vol.	Cl ppm	Phosphate ppm	Nitrates ppm	Ca ppm	Mg ppm	Cr ppm	Cd ppm	Pb ppm	Ni ppm	SiO_2 ppm	Carbon ppm Total	Organic	Inorganic
31	3.0	Aug. 10	-	0.5	2.5	2500	8.0	-	-	-	7.5	103	-	-	-	376.2	-	-	-																			
		Aug. 12	-	0.5	6.25	7900	9.0	10.0	86	-	8.5	154	-	-	-	>684.0	-	-	-																			
				3.0	6.25	7900	9.0	-	-	-	-	-	-	-	-	-	-	-	-																			
32	3.0	Aug. 11	-	0.5	6.0	7500	8.0	-	-	-	8.0	120	-	-	-	>684.0																						
				3.0	5.5	7500	8.5	-	-	-	-	-	-	-	-	-	-	-	-																			
33	3.2	Jul. 9	-	0.5	0.2	230	12.8	10.2	96	-	8.5	103	-	-	-	119.7	-	-	-																			
34	1.0	Jul. 9	9.5	0.5	0.1	170	12.5	9.8	92	-	8.5	103	-	-	-	119.7	-	-	-																			
38	1.0	Jul. 12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	79.0	-	-																			
57	1.0	Jul. 8	17.5	0.5	0.3	160	15.0	9.0	88	-	8.5	120	-	-	-	119.7	-	-	-																			
58	2.0	Jul. 17	-	0.5	0.2	162	14.0	10.0	96	-	8.5	120	-	-	-	103.0	-	-	-																			
				2.0	0	162	13.5	-	-	-	-	-	-	-	-	-	-	-	-																			
		Aug. 12	-	0.5	0.05	190	12.0	10.0	92	-	8.5	120	-	-	-	170.0	-	-	-																			
				2.0	0.05	165	9.5	-	-	-	-	-	-	-	-	-	-	-	-																			
59	4.6	Aug. 2		0.5	6.5	8000	9.0	9.0	77	-	9.0	120	-	-	-	>684.0	-	-	-																			
				4.6	6.5	8000	9.0	-	-	-	-	-	-	-	-	-	-	-	-																			
60	5.3	Aug. 2	-	0.5	10.47	17200	-	-	-	-	8.12	-	115.6	0.6	-	1991.7	3.35	5.5	<0.1	9.0	7.6	1.4	12190	9378	2812	5820.0	<0.01	<0.1	141.0	510.2	<0.005	<0.001	0.002	0.004	4.0	30	7	23
				6.0	19.20	30400	-	-	-	-	8.10	-	128.6	-	-	3649.6	-	-	-			-	-	-	-	10760.0	<0.01	<0.1	248.0	932.4	<0.005	<0.001	0.002	<0.001	3.3	38	13	25
		Aug. 20	13.8	0.5	3.0	3755	14.5	10.0	98	-	9.0	-	59.8	0	0	363.9	11.0	15.0	<0.05	8.9	8.0	0.9	1828	1390	438	986.0	<0.01	<0.1	34.3	93.2	<0.005	<0.001	<0.001	0.001	3.1	13	2	11
				0.9	3.0	4025	14.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				1.8	5.75	7500	14.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	8.0	10000	12.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	9.0	11000	11.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.3	9.0	11000	10.3	10.0	93	-	7.8	-	72.7	0	0	1294.1	8.7	9.4	<0.05	15.4	13.6	1.8	7656	6198	1458	3760.0	<0.01	<0.1	88.7	331.5	<0.005	<0.001	<0.001	0.001	2.8	15	2	13
62	1.3	Jul. 26	-	0.5	0	170	11.2	10.0	90	-	9	137	-	-	-	154.0	24.0	-	0.15																			
				1.3	0	170	11.0	-	-	-	-	-	-	-	-	-	-	-	-																			
		Aug. 13	17.5	0.5	0	100	13.5	10.0	95	-	8.5	154	-	-	-	120.0	-	-	-																			
				1.3	1.0	1850	12.8	-	-	-	-	-	-	-	-	-	-	-	-																			
67	5.0	Jul. 16	10.0	0.5	2.0	2750	10.9	11.2	101	-	8.5	752	-	-	-	103.0	-	-	-																			
				5.0	5.2	7250	2.2	-	-	-	-	-	-	-	-	-	-	-	-																			
69	1.0	Jul. 13	-	0.5	0	-	-	10.8	-	-	9.0	103	-	-	-	667.0	-	-	-																			
70	1.3	Jul. 14	-	0.5	0	180	16.0	8.8	88	-	8.5	120	-	-	-	103.0	-	-	-																			
				1.3	0	180	16.0	-	-	-	-	-	-	-	-	-	-	-	-																			
71	2.0	Aug. 18	-	0.5	0	300	13.5	9.0	86	-	9.0	188	-	-	-	103.0	-	-	0.07																			
				1.0	0	300	13.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.0	0	300	13.5	10.0	95	-	-	-	-	-	-	-	-	-	-																			

Stn.	Stn. Depth m	Date	Air Temp. °C	Sampling Depth m	Salinity °/oo	Cond. umhos/cm	Water Temp. °C	D.O. mg/l	% O_2 Sat.	CO_2 mg/l	pH	Alkalinity ppm Total	HCO_3	CO_3	OH	Hardness ppm	Turbidity ppm	JTU	Set. Mat. ml/l	Suspended Solids ppm Total	Fixed	Vol.	Dissolved Solids ppm Total	Fixed	Vol.	Cl ppm	Phosphate ppm	Nitrates ppm	Ca ppm	Mg ppm	Cr ppm	Cd ppm	Pb ppm	Ni ppm	SiO_2 ppm	Carbon ppm Total	Organic	Inorganic
73	5.0	Jul. 15	9.4	0.5	2.8	3500	11.0	9.8	93	15	8.9	-	87.2	0	0	103.0	30.0	23.0	0.1	31.2	26.0	5.2	3050	2240	810	1400.0	<0.01	<0.1	50.0	139.1	<0.005	<0.001	<0.001	<0.001	4.5	33	13	20
				1.5	2.9	3520	10.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				1.8	10.8	12000	9.4	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.1	11.0	13800	8.4	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	13.3	14700	7.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.7	13.5	14800	6.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	13.5	14600	6.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.6	13.5	14800	6.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.0	13.6	14800	6.4	10.2	106	-	8.10	-	107.2	0	0	2466.8	20.0	27.5	0.1	64.4	51.8	12.6	15586	12194	3392	7270.0	<0.01	<0.1	164.0	631.9	<0.005	<0.001	<0.001	<0.001	3.2	36	14	22
		Aug. 2	-	0.5	11.28	18200	-	-	-	-	8.10	-	116.8	0	0	2173.6	2.1	3.7	<0.05	8.4	5.5	2.9	12760	9946	2814	6280.0	<0.01	<0.1	149.0	556.8	<0.005	<0.001	<0.001	<0.001	3.8	37	10	27
				4.5	17.65	27800	-	-	-	-	8.05	-	123.6	0	0	3366.6	9.4	14.0	0.1	29.6	23.2	6.4	1594	954	640	9880.0	<0.01	<0.1	222.0	862.5	<0.005	<0.001	<0.001	<0.001	3.4	32	8	24
		Aug. 20	-	0.5	3.7	4950	15.5	9.0	94	-	9.5	-	90.6	0.5	0			5.4	<0.05	5.9	4.3	1.6	3298	2634	664	1660.0	<0.01	<0.1	56.2	161.8	<0.005	<0.001	<0.001	<0.001	4.3	30	10	20
				1.5	5.1	6500	15.3	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	6.2	8200	13.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.5	6.8	9200	11.4	9.0	92	-	8.0	-	72.4	0	0	1161.1	15.5	22.5	<0.05	33.8	27.4	6.4	6424	5282	1142	3110.0	<0.01	<0.1	78.0	285.9	<0.005	<0.001	<0.001	<0.001	3.0	19	5	14
74	5.2	Jul. 15	11.4	0.5	0.2	440	16.1	9.6	96	10	8.8	120	-	-	-	103.0	66.0	-	0																			
				1.5	0.2	450	16.1	-	-	-	-	-	-	-	-	-	-	-	-																			
				1.8	0.2	470	15.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.1	6.0	8000	13.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	10.5	12800	8.7	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.7	12.0	13700	8.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	14.0	15200	7.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	14.9	15900	6.2	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.5	15.0	16000	5.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.2	15.0	16000	6.0	9.6	98	-	-	-	-	-	-	-	17.0	-	0																			
		Aug. 2	-	0.5	12.60	20700	-	-	-	-	8.1	-	117.4	0	0	2410.0	2.35	4.2	<0.05	9.9	7.0	2.9	13160	10878	2282	7020.0	<0.01	<0.1	166.0	617.4	<0.005	<0.001	<0.001	<0.001	3.9	29	6	23
				5.2	14.97	24300	-	-	-	-	8.05	-	112.0	0	0	2800.5	9.8	15.0	0.1	24.6	20.2	4.4	16464	14280	2184	8360.0	<0.01	<0.1	184.0	717.4	<0.005	<0.001	<0.001	<0.001	3.4	28	6	22
		Aug. 20	-	0.5	1.0	1090	17.5	10.0	96	-	9.0	-	61.2	0	0	103.0	15.5	21.0	0.1	19.8	17.8	2.0	478	348	130	166.0	<0.01	<0.1	19.3	59.6	<0.005	<0.001	<0.001	<0.001	3.8	13	2	11
				1.5	2.5	3250	14.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	4.7	6200	13.7	-	-	-	-	-	-	-	-	-	-	-	-																			
				5.2	6.8	8400	11.8	4.0	41	-	8.05	-	94.0	0	0	257.0	98.0	85.0	0.2	169.3	87.6	81.6	7548	6348	1200	3700.0	<0.01	<0.1	94.0	339.3	<0.005	<0.001	<0.001	<0.001	3.8	26	7	19

Stn.	Stn. Depth m	Date	Air Temp. °C	Sampling Depth m	Salinity ‰	Cond. umhos/cm	Water Temp. °C	D.O. mg/l	% O_2 Sat.	CO_2 mg/l	pH	Alkalinity ppm Total	Alkalinity ppm HCO_3	Alkalinity ppm CO_3	Alkalinity ppm OH	Hardness ppm	Turbidity ppm	Turbidity JTU	Set. Mat. ml/l	Suspended Solids ppm Total	Suspended Solids ppm Fixed	Suspended Solids ppm Vol.	Dissolved Solids ppm Total	Dissolved Solids ppm Fixed	Dissolved Solids ppm Vol.	Cl ppm	Phosphate ppm	Nitrates ppm	Ca ppm	Mg ppm	Cr ppm	Cd ppm	Pb ppm	Ni ppm	SiO_2 ppm	Carbon ppm Total	Carbon ppm Organic	Carbon ppm Inorganic
75	4.9	Jul. 15	12.7	0.5	0.2	400	17.4	9.6	100	10.0	8.8	-	81.2	0	0	103.0	56.0	38.0	0.2	73.2	61.4	11.8	354	266	88	103.0	<0.01	<0.1	24.2	29.8	<0.005	<0.001	<0.001	<0.001	4.3	27	11	16
				1.5	0.2	425	17.4	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	0.2	418	17.3	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	0.5	800	16.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	6.3	6900	5.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.3	13.2	13600	4.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.5	13.1	13500	4.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.9	13.0	13300	5.0	9.6	90	-	-	-	-	-	-	-	34.0	-	0																			
		Aug. 20	16	0.5	0	322	16.8	10.0	103	-	9.0	-	75.2	0	0	103.0	15.5	28.0	0.3	42.9	38.6	3.3	186	120	66	35.9	<0.01	<0.1	20.2	22.0	<0.005	<0.001	<0.001	<0.001	4.5	22	7	15
				1.5	0	318	16.2	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	2.6	3380	14.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.5	5.4	7200	12.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.9	5.5	7300	12.5	11.0	87	-	8.1	-	97.8	0	0	1095.9	90.0	79.0	0.2	92.4	80.0	12.4	6540	5204	1336	3030.0	<0.01	<0.1	84.4	280.7	<0.005	<0.001	<0.001	<0.001	3.4	29	10	19
76	4.0	Aug. 20	20	0.5	0	295	17.0	10.0	103	-	9.0	-	87.2	0	0	103	21.0	28.0	0.2	36.7	31.3	5.4	160	106	54	78.4	<0.01	<0.1	23.4	22.0	<0.005	<0.001	0.001	0.001	5.4	24	4	20
				1.5	0	295	15.1	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	5.0	7000	13.2	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.0	5.8	7300	12.0	10.0	97	- -	7.95	-	92.1	0	0	952.4	58.0	60.0	0.2	124.0	107.6	16.4	5698	4168	1530	2710.0	<0.01	<0.1	77.6	243.9	<0.005	0.001	<0.001	<0.001	3.7	29	6	23
77	3.5	Jul. 15	12.5	0.5	0	190	17.6	9.4	98	10.0	8.9	-	128.6	0	0	103.0	88.0	2.8	<0.05	8.2	5.8	2.4	21098	16414	4684	9980.0	<0.01	<0.1	234.0	874.4	<0.005	<0.001	0.0025	0.001	3.2	38	13	25
				1.5	0	193	17.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	0	195	17.6	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.5	0	195	17.6	8.4	88	-	7.9	-	130.5	0	0	3862.0	98.0	4.8	<0.05	13.0	10.0	3.0	23750	19320	4430	11460.0	<0.01	<0.1	262.0	989.4	<0.005	<0.001	<0.001	<0.001	3.0	36	10	26
		Aug. 20	18.5	0.5	1.9	2500	18.0	10.0	105	-	9.0	-	93.9	0	0	103.0	20.0	22.0	0.1	23.5	20.5	3.0	1734	1332	402	740.0	<0.01	<0.1	38.9	85.5	<0.005	<0.001	0.01	<0.001	4.7	30	11	19
				1.5	3.8	5000	16.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	6.0	8000	14.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.5	7.5	9700	12.5	10.0	96	-	8.0	-	106.8	0	0	1037.3	22.5	26.0	0.1	50.4	44.4	6.0	6044	4754	1290	2890.0	<0.01	<0.1	82.6	265.7	<0.005	<0.001	0.001	0.001	4.0	28	9	19
78	4.6	Jul. 15	10.8	0.5	0.2	455	16.5	10.2	104	10.0	9.0	154	-	-	-	103.0	56.0	-	0																			
				1.5	0.2	465	16.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.1	0.3	480	15.1	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	0.4	510	14.3	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.7	4.5	2500	13.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	7.5	6000	6.9	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	8.3	9000	5.0	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.6	8.4	9000	4.6	10.0	95	-	-	-	-	-	-	-	47.0	-	0																			
		Aug. 2	-	0.5	7.01	12400	-	-	-	-	8.0	-	107.9	0	0	1374.9	8.7	7.8	<0.05	18.0	13.8	4.2	8122	6396	1726	3880.0	<0.01	<0.1	103.0	352.2	<0.005	<0.001	<0.001	0.002	4.3	29	8	21
				4.6	12.39	20200	-	-	-	-	8.05	-	117.7	0	0	2264.6	8.7	13.0	0.05	22.6	18.8	3.8	14318	11062	3256	6900.0	<0.01	<0.1	155.0	580.2	<0.005	0.002	<0.001	0.005	3.8	27	3	24
79	4.3	Aug. 2		0.5	12.78	21400	-	-	-	-	8.03	-	120.9	0	0	2446.6	3.6	4.4	<0.05	8.8	6.9	1.9	13734	10772	2962	7120.0	<0.01	<0.1	172.0	626.7	<0.005	<0.001	<0.001	<0.001	3.3	31	7	24
				6+	14.28	23500	-	-	-	-	7.95	-	116.7	0	0	2689.3	4.2	4.8	<0.05	14.8	11.4	3.4	16770	13194	3576	7970.0	<0.01	<0.1	179.0	688.9	<0.005	<0.001	<0.001	<0.001	3.2	27	6	21
		Aug. 20	16.0	0.5	6.1	8200	15.1	10.0	101	-	9.0	>684	-	-	-	103.0	-	-	-																			
				1.5	6.1	8200	15.1	-	-	-	-	-	-	-	-	-	-	-	-																			
				2.4	6.1	8200	14.2	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	6.1	8200	13.8	-	-	-	-	-	-	-	-	-	-	-	-																			
				4.3	6.9	8500	12.5	10.0	96	-	-	-	-	-	-	-	-	-	-																			
80	3.7	Aug. 20	14.5	0.5	4.0	5500	15.7	10.0	103	-	9.0	-	89.9	0	0	679.4	10.6	16.0	<0.05	18.2	15.4	2.8	3840	2964	876	1870.0	<0.01	<0.1	60.0	174.0	<0.005	<0.001	<0.001	<0.001	3.3	24	7	17
				1.5	4.8	6900	13.3	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.0	5.0	6500	12.5	-	-	-	-	-	-	-	-	-	-	-	-																			
				3.7	5.0	6500	12.5	10.0	98	-	-	-	-	-	-	-	-	-	-																			
81	4.8	Aug. 3	-	0.5	17.4	29500	-	-	-	-	8.0	-	128.0	0	0	3305.9	7.9	7.0	<0.05	21.0	12.4	8.6	21346	15392	5954	9740.0	<0.01	<0.1	220.0	846.9	<0.005	<0.001	<0.001	0.002	3.2	29	5	24
83	1.5	Jul. 14	17.0	0.5	<1.0	930	16.0	-	-	-	-	-	-	-	-	-	48.0	-	-																			

RANGES IN WATER CHEMISTRY CHARACTERISTICS & EFFECTS CAUSED BY CONSTRUCTION ACTIVITIES - MACKENZIE BAY, 1974 & 1975

		RANGES 1974 July Max.	July Min.	August Max.	August Min.	September Max.	September Min.	1974 Effects of Construction Activities	RANGES 1975 July Max.	July Min.	August Max.	August Min.	1975 Effects of Construction Activities
Salinity (‰)	surface	< 1.0		6.1	0	26.0	0	Surface salinities may be increased by prop. wash mixing subsurface saline water with fresher surface water.	17.0	0	17.4	0	None observed. However, mixing of saline subsurface water by prop. wash will increase surface salinity.
	bottom	< 1.0		26.0	0	16.5	2.2		25.0	0	19.2	0	
Cond. (umhos/cm)	surface	310	145	5,000	120	22,000	180	Surface conductivity at Immerk was 1800 umhos/cm August 12. This may be due to mixing of subsurface saline water with fresher surface water by prop. wash.	2,000	98	29,500	100	None observed.
	bottom	220	179	29,000	165	16,700	1,800		30,400	119	27,800	232	
Water (°C) Temperature	surface	18.0	8.2	16.0	5.0	9.0	-0.5	None observed. However, nearshore sites including 28a, 14 and other similar areas with high temperatures in July and August may require careful monitoring.	17.6	8.0	18.0	8.0	None observed.
	bottom	16.0	8.6	15.0	-2.0	5.2	-0.5		17.6	1.5	17.5	8.0	
Dissolved O_2 (mg/l)	surface	12.2	6.5	13.0	8.4	12.8	98.0	Dredging or wave action may have resulted in uplifting of high B.O.D. sediments at St. 8 July 21, causing a low bottom D.O. of 5.0 mg/l	13.0	8.8	11.0	9.0	Wave action at St. 8 July 28 caused uplifting of high B.O.D. sediments resulting in a low bottom D.O. of 2.0 mg/l (20% sat.)
	bottom	9.5	5.0	12.0	6.8	NT			15.0	2.0	11.0	4.0	
% Sat. O_2	surface	112	61	103	71	93	76		127	87	105	77	
	bottom	89	48	100	68	NT			127	20	99	41	
CO_2 (mg/l)		NT		NT		NT		---	10	20	NT		None observed.
pH		9.0	8.0	9.0	7.5	9.0	8.5	None observed.	9.5	7.9	9.5	7.5	None observed.
Alkalinity (ppm)	total	154	103	188	103	137	103	None observed.	> 684	103	> 684	34	None observed.
	HCO_3	NT		NT		NT			130.5	81.2	128.6	59.8	
	CO_3	NT		NT		NT			0	0	2.6	0	
	OH	NT		NT		NT			0	0	0	0	
Hardness (ppm)		160	103	> 1,027	103	> 1,027	103	None observed.	2,466.8	86	3,639.6	950	None observed
Turbidity (ppm)		250	90	800	10	480	5	Dredging operations near Garry Island in mid July increased turbidity to 305-370. Dredging near Pelly spit increased turbidity to 480 on September 28.	210	5.0	110	2.1	Dredging & boat traffic caused maximum measured turbidities of 210 & 110 ppm. July 20 & Aug. 3.
(JTU)		-		-		-			38	2.8	100	3.4	
Settleable Material (ml/l)		0.30	0	2.2	0	2.5	0	Dredging near Garry Island July 17 increased sediments to .15-.25 ml/l. Sediments on September 28 at the Pelly dredge were 2.5 ml/l.	2.55	<.05	0.6	<.05	Increased settleable material was noted due to dredging, barge traffic and wave action
Suspended Solids (ppm)	total	516.3	19.8	966.3	26.5	766.8	50	Suspended solids at Langley Camp (Stn. 23) were highest August 4 associated with high turbidity.	73.2	8.2	348.4	5.9	Short term increases where dredging or wave action uplifted sediments.
	fixed								61.4	5.2	311.4	4.3	
	volatile								11.8	2.4	81.6	1.4	
Dissolved Solids (ppm)	total	NT		NT		NT		---	21,098	354	23,750	160	Short term increases where dredging or wave action uplifted sediments.
	fixed								16,414	266	19,320	106	
	volatile								4,684	88	5,954	50	
Cl (ppm)		NT		NT		NT		---	9,980	103	10,760	23.6	None observed but chloride concentrations are a function of salinity & surface increases could result from uplifting subsurface saline water by prop. wash.
Phosphate (ppm)		0.15	< 0.10	0.20	0.10	0.15	< 0.10	None observed.	< 0.01		< 0.01		None observed
Nitrate (ppm)		1.02	< 0.10	0.24	< 0.10	0.61	< 0.10	None observed.	< 0.1		< 0.1		None observed.
Ca (ppm)		28.6	20.7	66.3	23.7	84.2	24.2	None observed.	262.0	24.2	248.0	19.3	None observed.
Mg (ppm)		9.8	7.6	163.5	7.7	49.0	8.9	None observed.	989.4	29.8	932.4	22.0	None observed.
Cr (ppm)		< 0.003		< 0.003		< 0.003		None observed.	< 0.005		< 0.005		None observed.
Cd (ppm)		0.001	< 0.001	0.0016	< 0.001	0.002	< 0.001	None observed.	< 0.001		0.002	< 0.001	None observed.
Pb (ppm)		0.005	< 0.001	0.005	< 0.001	0.005	< 0.001	None observed.	0.0025	< 0.001	0.01	< 0.001	None observed.
Ni (ppm)		0.009	< 0.001	0.004	< 0.001	0.0041	< 0.001	None observed.	0.001	< 0.001	0.005	< 0.001	None observed.
Si (ppm)		4.6	3.2	4.2	2.0	3.6	2.4	None observed.	4.5	3.2	5.5	2.8	None observed.
Carbon (ppm)	total	NT		NT		NT		---	38	11	38	13	None observed.
	organic								13	11	14	2	
	inorganic								25	16	28	11	
Water Depth (m)								Dredging activities at Garry Island increased water depth from 2.7 m to 6.3 m.					

NOTE: NT = not taken.

PART 5

A PRELIMINARY INVESTIGATION OF PLANKTONIC RESOURCES WITHIN THE MACKENZIE RIVER ESTUARY, N.W.T., 1975

BY

W.R. OLMSTED

FOR

IMPERIAL OIL LIMITED

F.F. SLANEY & COMPANY LIMITED
VANCOUVER, CANADA

PART 5

PLANKTON

5.1 INTRODUCTION

Beginning with the construction of Immerk artificial island by Imperial Oil Limited in 1972, the Mackenzie Estuary has received increasing scientific attention. Environmental studies related to artificial island construction have generated some baseline data with regard to components of the Mackenzie estuarine food web; however, the primary and secondary trophic levels and their inter-relationships remain poorly understood. In recognition of their biological importance, Imperial Oil Limited retained F.F. Slaney & Company Limited to conduct a study directed toward a preliminary evaluation of plankton resources within the Mackenzie Estuary as a component of an integrated environmental program.

5.2 PURPOSE

The purpose of the 1975 program was to supplement the existing planktonic data base related to the assessment of environmental effects arising from summer construction of artificial drillings islands in the Mackenzie Estuary.

5.3 OBJECTIVES

The specific objectives of the plankton program were to:

1. Provide baseline data on plankton distribution, species composition and relative abundance in the Mackenzie Estuary; and

2. Assess general phytoplankton productivity through chlorophyll _a_ measurements at selected stations in the Mackenzie Estuary.

5.4 SCOPE OF WORK

F.F. Slaney & Company first examined planktonic invertebrates in East Mackenzie Bay, related to the construction of Immerk artificial island, during the open water season of 1972 (Slaney, 1973). Winter studies conducted during March and April, 1974, described the under-ice environment and generated primarily faunistic data regarding planktonic resources (Slaney, 1974c, 1974d). As part of an integrated bio-physical program conducted in the summer of 1974 to assess the effects of artificial island construction, phytoplankton and zooplankton were quantitatively sampled at selected stations in East Mackenzie Bay (Slaney, 1975).

An integrated bio-physical environmental program, based upon the design and results of the 1974 study, was conducted during the open water season of 1975. This study monitored selected stations from the previous summer, and examined plankton communities in new development areas of East Mackenzie and Kugmallit Bays.

The burning of the Wilson III on August 8, 1975, with the subsequent loss of data, preserved samples and collection equipment, affected components of the plankton program to varying degrees. Equipment losses forced termination of zooplankton collection by means of horizontal trawls and the field processing of chlorophyll a samples. Limited phytoplankton sampling was continued. Much of the data presented in this report therefore, spans only approximately 30 percent of the estuarine open water period and represents a small portion of the range of natural seasonal variability.

Although other studies relevant to the Mackenzie Estuary are few the discussion of 1975 study results has integrated available data from other research agencies, particularly the Beaufort Sea Project

Study conducted by the Arctic Biological Station, Ste. Anne de Bellevue, Quebec.

5.5 METHODS

The following section presents a description of the field techniques and laboratory analyses used to attain the objectives of the 1975 plankton program.

5.5.1 Zooplankton

5.5.1.1 Field Treatment

Zooplankton were sampled in horizontal plankton trawls with 0.5 m diameter Oceanic plankton nets of 72 µ diameter Nitex mesh. The 2.5 meter-long net was constructed with a 5:1 conical taper. Plankton trawls were of approximately 90 second duration, 1 m below the surface at a consistent ship-indicated speed of approximately 1.6 kmh. Volumes of water sampled were measured with Gurly TS Pigmy flow meters rigidly mounted in front of the net mouth (Appendix 5.1).

Non-quantitative vertical zooplankton sampling was conducted at selected stations with a 0.12 m diameter Wisconsin type net of number 20 mesh. Following the loss of standard trawl equipment in the Wilson III, sampling was continued by making several 90 second horizontal collections at selected stations with this apparatus.

Planktonic invertebrates collected by both sampling techniques were fixed in dilute ethyl alcohol (6 percent v/v), and maintained in darkness at ambient temperatures onboard ship until transfer to Vancouver for laboratory analyses.

5.5.1.2 Laboratory Analyses

Volumetric subsamples of invertebrates from horizontal and vertical trawls were made by a method of division as described by Duval (1973). In most cases, a ten percent subsample was selected for enumeration under a M-5 dissection microscope. However, samples containing large numbers of Rotifera or eggs were counted from a one percent subsample. Those samples containing less than 50 organisms were counted completely.

Species identification was taken to the taxonomic classification level of specie where feasible, using a Wilde M-11 microscope.

5.5.2 Phytoplankton

5.5.2.1 Field Treatment

Phytoplankton were sampled quantitatively in clean, unused, 1 litre poly vinyl chloride (P.V.C.) bottles at a depth just below the surface. Samples were fixed by the addition of 60 mls ethyl alcohol (6 percent v/v). Care was taken to ensure complete filling and tight seal of the P.V.C. bottle to prevent sample oxidation. Phytoplankton collections were maintained in darkness at ambient temperatures onboard ship until transfer to Vancouver for laboratory analyses.

5.5.2.2 Laboratory Analyses

The 1 litre water samples containing phytoplankton were transferred to a 2 litre erlenmeyer flask and swirled vigorously to produce a homogeneous mixture. For the larger cells (primarily Nitzschia spp), a 1 ml aliquot was enumerated at 100 power under a Wilde M-11 inverted microscope. The total number of nannoplankton (averaging 3 to 5 μ in length) were enumerated from a 0.05 ml aliquot at 400 power magnification, and the total number of cells/sample volume calculated by extrapolation.

5.5.3 Chlorophyll *a*

5.5.3.1 Field Treatment

Surface collections of chlorophyll *a* were made in clean, unused 1 litre P.V.C. bottles. Immediately following collection, 1 ml of magnesium carbonate suspension ($MgCO_3$; 1 percent W/V) was added to each litre sample. Water samples were then filtered through either Whatman 47 mm GF/C grade glass-fiber filters, or Millipore 47 mm HA 0.45 μ acetate discs, stored individually in plastic specimen bags and frozen for shipment to Vancouver for laboratory analysis.

5.5.3.2 Laboratory Analysis

Upon laboratory receipt, frozen chlorophyll samples were warmed in darkness to room temperature and placed in a lyophalizer for three hours to remove excess water from the glass fiber filters.

Laboratory analysis of chlorophyll *a* samples followed the procedure described by Strickland and Parsons (1968). Chlorophylls were extracted in 90 percent analytical grade acetone and maintained at *ca* 5^{o} C for 20 hours. The samples were vigorously shaken at hour 2 of this incubation.

Following incubation, the extracted samples were warmed in darkness and at room temperature and centrifuged with a Sorvall RC2-B automatic refrigerated centrifuge for 15 minutes at 3,000 rpm. The supernatant was decanted into a 10 cm path-length cuvette, and the extinction co-efficient for each sample at wave lengths of 7,500, 6,650, and

6,300 Å was determined against a cell containing 90 percent analytical grade acetone using a Cary model 14 recording spectrophotometer. The amount of chlorophyll _a_ per meter^3 was calculated from the Strickland and Parsons (1968) equation:

$$\text{mg chlorophyll } \underline{a}/\text{m}^3 = \frac{11.6\ E_{6650} - 1.31\ E_{6450} - 0.14\ E_{6300}}{\text{volume of sample filtered}}$$

where E represents the extinction values at wave lengths indicated by the subscripts, measured in 10 cm cells after blank correction.

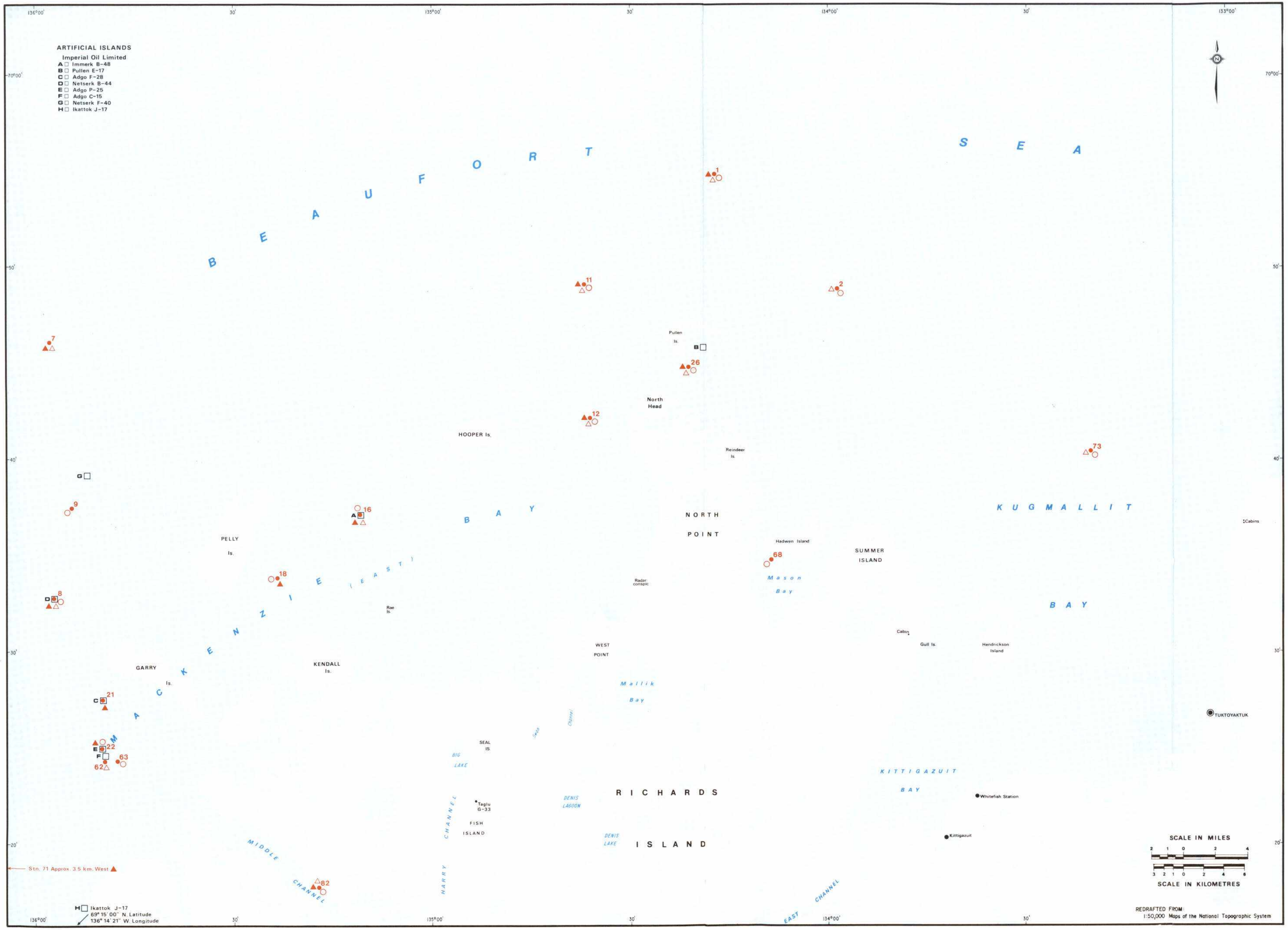
5.5.4 Sampling Frequency

Zooplankton and chlorophyll _a_ were sampled from July 10 to August 6, with program termination resulting from the loss of the Wilson III on August 8, 1975. Phytoplankton collection was conducted from July 13 through August 18, 1975. Sampling schedules for zooplankton, phytoplankton and chlorophyll _a_ are presented (Tables 5.2, 5.4 and 5.6 respectively), and sampling locations in East Mackenzie Bay and Kugmallit Bay are indicated (Map 5.1).

5.6 PLANKTON RESOURCES OF THE MACKENZIE ESTUARY

5.6.1 Zooplankton

An estimated 7.8 x 10^5 zooplankton were sampled from East Mackenzie and Kugmallit Bays in 17 horizontal and four vertical hauls conducted during the 1975 field season (Table 5.1). Samples were primarily comprised of two phyla (Arthropoda and Rotatoria; Appendix 5.2), representing 15 species which included both true marine and freshwater forms as well as brackish water representatives. By comparison, two phyla and ten species were collected in 41 horizontal hauls during



LEGEND

△ Chlorophyll a
▲ Phytoplankton
○ Zooplankton

MAP 5.1
Plankton Sampling Locations, Mackenzie Estuary, 1975

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Calgary Alberta
Project No. 1341

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Environmental Resource Consultants

the 1974 field season (Slaney, 1975). The full compliment of copepod metamorphic forms were observed during sample enumeration, including six naupliar and five copepodid stages (Figure 5.1). Approximately 3.0×10^5 eggs from both Arthropoda and Rotatoria were sampled, which indicates successful breeding within the study area. Results of enumeration and speciation of zooplankton from the Mackenzie Estuary are presented (Table 5.2).

TABLE 5.1

COMPARISON OF ZOOPLANKTON RELATIVE ABUNDANCE, MACKENZIE ESTUARY, 1974 AND 1975

INVERTEBRATE TAXA	1974 ESTIMATED TOTAL	1974 PERCENT COMPOSITION	1975 ESTIMATED TOTAL	1975 PERCENT COMPOSITION
PHYLUM Rotatoria	79,965	83.3	748,132	96.0
PHYLUM Arthropoda				
ORDER Copepoda	15,611	16.3	31,428	4.0
ORDER Mysidacea	405	0.4	38	0.0
	95,981	100.0	779,598	100.0

5.6.1.1 Phylum Rotatoria

During 1975, the phylum Rotatoria (rotifers) were clearly numerically dominant, occurring in 38 percent of all samples, and comprising 96 percent of the total zooplankton sample (Table 5.1). As in 1974, *Keratella* and *Kellicottia* were the dominant genera.

Rotifers were only found at outer bay stations (Stations 2, 11, 12, 68 and 73; Map 5.1) through a range of essentially freshwater to 17 ^{o}/oo salinity. However, approximately 93 percent of the total rotifer sample came from stations in excess of 8 ^{o}/oo salinity.

The genera Keratella and Kellicottia are described as essentially limnetic, freshwater forms, rarely occurring in saline or brackish environments (Pennak, 1953; Ward and Whipple, 1959). Their occurrence and high numerical abundance in the brackish areas of the Mackenzie Estuary is therfore considered unusual (John Kaeyes, pers. comm.) but demonstrates an apparent adaptibility to fluctuating salinity regimes.

5.6.1.2 Phylum Arthropoda

Although not as numerically abundant as Rotatoria, the phylum Arthropoda was represented taxonomically by two major orders: Copepoda (copepods) and Mysidacea (mysids). These orders collectively comprised about four percent of the total zooplankton sample during 1975.

Order Copepoda

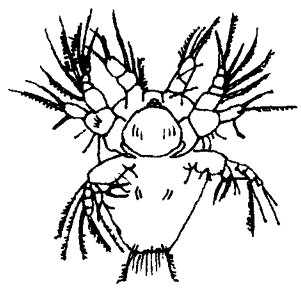
Copepods exhibited a rather ubiquitous distribution throughout the study area, occurring in over 94 percent of the samples containing zooplankton. A total of 12 genera were identified from a variety of environments ranging from essentially freshwater (<1 ^{o}/oo salinity) to brackish water (17 ^{o}/oo salinity). The copepod samples included four freshwater genera (Eurtyemora, Senecella, Epishura and Diaptomus), three marine genera (Acartia, Pseudocalanus and Calanus), and three cosmopolitan representatives (Limnocalanus, Cyclops and the suborder HARPACTICOIDA) which are capable of inhabiting a diverse range of environments (Pennak, 1953; Ward and Whipple, 1959).

FIGURE 5.1

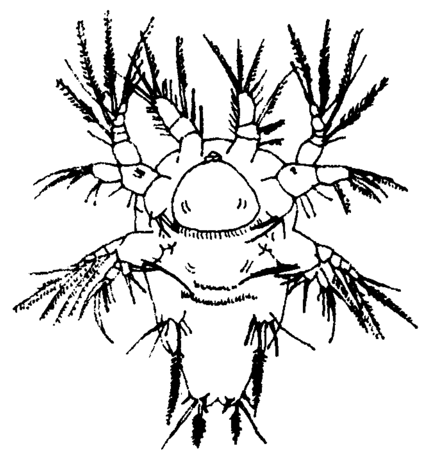
Copepod Metamorphic Forms Typical of the Mackenzie Estuary

All figures are redrawn from Pennak (1953)

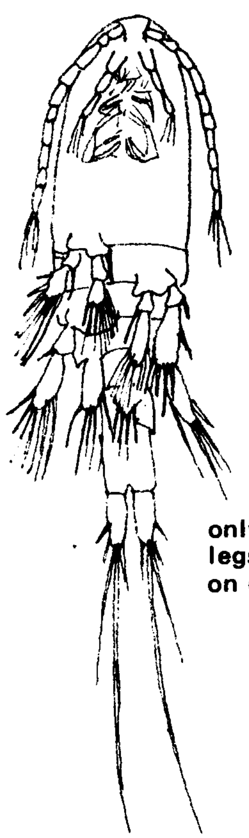
nauplius I of Cyclops (x 100)



nauplius IV of Cyclops (x100)



copepodid of Cyclops (x 90)



only alternate legs shown on each side

nauplius VI of Diaptomus (x 80)

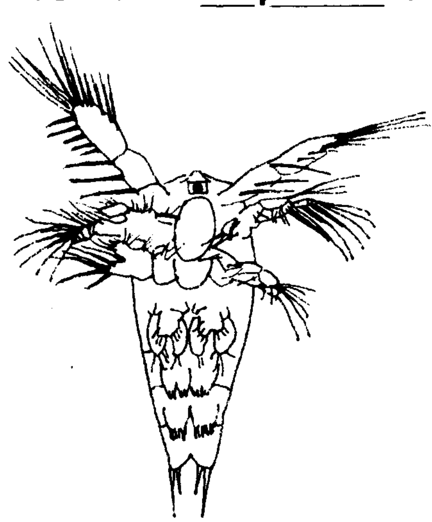


TABLE 5.2

MACKENZIE ESTUARY ZOOPLANKTON - NUMBERS AND TAXA

JULY 10 TO AUGUST 6, 1975

STATION	1	2	2	8 *	8	9 *	11	11	11	12	12	16	16	18 *	22	22 *	63	68	68	73	82	SPECIES	
SAMPLING DATE	31/7	17/7	1/8	16/7	28/7	16/7	13/7	16/7	31/7	11/7	30/7	10/7	30/7	15/7	6/8	13/8	26/7	12/7	16/7	1/8	26/7	TOTAL	
INVERTEBRATE TAXA																							
PHYLUM Rotatoria																							
GENERA Keratella)																							
Kellicottia)	-	9,850	127,200	-	-	-	180	-	52,500	-	900	-	-	-	-	-	-	1,250	52	556,200	-	748,132	
eggs *	-	3,700	29,400	-	-	-	-	-	60,000	-	1,860	-	-	-	-	-	-	250	-	69,600	-	______	748,132
PHYLUM Arthropoda																							
ORDER Copepoda																							
Eurytemora canadensis	32	18	7	-	-	-	1	-	-	-	-	-	-	-	4	-	-	-	6	-	-	68	
copedodites	55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	393	-	-	448	
Senecella calanoides	-	-	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2	-	126	
nauplii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2	
copepodites	-	-	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	
Cyclops bicuspidatus	-	-	-	-	-	-	660	-	-	2,467	-	65	290	-	-	1	-	-	6	-	-	3,489	
nauplii	-	-	-	-	-	-	820	-	-	26	-	-	-	-	-	-	-	-	-	-	-	846	
copepodites	-	-	-	-	-	-	-	-	-	13	-	13	-	-	-	1	-	-	-	-	-	27	
Pseudocalanus minutus	-	110	515	-	-	1	-	-	-	-	-	-	245	-	-	-	-	-	-	56	-	927	
nauplii	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	300	
copepodites	-	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	280	-	358	
Acartia longiremis	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	3	
copepodites	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	
Acartia clausi	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	
nauplii	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200	
Limnocalanus macrurus	-	9	-	22	-	4	-	-	1,500	9	480	-	2,360	-	3	-	9	-	-	30	-	4,426	
copepodites	-	-	-	1	-	-	630	-	6,000	160	180	-	-	-	5	-	-	35	-	120	-	7,131	
Epischura nevadensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	3,100	-	-	-	3,103	
copepodites	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	
Diaptomus pribliofensis	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	22	
Calanus plumchrus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	22	
copepodites	-	92	-	-	-	-	-	-	250	-	-	-	-	-	-	-	-	-	-	-	-	92	21,631
Unidentified Copepoda																							
nauplii	-	-	125	-	-	-	-	-	250	-	-	-	-	-	-	-	-	-	210	-	-	585	
copepodites	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9,050	-	-	-	9,050	9,635
eggs *	132,250	6,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
SUBORDER HARPACTICOIDA	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	129	-	-	132	132
ORDER Mysidacea																							
Mysis relicta	-	-	-	-	4	-	-	-	-	34	-	-	-	-	-	-	-	-	-	-	-	38	38
ORDER Amphipoda*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1				
PHYLUM Mollusca*																							
CLASS Pelecypoda	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Fish Larva *	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
STATION TOTAL	87	10,660	128,007	23	4	5	2,291	0	60,250	2,709	1,560	100	2,895	0	16	2	9	13,435	802	556,713	0		
STATION TOTAL /M^3	2	456			1		130	0	2,477	157	85	10	207								0		

* NOT INCLUDED IN ZOOPLANKTON TOTALS

Limnocalanus macrurus was the most numerically abundant and widely distributed copepod, occurring in 67 percent of all plankton samples and comprising 37 percent of copepod numbers. L. macrurus, by comparison, accounted for approximately 70 percent of the copepods sampled during the 1974 program (Table 5.3). L. macrurus is described as having evolved from a true marine form capable of adapting to a wide range of saline environments (Ward and Whipple, 1959). In the study area, preference was exhibited for only moderate saline conditions, as 98 percent of this species were sampled from waters of 8 $^{o}/oo$ salinity or less.

Cyclops bicuspidatus followed L. macrurus in numerical abundance within the study area, constituting 14 percent of the copepods (Table 5.3). Although described as cosmopolitan in distribution (Pennak, 1953), C. bicuspidatus was only found in the more freshwater stations of the Mackenzie Estuary (Stations 11, 12, 16 and 68) and was not observed in salinities in excess of 6 $^{o}/oo$.

Classical freshwater species such as Epischura nevadensis, Eurytemora canadensis and Senecella calanoides were limited in distribution to the more saline environments (Stations 1 and 2; 15 and 22 $^{o}/oo$ salinity respectively) of the study area, indicating a tolerance, at least, to relatively saline waters. Collectively these three species comprised approximately 12 percent of the copepod standing crop during 1975. E. canadensis and S. calanoides were not observed in copepod samples during the 1974 study of East Mackenzie Bay.

Sampling results indicate that true marine genera were not abundant in the study area during 1975. Pseudocalanus minutus, comprising approximately five percent of the copepod sample, occurred only at stations with salinities of 6 $^{o}/oo$ or greater. (Stations 1, 2, 16 and 73). Acartia spp occurred infrequently and accounted for 0.7 percent of the copepod total.

The occurrence of other genera was infrequent throughout the study area. Diaptomus probilofensis, Calanus plumchrus, Calanoida copepodete, and species from the suborder HARPACTICOIDA collectively accounted for only 0.9 percent of copepod numbers.

Unidentified copepod metamorphic forms, primarily copepodites III to V and nauplii comprised 29 percent and two percent (585) respectively of the sample total.

Order Mysidacea

The occurrence of mysids in zooplankton samples was extremely infrequent in 1975, as only 38 specimens were found in less than ten percent of the horizontal hauls (Table 5.2). The 1974 studies also demonstrated a low numerical abundance (105 specimens), but Mysis relicta was found to occur in 51 percent of the samples during 1974. M. relicta is an epibenthic marine species described by Pennak (1953) to be confined to the meter of water above the bottom substrate. Low species abundance during both study years from horizontal sampling is probably a reflection of collection technique.

5.6.2 Phytoplankton

Large standing crops of phytoplankton were found at all sampling locations throughout the sampling period, with a range in cell numbers from approximately 3.55×10^6 to 8.91×10^{12} cells/m^3 (Table 5.4). A limited generic diversity was found with only four identified genera representing two major taxonomic divisions (Chrysophyta-diatoms and Pyrrophyta-dinoflagellates). Phytoplankton were found to occur within relatively wide ranges of temperature (8.5 to 18^{o}C) and salinity (0 to 22 ^{o}/oo) throughout July and August. The taxonomic classification of Mackenzie Bay phytoplankters is presented (Appendix 5.3).

TABLE 5.3

COMPARISON OF COPEPOD RELATIVE
ABUNDANCE, MACKENZIE ESTUARY, 1974 AND 1975

INVERTEBRATE TAXA	1974 PERCENT COMPOSITION	1975 PERCENT COMPOSITION
PHYLUM Arthropoda		
ORDER Copepoda		
Eurytemora canadensis	N/F	1.6
Senecella calanoides	N/F	0.5
Cyclops bicuspidatus	16.6	13.9
Pseudocalanus minutus	N/F	5.0
Acartia longiremis	N/F	0.0
Acartia clausi	N/F	0.6
Limnocalauus macrurus	68.2	36.9
Epischura nevadensis	4.7	9.9
Diaptomus pribliofensis	2.2	0.1
Diaptomus minutusi	0.0	N/F
Calanus plumchrus	N/F	0.4
Calanoida copepodete	8.1	0.0
SUBORDER HARPACTICOIDA	0.2	0.4
Unidentified Copepoda	N/F	30.7
	100	100

N/F - NOT FOUND

TABLE 5.4

ESTIMATED PHYTOPLANKTON NUMBERS - JULY 13 TO AUGUST 18, 1975

STATION NUMBER	SAMPLING DATE	PHYTOPLANKTON GENERA - ESTIMATED CELLS/M^3					ESTIMATED TOTAL CELLS/M^3
		Melosira	Tabellaria	Nitzschia	Ceratium	Nanoplankton	
1	31/7/75	-	-	-	-	5.43×10^{10}	5.43×10^{10}
2	1/8/75	-	-	-	3.55×10^{6}	-	3.55×10^{6}
7	29/7/75	-	-	-	-	1.97×10^{10}	1.97×10^{10}
8	28/7/75	-	-	-	-	5.72×10^{12}	5.72×10^{12}
	16/8/75	-	-	9.57×10^{5}	-	1.50×10^{12}	1.50×10^{12}
11	13/7/75	-	-	-	-	1.58×10^{12}	1.58×10^{12}
	31/7/75	-	-	-	-	4.93×10^{11}	4.93×10^{11}
12	30/7/75	-	-	-	-	3.99×10^{11}	3.99×10^{11}
16	30/7/75	-	-	-	-	5.76×10^{12}	5.76×10^{12}
18	15/8/75	-	-	-	-	4.09×10^{11}	4.09×10^{11}
21	10/8/75	-	-	-	-	8.19×10^{11}	8.19×10^{11}
22	13/8/75	-	-	-	-	2.27×10^{12}	2.27×10^{12}
26	18/7/75	-	-	-	-	1.04×10^{12}	1.04×10^{12}
71	18/8/75	1.05×10^{7}	4.78×10^{6}	9.57×10^{5}	-	8.91×10^{12}	8.91×10^{12}
82	20/7/75	2.86×10^{7}	-	-	-	2.59×10^{12}	2.59×10^{12}

5.6.2.1 Division Chrysophyta

The diatom community during 1975 included two major orders (Biddulphiales and Bacillariales), representing centric diatoms (Melosira spp) and pennate diatoms (Tabellaria and Nitzschia spp) which collectively accounted for approximately 16 percent of Mackenzie Bay phytoplankton (Figure 5.2). Diatoms of the genus Melosira represented about 68 percent of the phytoplankton standing crop sampled during 1974.

Bursa (1961) documented five species of diatoms from the genus Nitzschia and three from Melosira near Igloolik Island in the eastern arctic. The genus Nitzschia was numerically more abundant than Melosira, with mean numbers in cells/m^3 of 1.43×10^6 and 2.81×10^5 respectively. Horner et al (1974) reported only representatives of the genus Nitzschia in the diatom community of Prudhoe Bay, Alaska. There, Nitzschia spp comprised approximately ten percent of the algal cells ($8.19 \times 10^9/m^3$) at the ice-water interface.

Pennate diatom species of the genus Tabellaria were found at only one station in East Mackenzie Bay, and contributed about three percent of the total crop sampled. The occurrence of this genus in arctic ecosystems has not been previously documented in the literature reviewed for this report. Whereas diatom species have been reported through a wide range of saline environments, Tabellaria spp are described primarily as freshwater phytoplankters (Ward and Whipple, 1959). The occurrence of this genus may represent an ephemeral condition in non-saline waters near Station 71 resulting from freshwater populations within the Mackenzie River system that have been flushed downstream, or a much wider range of salinity tolerance than has been identified.

5.6.2.2 Division Pyrrophyta

The dinoflagellate Ceratium occurred in early August at Station 2 (Table 5.4; Figure 5.2), and numerically represented about three percent of the phytoplankton sampled during 1975. Dinoflagellates were not found during 1974 studies of the Mackenzie Estuary (Slaney, 1975). Dinoflagellates were described as a relatively minor component (4 percent) of Alaskan phytoplankton communities by Horner et al (1974). Bursa (1961) identified 32 dinoflagellate species in phytoplankton samples near Igloolik Island. Total dinoflagellate numbers at Igloolik averaged 6.56×10^5 cells/m^3 with a maximum abundance of $4.44 \times 10^7/m^3$ in August. Ceratium spp were not recorded at Igloolik by Bursa, but Grontved and Seidenfaden (1938) reported Ceratium arcticum (a true arctic marine species) from the adjacent waters of Foxe Basin.

5.6.2.3 Nannoplankton

The majority of phytoplanktonic cells were comprised of unidentified non-flagellated nannoplankton (81 percent), which averaged three to five microns in length. Their distribution during the 1975 sampling period was found to be ubiquitous throughout the Mackenzie Estuary (Table 5.5). Greatest numerical abundance occurred at Station 71, an essentially freshwater station strongly influenced by Mackenzie discharges (Map 5.1) where an estimated 8.91×10^{12} cells were recorded. Mean cell numbers of $4.14 \times 10^{11}/m^3$ were estimated for all stations sampled (N=15) during July and August. Nannoplankton were not found during planktonic investigations conducted in 1974, even though identical sampling and identification techniques were employed.

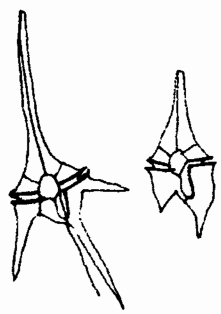
The data on Mackenzie Bay phytoplankton is generally scant, and the occurrence of nannoplankton in this area has not been previously documented. Horner et al (1974) reported a significant microflagellate

FIGURE 5.2

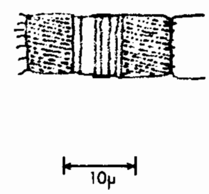
Phytoplankton Species Typical of the Mackenzie Estuary

All figures are redrawn from Ward and Whipple (1959)

Ceratium sp (x 195)



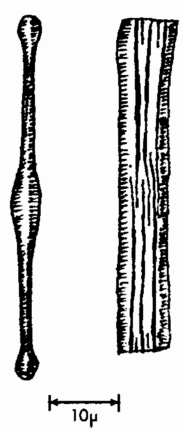
Melosira sp (x1000)



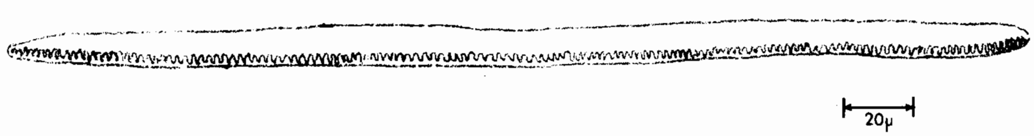
Tabellaria sp

valve view

girdle view showing septae



Nitzschia sp



community in brackish areas of Prudhoe Bay. These flagellated cells, however, would approximate ten to 15 microns or greater, somewhat larger than those encountered within the study area.

The contribution of nannoplankton to total chlorophyll a production is presently unknown. Given their ubiquitous distribution throughout the study area, nannoplankton may provide a significant energy source for certain zooplankton species. Their minute size (3 to 5 µ) approaches the lower size class limits of particulate matter for efficient grazing by most copepod species (W.S. Duval, pers. comm.). Rotifers, however, may utilize these algal cells and, in turn, be grazed upon by larger copepods, thereby providing an important intermediary link between autotrophic and heterotrophic components of the food web.

5.6.3 Chlorophyll a

Surface chlorophyll a concentrations were generally low within the Mackenzie Estuary during 1975, ranging from 0.026 mg/m^3 to 1.210 mg/m^3 (Table 5.6). Results were consistent with the range established by the 1974 summer study (Table 5.5).

TABLE 5.5

CHLOROPHYLL a DATA, EAST MACKENZIE BAY
1974 AND 1975

	MINIMUM (mg/m^3)	MAXIMUM (mg/m^3)	$\overline{X}$ (mg/m^3)	SAMPLE SIZE N
1974	ND*	1.050	0.426	18
1975	0.026	1.210	0.507	15

*ND = Not Detectable

Grainger (1974) reported a mean surface chlorophyll a value of 1.72 mg/m^3 (N = 16) from a biological-oceanographic cruise of the southern Beaufort Sea during July, 1973. Highest chlorophyll a concentrations ($\bar{X}$ = 2.60 mg/m^3, N = 7) were found in turbid conditions near discharging river mouths. Lowest values ($\bar{X}$ = 0.997 mg/m^3, N = 6) were measured in areas removed from the Mackenzie River influence.

Grainger (1974) suggested that relatively high primary production near discharging river mouths may result from either constant replenishment of chlorophyll carrying organisms from the outflowing river, or sustained planktonic production just off the river mouth. Data from the 1974 and 1975 studies tends to support latter hypothesis. Highest chlorophyll a values were obtained near Mackenzie outflows; lowest concentrations were found at stations removed from direct Mackenzie influence, while only moderate chlorophyll a values were found within the Mackenzie River (Table 5.7).

TABLE 5.7

MEAN CHLOROPHYLL a VALUES FROM THREE ENVIRONMENTS WITHIN THE MACKENZIE ESTUARY, 1974 AND 1975

	STATIONS DIRECTLY WITHIN MACKENZIE RIVER INFLUENCE (mg/m^3)	N	STATIONS REMOVED FROM DIRECT MACKENZIE RIVER INFLUENCE (mg/m^3)	N	MACKENZIE RIVER STATIONS (mg/m^3)	N
1974	0.792	5	0.070	5	0.393	2
1975	0.605	7	0.316	7	0.442	1

TABLE 5.6

MACKENZIE ESTUARY

CHLOROPHYLL *a* CONCENTRATIONS

JULY 10 TO AUGUST 6, 1975

STATION	SAMPLING DATE	CHLOROPHYLL *a* CONCENTRATION mg/m^3
1	31/7/75	0.313
2	13/7/75	0.218
2	1/8/75	0.282
7	29/7/75	0.792
8	28/7/75	0.614
11	31/7/75	0.375
12	11/7/75	1.210
12	30/7/75	0.392
16	10/7/75	1.058
16	30/7/75	0.325
26	18/7/75	0.026
62	26/7/75	0.705
62	6/8/75	0.639
73	1/8/75	0.209
82	26/7/75	0.442

Several stations from Grainger's study are comparable in location to sampling sites of the 1975 summer program, and these data are summarized (Table 5.8).

TABLE 5.8

CHLOROPHYLL a DATA FROM COMPARABLE SAMPLING SITES, MACKENZIE ESTUARY, 1973 AND 1975

Grainger-Summer 1973			Slaney-Summer 1975		
STATION	DATE	CHLOROPHYLL a (mg/m^3)	STATION	DATE	CHLOROPHYLL a (mg/m^3)
527	20/7/73	2.49	73	1/8/75	0.209
535	25/7/73	2.25	2	13/7/75 1/8/75	0.218 0.282
536	26/7/73	1.19	1	31/7/75	0.313

As chlorophyll a analysis for both Grainger and Slaney followed an identical procedure as described by Strickland and Parsons (1968) (E.H. Grainger, pers. comm.), differences in observed values are likely a function of the natural range of variability.

Horner et al (1974) recorded a mean surficial chlorophyll a value of 0.740 mg/m^3 (N = 45) for summer research within Prudhoe Bay, Alaska. In general, primary production during their study was found to be higher in deeper more saline waters, than the brackish surface waters that are typical throughout much of the Mackenzie Estuary.

5.7 EFFECTS OF ISLAND CONSTRUCTION ON PLANKTON

Arctic ecosystems are documented to display large year-to-year variability (Dunbar, 1975), which presents a significant problem to the establishment of a data base in previously unstudied areas, and relating that data base to possible effects of development activities.

The 1974 and 1975 environmental programs generated preliminary quantitative and faunistic data regarding planktonic resources within the Mackenzie Estuary which provided evidence of considerable annual variability. Several components of the primary trophic levels identified in the 1975 study deviated extensively from the results derived from 1974 studies. For example, an estimated total of 9.6×10^4 zooplankton were sampled from East Mackenzie Bay in 41 plankton trawls in 1974, compared with 7.8×10^5 zooplankton from 17 trawls during 1975. Equating sample catch per effort for both years, this represented almost 20 times more zooplankton collected in 1975 over 1974, using identical sampling techniques in similar areas during approximately the same period of time.

Potential turbidity effects arising from construction activities were given attention throughout 1974 and 1975. Data from both years indicate that although turbidity is of major importance, it may not be the sole factor limiting phytoplanktonic production in the Mackenzie Estuary. Highest chlorophyll a concentrations were found in turbid waters with shallow euphotic zones proximate to discharging river mouths. Lowest values occurred in comparatively clearer waters removed from Mackenzie River influence which should, theoretically, favour an improved euphotic zone for photosynthetic production. Grainger (1974) suggested that higher chlorophyll values off river mouths probably reflect primarily river transported plant material. However, chlorophyll values measured at Mackenzie River stations during 1974 and 1975 were consistently lower than the receiving waters of the estuary. It appears more likely that low, but sustained, planktonic production occurs in the vicinity of river mouths despite the apparent stressful conditions imposed by Mackenzie River turbidity.

Major potential effects to planktonic invertebrates associated with summer island construction are:

1. Physical modification of the marine environment; and,

2. Increased turbidity during periods of construction.

The effects of the physical presence of artificial islands to the marine environment of East Mackenzie Bay (such as wind distribution, waves and ocean currents) appear to be minimal and site-specific. Winds and ocean currents are deflected around, and, in the case of winds, over each island site. The affected area is small (usually less than 1,000 m in diameter), and mainly downstream of each island site (Slaney, 1975). Incoming waves, partially focused on island structures, lose energy in breaking, resulting in a wake effect with waves of reduced magnitude extending from the lee side of each island for several hundred meters (Slaney, 1975).

A monitored gravel dredging and island construction operation maintained turbidity levels in the 305 to 370 ppm range, compared with natural turbidity levels of 140 to 180 ppm at adjacent control stations (Slaney, 1975). When placed in perspective, this induced increase in turbidity was probably not significant to plankton productivity in the long term, as sustained natural storm-generated turbidity reached 400 to 680 ppm in nearby unaffected areas.

It is highly unlikely that island construction activities per se significantly affect overall plankton productivity within the study area. However, it must be recognized that no intensive plankton monitoring program has been conducted in the Mackenzie Estuary area that relates natural seasonal variability with regard to species composition, distribution and abundance to a major construction operation involving dredging activities. The implications of sustained turbidity increases above natural levels to primary productivity are not documented.

5.8 SUMMARY OF IMPORTANT POINTS

1. Zooplankton samples from the Mackenzie Estuary, 1975, were comprised of 14 identified genera, including 11 Copepoda, two Rotatoria and one Mysidacea. True marine and freshwater forms, as well as brackish water species, were represented. By comparison, ten genera were collected in similar studies during the 1974 field season. As in 1974 studies, Rotatoria (rotifers) were numerically dominant, accounting for approximately 96 percent of the total zooplankton catch during 1975.

2. The 1974 and 1975 programs provided evidence of high natural variability in zooplankton relative abundance, as almost 20 times more zooplankton were collected in 1975 over 1974 on the basis of catch per unit of effort.

3. Large standing stocks of phytoplankton were found at all sampling locations throughout summer. In 1975, cell numbers ranged from approximately 3.55×10^6 to 8.91×10^{12} cells/m^3, compared with 6.00×10^5 to 7.89×10^6 cells/m^3 from the 1974 program. Four genera of phytoplankters and an unidentified nannoplankton species were found during 1975, with nannoplankton accounting for approximately 81 percent of the total algal cells sampled.

4. Surface chlorophyll _a_ concentrations were generally low within the Mackenzie Estuary during the summer of 1974 and 1975, ranging from non-detectable amounts to 1.210 mg/m^3.

5. During 1974 and 1975, chlorophyll _a_ values were consistently

higher in areas proximate to discharging river mouths than in the river environment per se, suggesting low but sustained production in the receiving waters despite high natural turbidity levels.

6. The potential effects of the physical presence of artificial islands to plankton productivity of the study area (wind distribution, waves and ocean currents) are, in all probability, minimal and site-specific.

7. As natural sustained storm-generated turbidity levels reached the 400 to 680 ppm range compared with construction-created turbidities of 305 to 370 ppm, it is unlikely that island associated construction activities are significant to plankton productivity of the study area.

8. No intensive plankton monitoring program has been conducted relating natural seasonal variability (species composition, distribution and relative abundance) to a major construction operation involving dredging activities, and the implications of large and sustained turbidity increases above natural levels to primary production are not documented.

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APPENDIX 5.1

PLANKTON COLLECTION DATA, JULY TO AUGUST, 1975

STATION NUMBER	COLLECTION DATE	TIME OF DAY COLL.'D.	TOTAL PROP REVOL'NS	DURATION OF TOW-IN SECONDS	PROP REVOL'NS PER SECOND	N VALUE RPS - .009	VELOCITY (METRES/SEC) V = .157 N	CALCULATED TOW DISTANCE IN METERS = T VELOCITY X DURATION	NET DIAM. IN METRES^2 = D	VOLUME THRU NET (M^3) VOL = T.D
1	31/7/75	16:30	1160	90	12.889	12.880	2.022	181.993	0.1963	35.725
2	17/7/75	18:00	760	90	8.444	8.435	1.324	119.193	0.1963	23.398
	1/8/75*									
8	28/7/75	12:30	153	120	1.275	1.266	0.199	23.880	0.1963	4.688
11	13/7/75	09:30	575	90	6.389	6.380	1.002	90.149	0.1963	17.696
	16/7/75	13:30	412	90	4.578	4.569	0.717	64.560	0.1963	12.673
	31/7/75	19:00	790	90	8.778	8.769	1.377	123.906	0.1963	24.323
12	11/7/75	13:30	560	90	6.222	6.213	0.975	87.793	0.1963	17.234
	30/7/75	15:00	595	90	6.611	6.602	1.037	93.330	0.1963	18.321
16	10/7/75	20:00	340	90	3.778	3.769	0.592	53.253	0.1963	10.454
	30/7/75	11:30	455	90	5.056	5.047	0.792	71.308	0.1963	13.998
22	6/8/75*									
63	26/7/75*									
68	12/7/75*									
	16/7/75*									
73	1/8/75*									
82	26/7/75	15:00	620	180	3.444	3.435	0.539	97.086	0.1963	19.058

* Data destroyed with loss of R.V. Wilson III

APPENDIX 5.2

TAXONOMIC CLASSIFICATION OF MACKENZIE BAY ZOOPLANKTON, 1975

Phylum	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Rotatoria
Class	Crustacea	Crustacea	Crustacea	Malacostraca	Monogononta
Order	Copepoda	Copepoda	Copepoda	Mysidacea	Ploima
Suborder	CALANOIDA	CYCLOPOIDA	HARPACTICOIDA		
Family	Pseudocalanidae	Cyclopidae			Brachioninae
Genus	_Senecella_	_Cyclops_		_Mysis_	_Keratella_ _Kellicottia_
Family	Centropagidae				
Genus	_Limnocalanus_				
Family	Temoridae				
Genus	_Eurytemora_ _Epischura_				
Family	Diaptomidae				
Genus	_Diaptomus_				
Family					
Genus	_Acartia_				
Family	Calanidae				
Genus	_Calanus_				
Family	Pseudocalanidae				
Genus	_Pseudocalanus_				

Compiled from Ward and Whipple (1959), Pennak (1953)

APPENDIX 5.3

TAXONOMIC CLASSIFICATION OF MACKENZIE BAY PHYTOPLANKTON, 1975

Division		Chrysophyta		Pyrrophyta
Class		Bacillariophyceae		Dinophyceae
Order	Biddulphiales	Bacillariales		Peridinales
Suborder	DISCINEAE	ARPHIDINEAE	SURIRELLINEAE	
Family	Coscinodiscaceae	Fragilariaceae	Nitzschiaeae	Ceratiaceae
Subfamily	Melosiroideae	Tabellarioideae		
Genus	*Melosira*	*Tabellaria*	*Nitzschia*	*Ceratium*
Common Name	Centric Diatoms	Pennate Diatoms		Dinoflagellates

Compiled from Ward and Whipple (1959)

PART 6

SUMMER BENTHIC SAMPLING
IN THE COASTAL
MACKENZIE DELTA, N.W.T., 1975

BY

W.E. BENGEYFIELD

FOR

IMPERIAL OIL LIMITED

F.F. SLANEY & COMPANY LIMITED
VANCOUVER, CANADA

PART 6

BENTHOS

6.1 INTRODUCTION

Benthic invertebrates are important in most aquatic ecosystems because of their intermediary but vital role in transmitting energy from lower to higher trophic levels. Estuarine benthos feed on bacteria, phytoplankton and zooplankton, and provide an energy source to larger benthic invertebrates, fish, birds and occasionally mammals. Any significant effects on the benthos arising from artificial island development may have implications to the ecology of the Mackenzie Estuary.

6.2 PURPOSE

The purpose of the benthos program was to supplement existing data for the assessment of effects on benthic organisms associated with artificial island construction in the Mackenzie Estuary.

6.3 OBJECTIVES

The specific objectives of the benthos program were to:

1. Assess the spatial distribution and relative abundance of benthic organisms within the study area, particularly in the offshore areas not accessible in 1974; and,

2. Determine the effects of artificial island construction and associated activities on indigenous benthos populations.

6.4 SCOPE OF WORK

F.F. Slaney & Company limited have examined benthic invertebrates in East Mackenzie Bay related to hydrocarbon exploration since the construction of the first artificial island in 1972. Investigations have included two major summer studies (Slaney, 1973 and 1975), and two winter programs where quantitative through-ice sampling of benthic organisms was conducted (Slaney, 1974c, 1974d) and several investigations by federal agencies have been conducted in the general area (Brunskill et al, 1973; Wacasey, 1974).

Sampling of benthic invertebrates was conducted throughout the study area for the duration of the 1975 program. Emphasis was placed on the benthos in deeper offshore waters, and especially Kugmallit Bay, for reference to possible artificial island development.

On the basis of 1974 data, the potential importance of the epibenthic component was recognized, and comprehensive sampling to determine epifaunal quantitative abundance was planned. The loss of the Wilson III on August 8, however, destroyed six of the 12 epibenthic samples collected to date, as well as the data for another. The specialized trawling equipment was also lost, and could not be replaced before the sampling season ended. The data on epifauna presented is thus incomplete.

6.5 METHODS

The following section includes a brief description of the sampling methods, sites, and frequency for the 1975 benthos program.

6.5.1 Ekman Grab Sampling

Sampling by Ekman grab was conducted from two research vessels, the Arcticus and Wilson III, as well as a small outboard equipped boat, throughout the study area from July 10 to August 20, 1975. A total of 19 stations were sampled, including active, abandoned, and potential artificial island sites, as well as along general transects (Map 6.1). Substrate samples were collected with a 15 x 15 cm tall model Ekman grab. Organisms were separated from the sediment by washing through a 0.5 mm brass sieve, and preserved in a 5 percent formalin solution.

Laboratory analyses included identification and enumeration of benthic invertebrates under a binocular dissection scope at 10X magnification.

6.5.2 Bottom Trawl Samples

An epibenthic sled was designed for collecting organisms in the water column just above the substrate. Two parallel sled runners held the one m^2 net mouth 15 cm above the sea floor permitting the trawl to slide easily while towing. The sled net was three m long and utilized three mesh sizes - 12.7 mm, 6.4 mm and 3.2 mm at the cod end. Tows were made on the bottom for 20 minutes, usually in the direction of the next station. Tow speeds were estimated at 3.7 to 5.6 kmh. Volumes of water sampled were measured by TSK flow meter rigidly mounted in the net mouth (Table 6.3).

All organisms entrained in the net were collected and preserved in 5 percent formalin solution.

Preserved benthic invertebrates shipped to Vancouver for laboratory analyses were counted and segregated into similar taxonomic categories as per the Ekman grab samples.

6.5.3 Sampling Efficiency

The Ekman grab effectively sampled soft mud bottoms for infauna, and for relatively immobile epifauna like gastropods, foraminiferans, isopods, cumaceans and burrowing amphipods. It was not effective, however, in estimating mobile fauna populations such as mysids and free-swimming amphipods, although incidental catches were sometimes made. The latter two groups were best sampled by the epibenthic sled trawl.

6.5.4 Sampling Sites

The 1975 benthos program as compared with 1974, expanded its study area eastward to include Kugmallit Bay. In addition to these new locations, selected sampling stations from previous years were revisited (Map 6.1).

Recent work (Slaney, 1974c, 1975) indicated that a "marine index" of depth and salinity best described the distribution of benthos in the study area. Stations for 1975 program were grouped into regions, based on the depth parameter alone (Map 6.1), since depth has generally correlated well with salinity in this estuary.

Region 1 stations were defined as those whose average sampling depth was greater than five m (Stations 1, 7, 9, 11, 60, 74 and 75). Region 2 stations were located along the Barrier Island perimeter, with depths between three and five m (Stations 2, 8, 12, 16, 26, 67, 73 and 79). Region 3 stations all were less than three m in depth (Stations 14, 21, 62 and 72).

The distribution of sampling effort in 1975 is shown (Table 6.1).

TABLE 6.1

DISTRIBUTION OF 1975 SAMPLING EFFORT

	REGIONS 1	2	3
No. Ekman grabs	42	75	45
No. Bottom trawls*	2	4	0

* Number of collections retained after loss of Wilson III

6.5.5 Sampling Frequency

Each benthic station was sampled at least once with five replicate Ekman grabs. Station 2 represented the most visited station with a total of 20 Ekman grabs. Epibenthic trawl stations were only sampled with a single tow.

Slaney (1975) determined, on the basis of previous sampling, that strong seasonal variation in abundance (winter vs. summer) was not evident for most benthic groups within regions. Therefore, July and August samples were collectively considered representative of the summer season.

6.6 BENTHOS OF THE INSHORE MACKENZIE ESTUARY

Benthos, or bottom-dwelling invertebrates, have been traditionally separated into categories based upon their different relationships with the substrate/water interface. There are two basic categories in the Mackenzie Estuary: infauna and epifauna.

An example of the infaunal category is the sedentary tube-dwelling polychaete worm, which spends most of its life beneath the seafloor with one or both tube ends protruding into the water column through which food and oxygen must enter and waste products be expelled. Also considered in this group of organisms are other annelid worms - sipunculoids, oligochaetes, and errant polychaetes as well as nematode worms and pelecypods. Adult infauna are usually capable of limited mobility over small areas, but are most often sedentary in habit. They are usually filter feeders on particulate matter. The young have a pelagic dispersal phase. The pelecypod-annelid infauna is typical of unconsolidated substrata in all seas and depths. Some examples of the Mackenzie Estuary infauna are shown (Figure 6.1).

Epifauna is a category applied to animals living on top of the substratum, and which swim up into the water column from time to time. In the Mackenzie Estuary area, members of the epifauna are primarily crustaceans - mysid shrimp, amphipods, isopods, and cumaceans. Foraminiferans and gastropods occur less frequently. Some epifauna feed by filtering particulate detritus (mysids and cumaceans), while others may be predatory (isopods, mysids and gastropods) or grazers (certain amphipods). Epibenthos on unconsolidated substrata, such as is found in the Mackenzie Estuary, are typically mobile, and roam the sea bottom in search of food and suitable environmental conditions. Salinity is a key factor in governing distribution in the estuarine area. Selected representatives of the estuarine epifauna are shown (Figure 6.2).

6.7 DISTRIBUTION OF BENTHIC INVERTEBRATES

6.7.1 Infaunal Components

Two infaunal taxonomic groups, polychaete worms and pelecypod clams, mumerically dominated the Ekman grab samples in 1975 (Table 6.2). Polychaete worms represented 49 percent of the total catch with 668 specimens collected. They were taken at the majority of stations (84 percent), but were most abundant in Region 1. A similar trend was observed in winter, 1973 (Slaney, 1974c) and summer, 1974 (Slaney, 1975) and confirms the group's affinity for more saline waters.

A total of 382 pelecypod clams, primarily *Portlandia arctica* and some *Cyrtodaria kurriana*, comprised 28 percent of the total Ekman grab catch during 1975. Their distribution generally coincided with that of the polychaetes, being absent in Region 3 and becoming more numerous towards deeper water in Regions 2 and 1. A single station in Kugmallit Bay (Station 60) accounted for 33 percent of the total pelecypod catch, with a mean of 25.0 organisms/grab at this location. *Cyrtodaria kurriana* was collected more frequently at Kugmallit Bay stations than those seaward of the Barrier Islands where *Portlandia arctica* predominated.

Other infaunal taxa usually appeared sporadically and contributed little to the total Ekman catch. Nematode and oligochaete worms were each collected twice. Sipunculoid-priapulid worms of marine derivation were collected at seven stations in Regions 2 and 1, but totalled only 20 specimens.

6.7.2 Epifaunal Components

Two epifaunal taxonomic groups (mysids and amphipods) dominated all bottom trawl samples in 1975 (Table 6.3).

6.7.2.1 Mysids

Mysid shrimp, mostly adults and juveniles of *Mysis relicta*, comprised 85 percent (3,583 individuals) of the total trawl catch. They also appeared infrequently in Ekman grab samples as well as plankton samples (Part 5, Section 5.6.1.4). Mysids, however, were most effectively sampled by bottom trawl, as they typically swim or hover in the water column just above the bottom while feeding. In most lakes, and possibly in the Mackenzie Estuary, this species exhibits diel vertical migrations (Green, 1968).

The largest documented catch was 2,280 mysids (0.68 per m^3) at Station 12 on July 30 (Table 6.3). Although counts and collection data were subsequently lost, one sample with an estimated 10,000 mysids was taken at Station 16 on July 30, with organisms nearly filling a 946 ml sampling jar, compared with the documented catch which filled a 237 ml jar. The smallest catch was also lost, but field notes estimated less than 20 mysids from Station 1 on July 31. Previous data from the 1974 summer program documented the presence of mysids in Regions 1, 2 and 3.

Although information is scant, the data suggests that mysids are much more common throughout the inshore areas of the Mackenzie Estuary than has been credited to date. Populations may tend to decrease in abundance offshore in true marine waters due to increased salinity regimes. Green (1968) reports *Mysis relicta* from fresh waters in North America and Europe, as well as partly saline waters of the Baltic Sea. Pennak (1953) describes *M. relicta* as occurring in many deep Canadian lakes and northern brackish waters.

6.7.2.2 Amphipods

The second largest group of epifauna were large, free-swimming amphipods which comprised 14 percent (581 individuals) of the total trawl catch. Most of these amphipods were Gammaracanthus loricatus, which have been previously collected in the area, Slaney, 1973; 1975) in both adult and juvenile forms. This species was not found in the Ekman grab samples. The largest tallied catch was 372 amphipods ($0.11/m^3$) at Station 12 on July 30 (Table 6.3).

6.7.2.3 Other Fauna

Other miscellaneous members of the epifauna collected in 1975 were coelenterate medusae (N = 5), copepods (N = 4), cumaceans (N = 2), and isopods (N = 43). All groups have been previously collected in the estuary. No obvious trends in species diversity were observed in the few retained samples. Stations 2 and 12 were each represented by five taxa while Stations 8, 11 and 16 had three taxa (Table 6.3).

6.8 BENTHIC COMMUNITIES AND THEIR ENVIRONMENTS

In summer, the vast shallow waters of the study area are part of an ecological transition zone between the large Mackenzie River outflow and the cold marine waters of the Beaufort Sea. The river discharges very warm (by arctic standards) and turbid freshwater into the surface layer of the southern Beaufort Sea for approximately a three-month period each summer. During this time, the ice cover typically retreats to some variable distance offshore. Continual fluctuation of water environments in the estuary is characteristic of the open water period as wind, river discharge, and small tidal exchange mix and shift the interface between the two water masses. Consequently, those organisms inhabiting the study area must have a wide range of salinity tolerance (osmoregulation) to survive during this unstable summer period.

Organisms unable to effectively osmoregulate are limited in their distribution. Mortality of strictly freshwater organisms from the river environment usually occurs when they are flushed into saline areas. Conversely, true marine organisms penetrate the estuary only so far as their individual freshwater and temperature tolerances allow.

Autumn brings a progressive reduction in river discharge and turbidity. Water temperatures decline rapidly, with ice cover forming on outer Mackenzie River channels by early October. As the ice cover thickens, the winter-long river flow extends out certain channel mouths beneath the ice, penetrating the estuary by pushing the marine water further offshore or by flowing in a layer above it. Under-ice vertical profiles in March show strong layering between saline and freshwaters in depths greater than seven m.

In winter months, ice sheets averaging two m thick form atop both river and sea. In estuarine areas where the water depth in summer is only two m or less, little water remains in winter. The entire water column can become solid ice and, in this situation, the bottom sediments usually freeze.

Pressure ridges between the large ice "plates" further offshore may have keels extending to 15 m below the surface (Reimnitz and Barnes, 1974). When these ridges shift, bottom scouring occurs as the keels drag across the substrate. At spring break-up in June, the fast ice in shallow water also moves, scouring much of the shallow nearshore areas and mudflats.

With these harsh environmental conditions, a broad categorization of the benthos capable of inhabiting the study area may be made. Only a mobile, euryhaline epifauna can utilize the shallow inshore areas as habitat. Their mobility enables them to cope with ice scouring and the changing of key environmental parameters such as salinity. Ice interference essentially prohibits large sedentary pelecypod-annelid infaunal communities from establishing themselves in depths less than 2 m, and allows only sporadic colonization to five m.

Increasing depth relates to infaunal benthos in two ways:

1. Decreasing probability of ice scouring; and,

2. Increasing probability of stable marine water conditions on the bottom, ie. less annual temperature and salinity fluctuation.

Particulate organic detritus with attached bacterial flora is believed to be the major food source for benthos in the Mackenzie Estuary, as in other large estuaries (Odum, 1970). The majority of local benthos such as polychaetes, pelecypods, cumaceans, amphipods and mysids are detrital feeders (MacGinitie, 1955; Newell, 1965; Odum, 1970). The discovery of abundant nannoplankters in 1975 (Part 5, Section 5.6.2.3), as well as the usual assemblage of phyto and zooplankters, may represent an important seasonal diet component, especially to the amphipods and mysid shrimp.

For 1975, the same general trend of increasing infaunal densities in deeper and more saline waters was observed as in other years (Slaney, 1974c; 1975). Mean log densities of 1975 Ekman grab catches were calculated and plotted for each station's average depth and salinity (Figure 6.3). The density at Station 2 during 1975 is somewhat anomalous in this gradient; however, this sampling took place in considerably shallower water (on top of a sand bar) than previous collection. Station 2 is further distinguished from all other 1975 sampling stations by the high sand content on the bottom, which tends to contain fewer benthic invertebrates.

The existence of an abundant epifauna in the Mackenzie Estuary had been previously postulated from their frequency in fish stomach samples, and incidental catches in fish trawls (Slaney, 1975). However, they were first sampled as part of a quantitatively designed program during the 1975 study. Conventional grab techniques to determine benthos abundance, as employed by most Mackenzie Delta research studies to date, have missed major epifaunal components. The epibenthos probably represents a significant biomass in much of the study area, which suggests further investigation because of their trophic importance to fisheries stocks. Steele (1974) for example, examined the energy budget for the North Sea environment, and determined that the infaunal benthos was not utilized as a food source as extensively as the epifauna by commercial fishes.

The role of benthic invertebrates in the energy web of the Mackenzie Estuary can be assessed by their occurrence in fish stomachs (Slaney, 1973; 1975). The epibenthos comprised the greater proportion of food items than the infauna for least and arctic ciscoes, boreal smelt, burbot, fourhorn sculpin, arctic flounder, and saffron cod (Part 7, Section 7.8.3, Table 7.2).

As indicated by fish stomach data over three summers, the infaunal benthos are rarely utilized by local fish species, and their small sizes probably precludes their use by the local marine mammals. Watson and Divoky (1974) suggest that diving birds feed on benthic bivalve mollusks (pelecypods) in Beaufort shelf waters down to 30 m.

6.9 CONSTRUCTION EFFECTS ON BENTHOS

On the basis of three summer and two winter investigations, all evidence indicates that the effects of artificial island construction and associated activities on benthic organisms have been short-term and site-specific. Although direct loss of habitat and mortality may be assumed on site through spit removal, dredging, dock facilities and/or establishment of artificial islands (Slaney, 1975), no significant loss of food sources for higher trophic levels is expected.

Sampling of infaunal benthos before, during and after construction of Immerk artificial island in 1972 has revealed that:

1. Infaunal density is very low in the general inshore area; and,

2. Post-construction sampling in winter and summer (Slaney, 1974c; 1975) adjacent to the artificial island indicates that infaunal densities have not declined from densities sampled before and during construction in 1972 (Table 6.4).

The general presence of epifauna was identified during construction of Immerk in 1972 (Slaney, 1973). The epifaunal component was not quantitatively sampled until 1975, but their obvious abundance around the Immerk site at that time supports the interpretation of short-term and site-specific effects for construction activity in shallow areas away from shorelines.

Assessing the potential effects of turbidity and sedimentation on benthos from island construction operations was a prime focus of the benthos program. On the basis of three summers of observation, it is concluded that the additional turbidity and sedimentation caused by island construction in the naturally turbid ecosystem is considered to be of the same magnitude as that caused by severe summer storms encountered within the Mackenzie Estuary (Slaney, 1975), and no significant loss of organisms is to be expected under present construction methods. Copeland (1970) points out that dredge spoil and turbidity disturbances are generally "slight" in river mouth habitats.

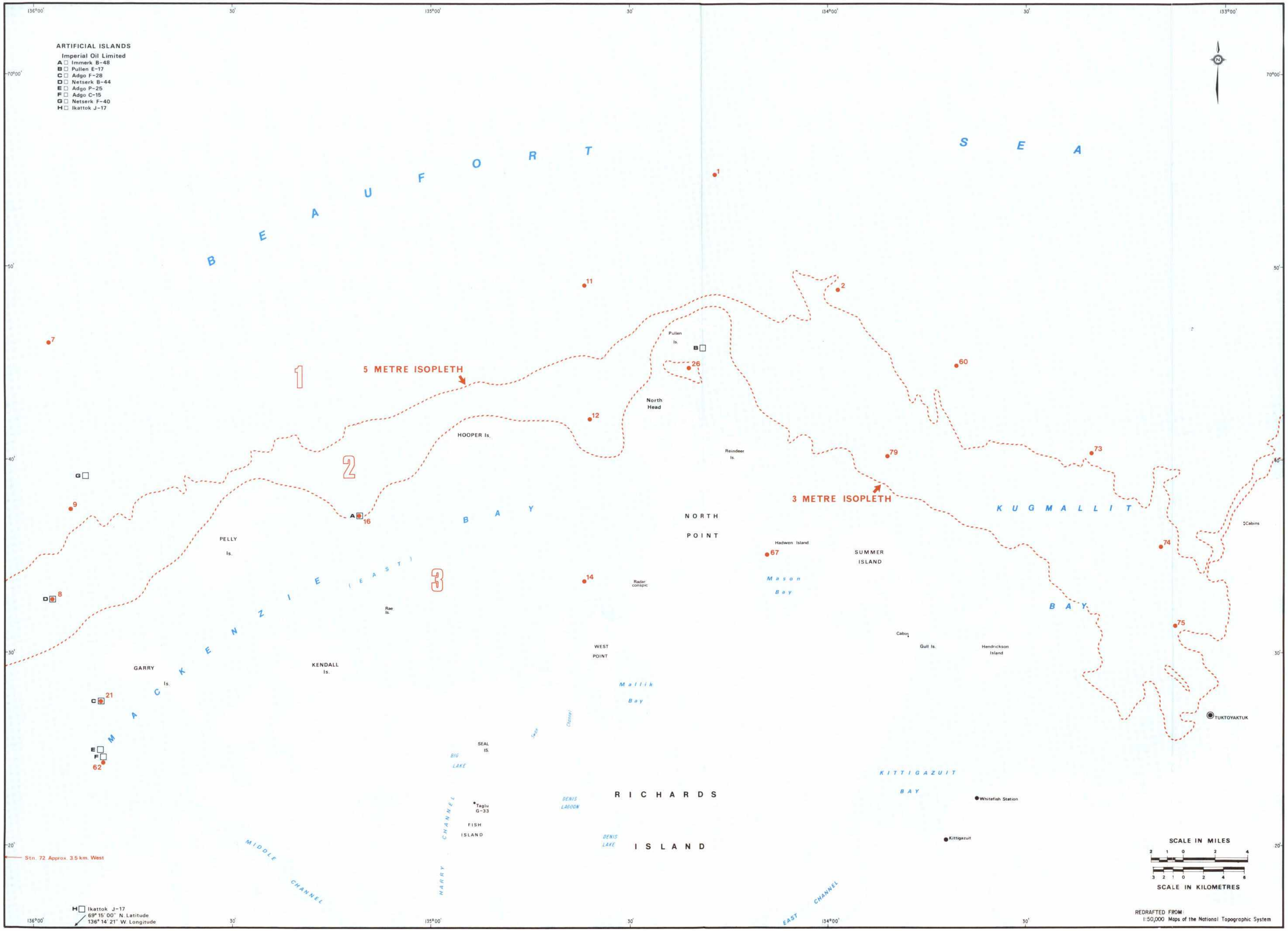
6.10 SUMMARY OF IMPORTANT POINTS

1. Depth and salinity are key factors influencing community types and numbers of organisms. Diversity and abundance tend to increase with deeper and more saline waters.

2. Polychaete worms and pelecypod clams numerically dominated the Ekman grab samples in 1975 (combined, 77 percent), and both groups of infauna were most abundant in the deeper Region 1.

3. The epibenthos, about which little is presently known, probably represents a significant biomass in much of the study area. Mysid shrimps and amphipods dominated the epibenthic trawl catches (combined, 99 percent).

4. On the basis of three summer and two winter investigations, all evidence indicates that the effects of artificial island construction and associated activities on benthic organisms have been short-term and site-specific.



LEGEND

- Infauna Sampling Stations
- Region Boundary — determined by depth
- Regions

MAP 6.1
Study Area Regions and Stations Sampled by Ekman Grab
July-August, 1975

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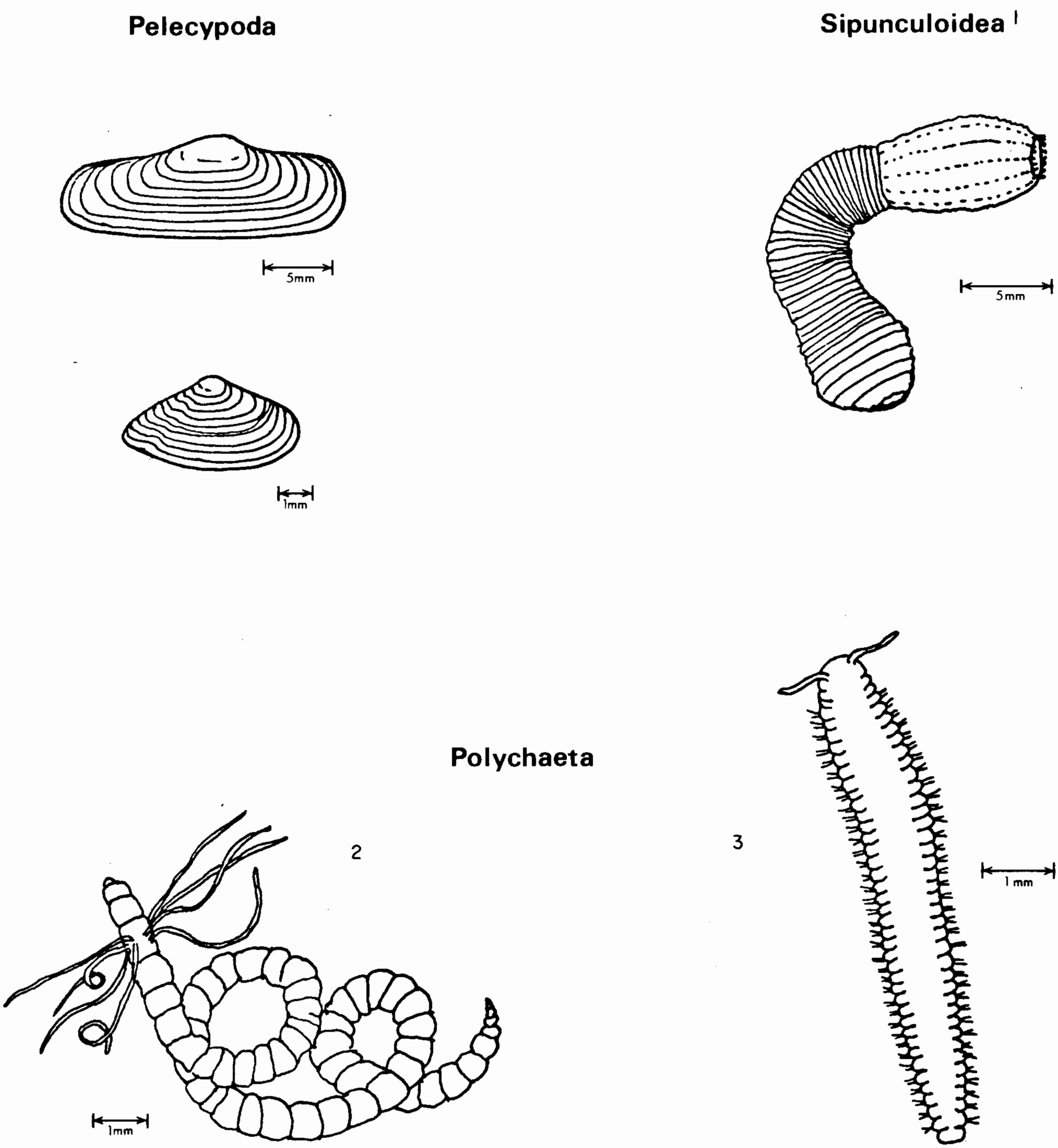
FIGURE 6.1

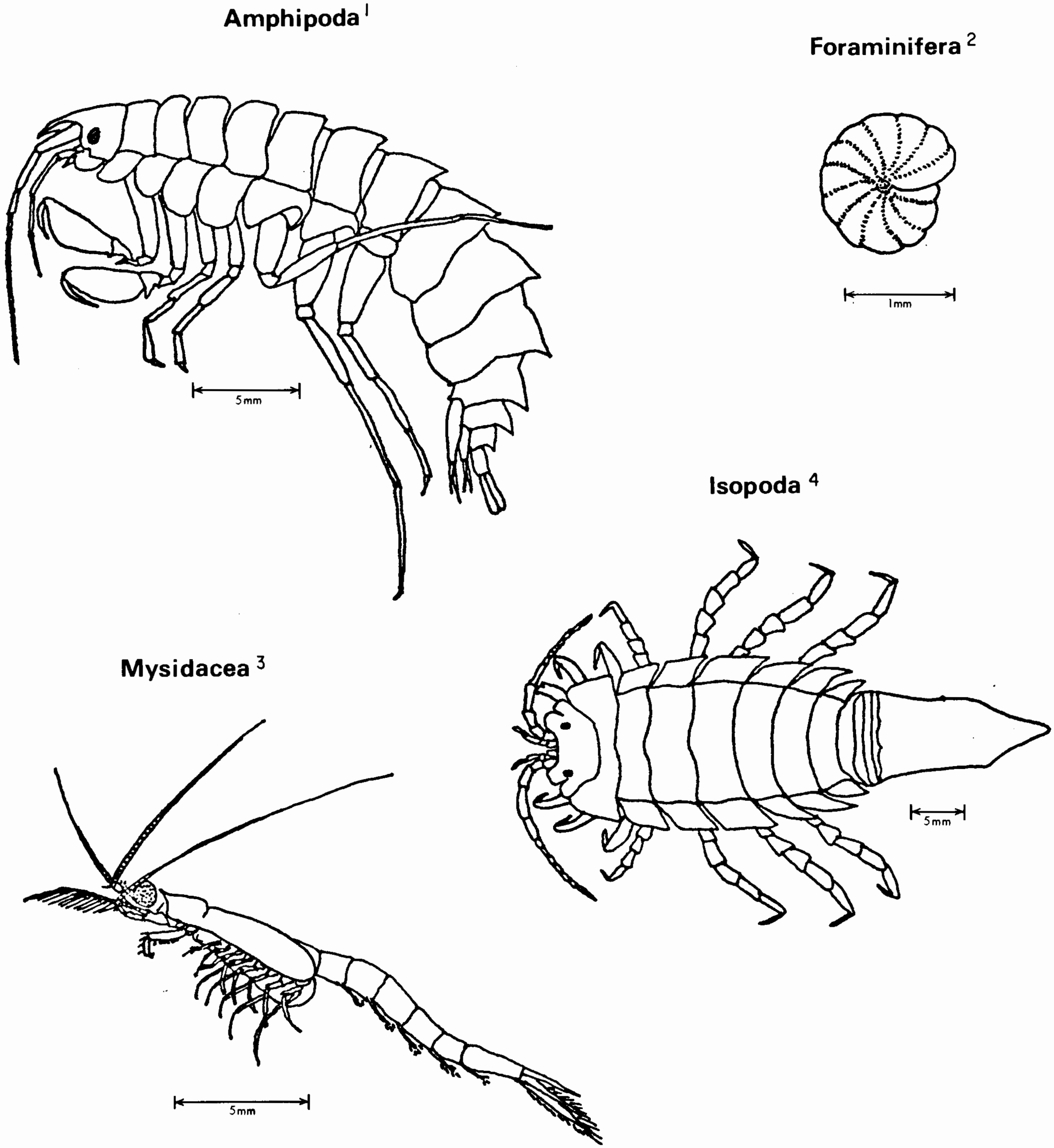
Some Members of the Mackenzie Delta Infauna*



*These figures are redrawn from the following sources: 1 and 2 (Barnes, 1968); 3 (Banse and Hobson, 1974).

FIGURE 6.2

Some Members of the Mackenzie Delta Epifauna*



*These figures are redrawn from the following sources: 2, 3 and 4 (Green, 1968); 1 (Barnard, 1969).

TABLE 6.2

EKMAN GRAB SAMPLING OF MACKENZIE ESTUARY BENTHIC FAUNA, 1975

	DEEP WATER STATIONS (DEPTH >3M)														SHALLOW STATIONS (<3M)					
	Region 1							Region 2							Region 3					
	1	7	9	11	60	74	75	2	8	12	26	67	73	79	14	16	21	62	72	TOTAL
PROTOZOA																				
Foraminifera					1								45							46
NEMATODA							1						1							2
ANNELIDA																				
Polychaetae	56	6	21	23	28	66	57	18	1	14	4	29	315	14	7	9				668
Obligochaetae										1						1				2
Sipuneuloidea			1		5	3					2	1	5	3						20
ARTHROPODA																				
Ostracoda												3	4							7
Copepoda																	5			5
Cumacea				1		6	1	6		1	1	3	11	5						35
Isopoda	1				2	1		1	2	2					1	1				11
Amphipoda	2			2	2	10	11	4	12	23	18	3	22	8		8	35			160
Mysidacea				1				1		5										7
MOLLUSCA																				
Gastropoda	1	1			7							3								12
Pelecypoda	18	14	27	35	125	11	1	28			2	19	86	16						382
TOTAL NUMBERS	78	21	49	62	170	97	71	58	15	46	27	61	489	46	8	19	40	0	0	1,357
Total No. of Grabs	5	5	5	10	5	5	7	20	15	10	5	5	15	5	5	10	10	15	5	
Mean Organisms/Grab	15.6	4.2	9.8	6.2	34.0	19.4	10.1	2.9	1.0	4.6	5.4	12.2	32.6	9.2	1.6	1.9	4.0	0	0	
Mean Log Density/Grab	2.51	1.52	2.34	1.84	3.54	3.0	2.34	0.90	0.45	1.58	1.82	2.40	3.37	2.23	0.74	0.90	0.97	0	0	
Average Depth (m)	10.3	11.2	7.0	6.5	5.5	5.1	5.1	4.2	4.3	4.0	3.9	4.3	4.5	4.3	2.0	3.0	2.0	1.2	2.0	
Average Salinity (o/oo)	20.1	24.1	10.8	3.8	19.2	6.8	9.3	14.7	8.3	<1.0	3.3	5.2	9.7	6.9	4.8	4.0	3.2	<1.0	<1.0	

TABLE 6.3

EPIBENTHIC TRAWL CATCHES, MACKENZIE ESTUARY, N.W.T., 1975

	STATION AND DATE					
	2 July 17	8 July 29	11 July 31	12 July 30	16 July 10	TOTAL NUMBER OF ORGANISMS
Coelenterata	1		1	3		5
Copepoda	4					4
Cumacea				2		2
Isopoda	4	12		2	25	43
Amphipoda	4	137	15	372	53	581
Mysidacea	844	194	188	2,280	77	3,583
TOTALS:	857	343	204	2,659	155	4,218
Meter Reading	13,275	28,680	18,531	21,430	10,169	
Elapsed Time (min.)	13	20	20	20	20	
Bearing (mag.)	210^o	100^o	010^o	330^o	180^o	
Depth Range (m)	3-4	3-4	6	3	3	
Volume Strained (m^3)	2,083.4	4,501.2	2,907.6	3,362.4	1,594.8	
Epibenthos Per M^3	0.41	0.08	0.07	0.79	0.10	

FIGURE 6.3

Relationship of Mean Log Benthos Density to Station Depth and Salinity~ Summer, 1975

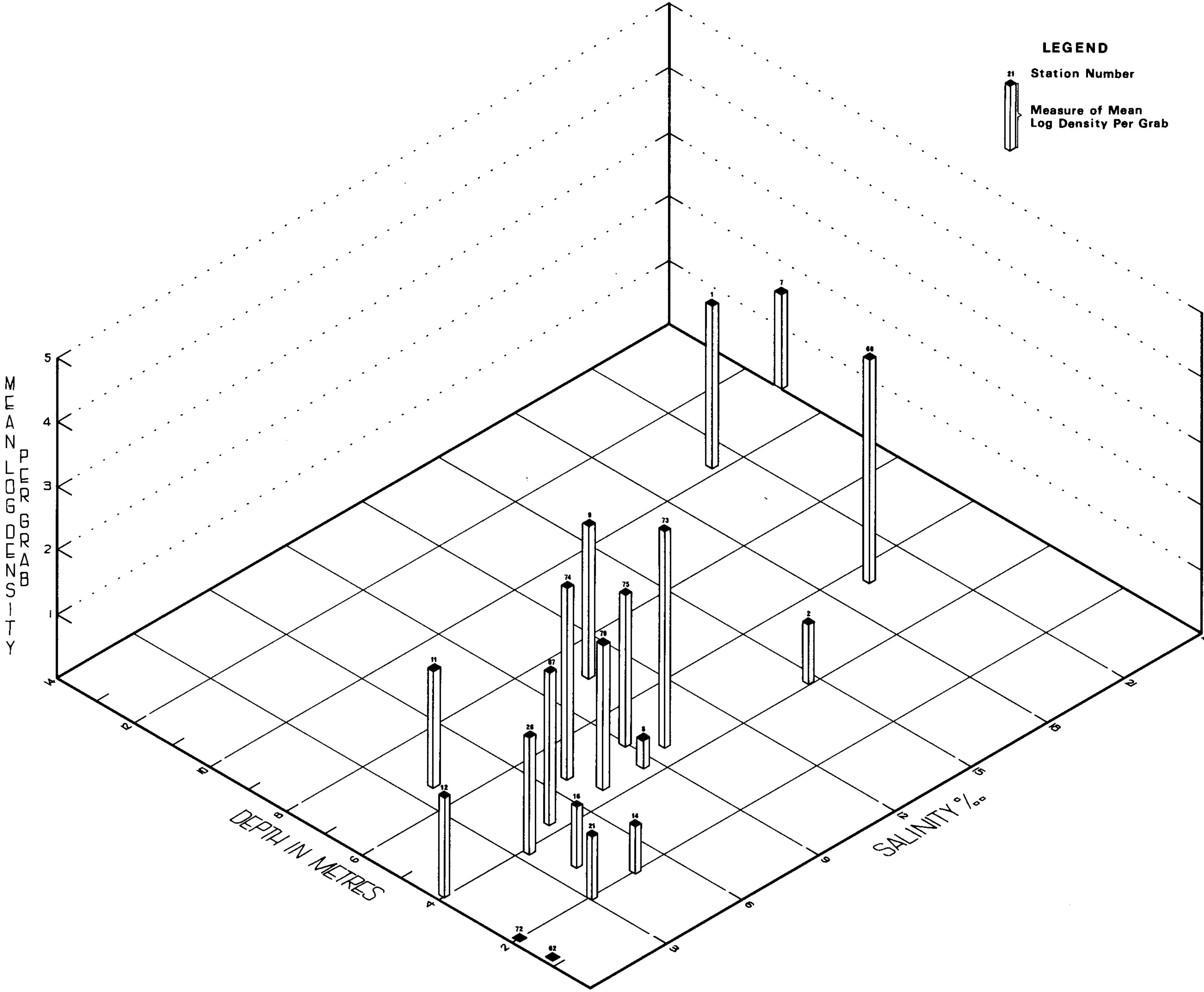


TABLE 6.4

INFAUNAL BENTHOS AT IMMERK ARTIFICIAL ISLAND
(STATION 16), 1972 TO 1975

	1972	1973	1974	1974	1975
Period	Jul-Sept	March	April	Jul-Aug	July
Grab Type[1]	Petersen	Ekman	Ekman	Ekman	Ekman
Grab Area (cm^2)	900	225	225	225	225
Total Grabs	11	3	15	18	10
No. of Barren Grabs	9	1	8	12	2
No. of Organisms[2]	4	2	10	12	19
Organism/m^2	4.0	29.6	29.6	29.6	84.4
Taxa	Polychaeta Amphipoda	Polychaeta Nematoda	Polychaeta Amphipoda Mysidacea	Amphipoda Isopoda Sipunculoidea	Polychaeta Oligochaeta Amphipoda Isopoda

[1] Caution should be exercised in comparing the numbers collected By Petersen grab with those collected by Ekman grab, due to differences in design and operation.

[2] Retained after sediments were sieved through 0.5 mm screen.

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PART 7

SUMMER FISHERIES INVESTIGATIONS IN THE COASTAL WATERS OF THE MACKENZIE ESTUARY, N.W.T., 1975

BY

V.A. POULIN

FOR

IMPERIAL OIL LIMITED

F.F. SLANEY & COMPANY LIMITED
VANCOUVER, CANADA

PART 7

FISHERIES

7.1 INTRODUCTION

The importance of the coastal waters along the outer Mackenzie Delta to the fishery resources of the northern territories has become more apparent as a result of environmental studies supported by industry and Government during the past few years. Studies conducted by F.F. Slaney & Company Limited, the Beaufort Sea Project, and information extrapolated from other fishery investigations along the northern Yukon coastline have shown the outer Mackenzie Delta to be a significant coastal rearing and summer feeding area for many important domestic and commercial fish species.

Fisheries resources lying offshore of the coastal shelf have been little studied, and are presently not well understood. Harsh climatic conditions typical of sub-arctic regions have been responsible for research efforts to date being primarily confined to the coastal waters. The offshore waters of the Beaufort Sea support a variety of marine fish species which are presetnly unexploited by local fisheries.

7.2 PURPOSE

The purpose of the 1975 fisheries program was to supplement the existing data base for the assessment of effects upon fish resources which may arise from artificial island construction in the Mackenzie Estuary.

7.3 OBJECTIVES

The specific objectives of the fish program were to:

1. Describe the distribution and relative abundance of fish at selected nearshore, inshore freshwater and inshore estuarine locations in East Mackenzie Bay and Kugmallit Bay.

2. Provide quantitative data on the relative abundance of fish in important nearshore areas utilized by fish for rearing and/or feeding grounds in East Mackenzie Bay and Kugmallit Bay; and,

3. Supplement existing life history information on the principal fish species of the study area, with emphasis on filling gaps in the 1974 data.

7.4 SCOPE OF WORK

The 1975 fisheries investigations of East Mackenzie and Kugmallit Bays were undertaken as part of an integrated summer environmental program conducted by F.F. Slaney & Company Limited for Imperial Oil Limited. The scope of the program was designed to supplement the data base established during the 1974 fisheries program pertaining to the distribution, occurrence and abundance of fish in East Mackenzie Bay with data from proposed artificial island sites not sampled in 1974 and additional locations in Kugmallit Bay.

Site-specific and regional information describing the distribution and relative abundance of fish were obtained in the inshore freshwater, inshore estuarine and nearshore reaches of East Mackenzie Bay and in the nearshore of Kugmallit Bay along the NE coastline of Richards Island. Adverse weather conditions precluded fish sampling at proposed inshore sampling stations in Kugmallit Bay.

For the summer program, sampling was to be conducted from July 1 to August 31, 1975. During that period, an 11 m vessel (Wilson III) and a six m runabout were to be available for use by the fisheries field crew. The Wilson III, a self-contained boat equipped with shipboard laboratory facilities, was utilized to conduct inshore trawling and gillnetting in East Mackenzie Bay until August 8. On August 8, the boat caught fire while undergoing repairs at an artificial island site, and all equipment and fisheries data on-board were lost.

After August 8, sampling was not possible in the inshore waters. Sampling in the nearshore was continued, however, although sampling effort was reduced. Field sampling was concluded on August 31, 1975.

This report presents the findings and conclusions of the 1975 fish study, and has endeavoured to utilize all available published information pertaining to the study area.

7.5 METHODS

The 1975 fishery program was, in essence, a continuation of the 1974 studies. Consequently, the materials and methods employed were consistent to insure comparative results.

7.5.1 Sampling Sites

Thirty-two stations, located primarily in East Mackenzie Bay and Mason Bay, were sampled by the fisheries field crew (Map 7.1). Fourteen of the stations sampled during the 1975 summer program were also sampled in 1974. Additional stations included three proposed artificial island sites north of the Barrier Islands.

(Stations 1, 4, and 7), two recently constructed artificial islands located offshore of Langley and Olivier Islands (Stations 72, 71, 62, and 63), and nine stations in the coastal reaches (Stations 57, 58, 61, 64, 65, 66, 67, 68, and 70).

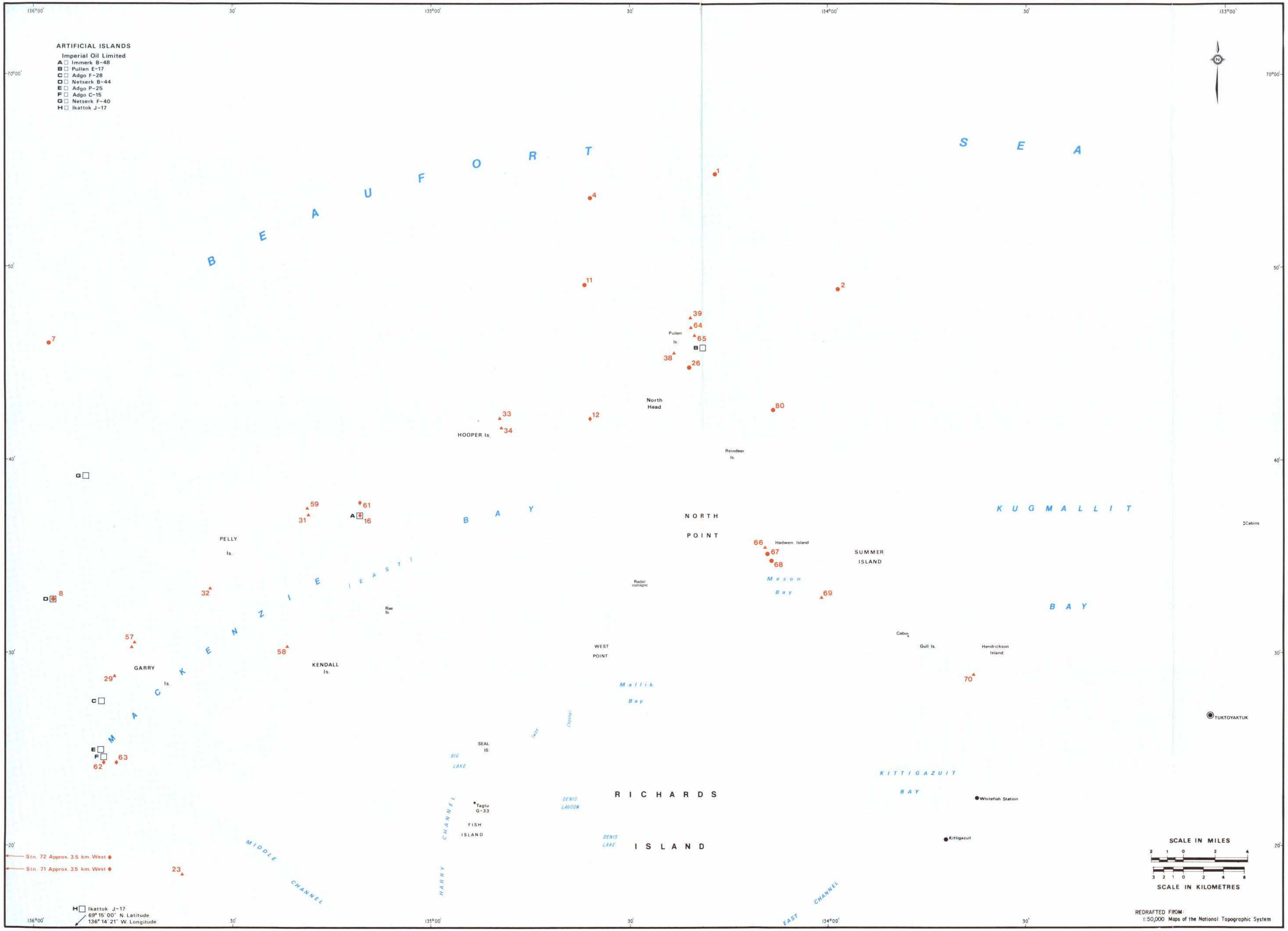
Throughout the text reference is made to stations located in the nearshore, inshore freshwater and inshore estuarine areas. Stations designated as nearshore were those located within 50 m of shoreline or lagoon or within the influence of a river mouth. Salinity at nearshore stations was typically low (range <1.0 to 4.6 ^{o}/oo), except during periods of salt water intrusion when salinities as high as 15.2 ^{o}/oo were recorded.

Stations occurring beyond 50 m of shoreline and south of the three m depth contour were classified inshore freshwater. These stations were located in predominantly freshwater with salinities ranging from <1.0 to 5.2 ^{o}/oo. Stations situated north of the three m depth contour in predominantly brackish and marine waters (salinity range 2.0 to 24.1 ^{o}/oo) were designated inshore estuarine.

7.5.2 Sampling Methods

Fish sampling was conducted in nearshore and inshore waters with a variety of gear depending upon water depth, timing and location of sampling sites.

Nearshore areas were sampled by variable mesh gillnet and beach seine. Gillnets 77.6 m by 2.4 m were constructed from 15.5 m panels of 25, 50, 75, 100, and 125 mm stretch mesh nets. Soak times varied from four to 13 hours. At nearly all nearshore locations sampled by gillnet, fish numbers were such that gillnets set for longer periods would have resulted in excessive catches.



LEGEND

- Inshore Estuarine Station
- Inshore Freshwater Station
- Nearshore Station

MAP 7.1
Fish Sampling Stations, 1975

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Beach seining was the principle means of fish capture in the shallow coastal areas. At each station, one to three hauls were made with a 30.84 m (6.5 mm stretch mesh) beach seine. All hauls were made within approximately 100 m of shoreline. In order to standardize the amount of effort expended in hauling the seine, a single haul consisted of either pulling the seine by hand or power boat perpendicular to the beach, then swinging the net in a large arc back to the beach where the net was then pulled ashore and catch recorded.

Additional efforts using a fine mesh, 9.6 m (0.64 mm stretch mesh) beach seine were made to ascertain the presence of young-of-the-year (fry) not captured by the larger mesh beach seine. Efforts were not made to obtain quantitative samples with this net. As a result, sampling area varied, ranging from ten to 20 m of shoreline.

Inshore sampling was conducted by variable mesh gillnet, bottom trawl and epibenthic sled. Gillnets of the same length and mesh sizes described above were set on surface at all stations sampled. At most stations, water depth did not exceed the depth of the net, allowing for collection of both bottom and pelagic species.

Unlike the nearshore, gillnet soak time was thought to be a contributing factor in low catches obtained during the 1974 inshore sampling, and considerable effort was made to increase the minimum soak times of gillnets placed in the inshore waters. However, logistics often prevented leaving nets unattended for lengthy periods, and soak times varied from seven to 29 hours.

A bottom trawl with a mouth opening 2.5 m by 1.6 m and fitted with a 7.4 m net of variable mesh (50 to 6.5 mm stretch mesh at the cod end) was used to capture bottom dwelling and juvenile pelagic fish.

Tows were made at an estimated speed of 4.8 kmh in the direction of the next station.

In addition to being sampled by bottom trawl, young-of-the-year and juvenile fish were also collected by epibenthic sled. A complete description of this equipment is provided in Part 6, Section 6.5.2.

All fish captured were identified to species, measured for length, and released alive or kept for detailed laboratory analyses.

7.5.3 Laboratory Analyses

Detailed examination of fish samples included determinations of fork length (tip of snout to fork in tail), total weight, sex, condition, maturity and stomach contents.

The following criteria were used to classify fish as to sexual maturity:

1. Immature

   Fish which exhibited no evidence of previous spawning and did not appear capable of spawning in the coming spawning season. Gonads appeared regular, lacking development and, in small juveniles, threadlike.

2. Mature

   Those fish which would spawn in the coming spawning season, or had spawned before. Indications of previous spawning included vascularization, irregular gonad shape in males and retained eggs in females.

Fish classified as mature were further described as mature spawners or mature non-spawners according to their state of maturity or gonad condition. Fish which were ripe or green were classified mature spawners. Mature fish which could not spawn in the coming season were described as mature non-spawners.

The following definitions were applied to these categories:

1. Mature Spawners - Ripe

   Sexual products could be expressed by gentle pressure exerted on the abdomen when stroked from beneath the gills to the cloaca.

2. Mature Spawners - Spawned-Out

   Fish which had completed the spawning act. Sexual products were lacking or absent. Abdomen appeared flacid and empty. In females, retained eggs may be found in the body cavity; males often excude trace of milt when pressure is applied to abdomen.

3. Mature Spawners - Green

   Fish which exhibited developed gonads (i.e. large eggs in females; opaque white colour in males) but sexual products could not be expressed by pressure on abdomen.

4. Mature Non-Spawners

   Fish which lacked sufficient gonad development to be capable of spawning in the coming spawning season, but exhibited signs of previous spawning. Distinguishing fish in this category from green mature-spawners was difficult, particularly in those species where life history information is incomplete. Field interpretations were based primarily on egg size in females and appearance in males, and was consequently subject to individual interpretation.

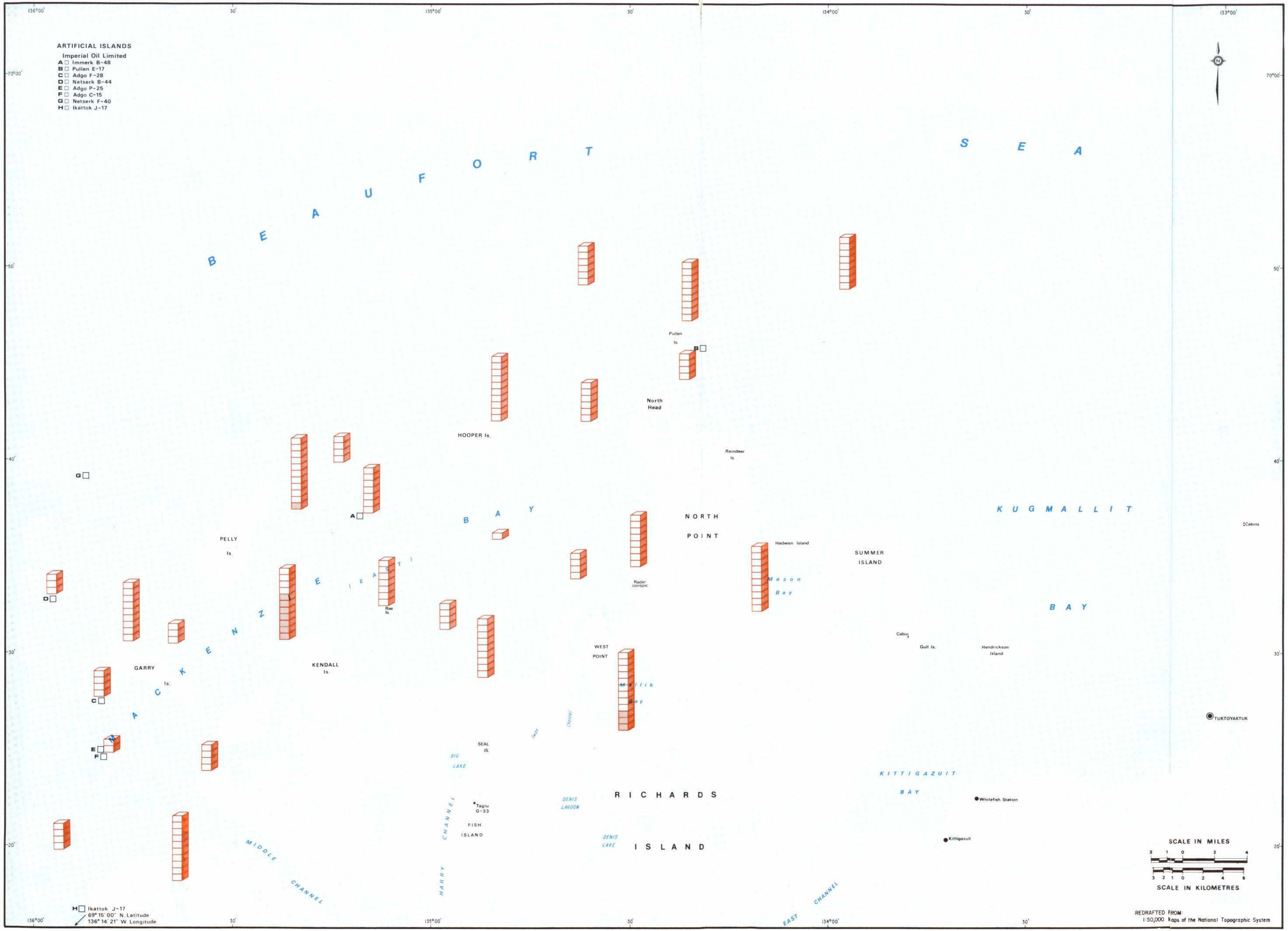
Where encountered, stomach content was identified and recorded to the level of taxonomic order.

Egg sizes were determined for all green females by lining up ten large eggs from the gonad, measuring the combined length, then calculating an average diameter for one egg.

Otoliths were taken for age determinations and stored in 100 percent glycerine. Because of project time and budgetary constraints, age analysis was not completed on otoliths taken during the field program but otoliths have been retained for future analysis if required.

7.5.4 Sampling Frequency

The frequency at which stations were sampled was dependent upon factors such as weather, boat availability and size of the study area. The field program was designed to provide at least one-time sampling at all Imperial Oil Limited sites considered for artificial island construction in East Mackenzie Bay and Kugmallit Bay. Most of the proposed deepwater island sites in East Mackenzie Bay were sampled at least once during the sampling program. Severe weather conditions encountered while operating in the Kugmallit Bay area precluded fish sampling except in the nearshore. Stations occurring in the coastal reaches were generally sampled on a one-time basis.



LEGEND

Fish species collected by F.F. Slaney & Co., 1974 and 1975

Fish species collected by Percy, 1975

MAP 7.2

Diversity of Fish Species

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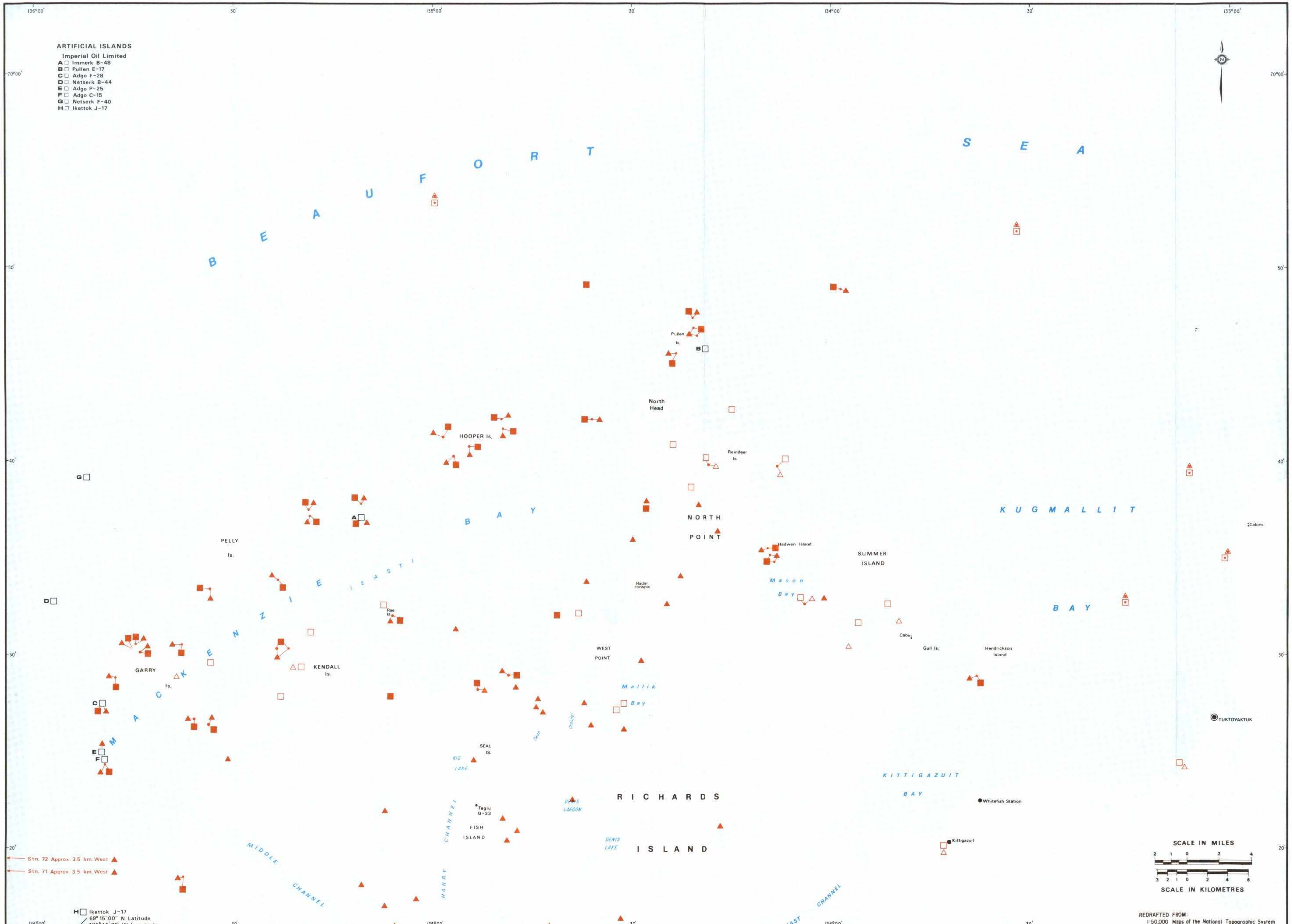

LEGEND

- ▲ Least Cisco
- ■ Arctic Cisco
- ▲ F.F. Slaney studies, 1972, 1973, 1974 and 1975
- △ Percy *et al* studies, 1975 (locations approximate)
- ▲ Galbraith & Fraser studies, 1974 (locations approximate)

MAP 7.3

Distribution of Arctic Cisco and Least Cisco

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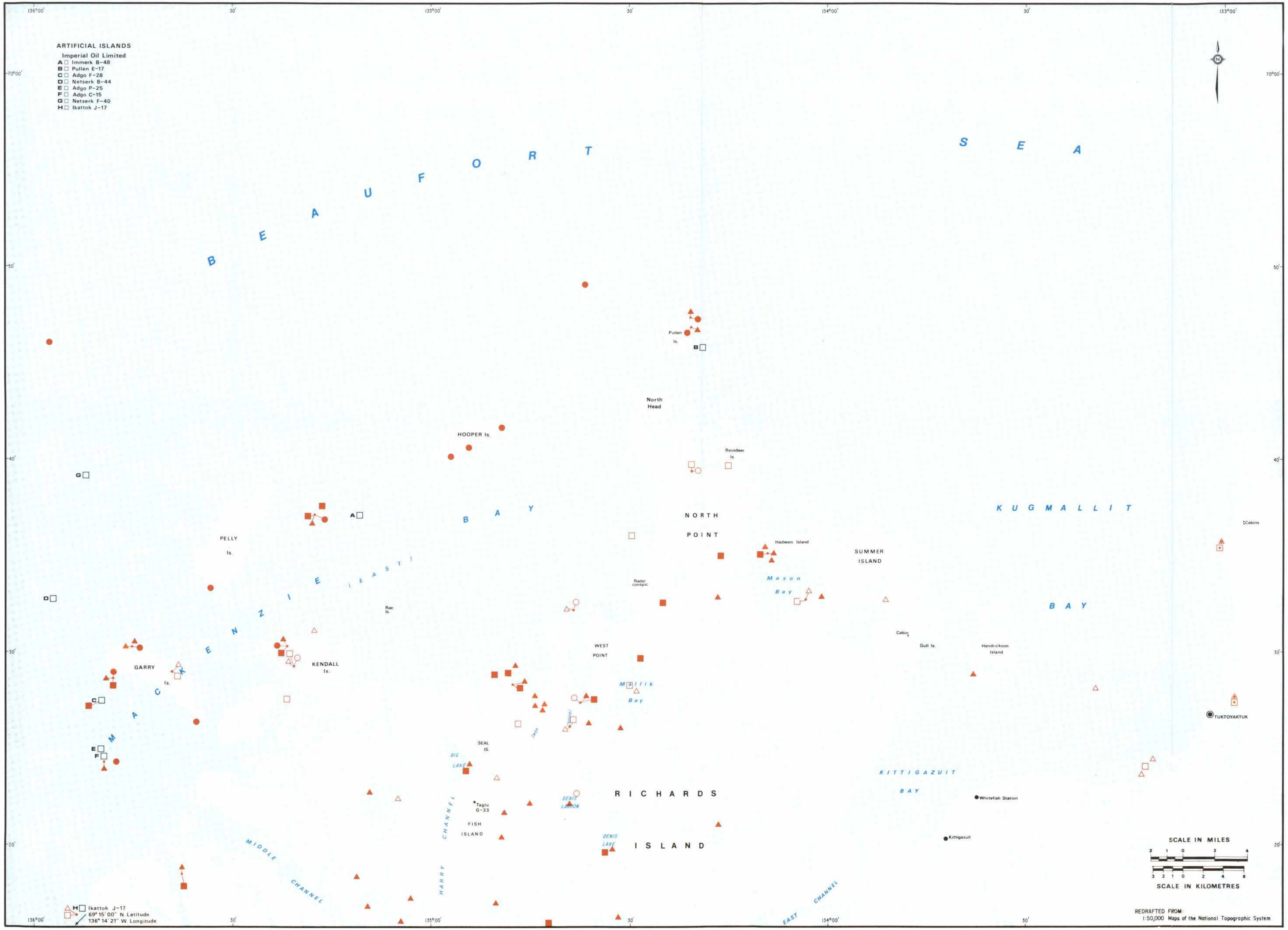

LEGEND

- ▲ Humpback Whitefish
- ■ Broad Whitefish
- ● Unidentified Whitefish

- ▲ F.F.Slaney studies, 1972, 1973, 1974 and 1975
- △ Percy *et al* studies, 1975 (locations approximate)
- ▲ Galbraith & Fraser studies, 1974 (locations approximate)

MAP 7.4
Distribution of Humpback Whitefish and Broad Whitefish

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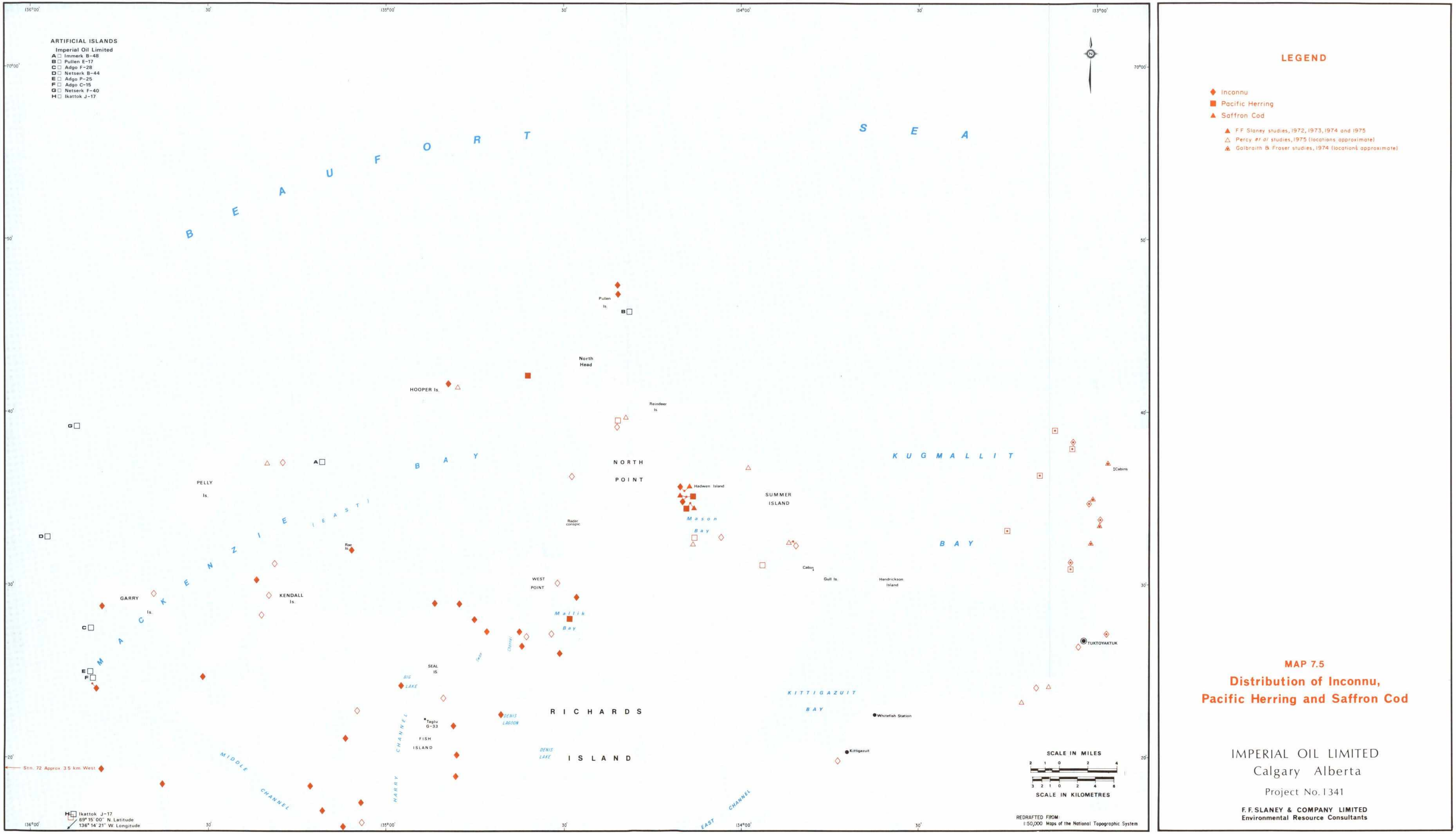
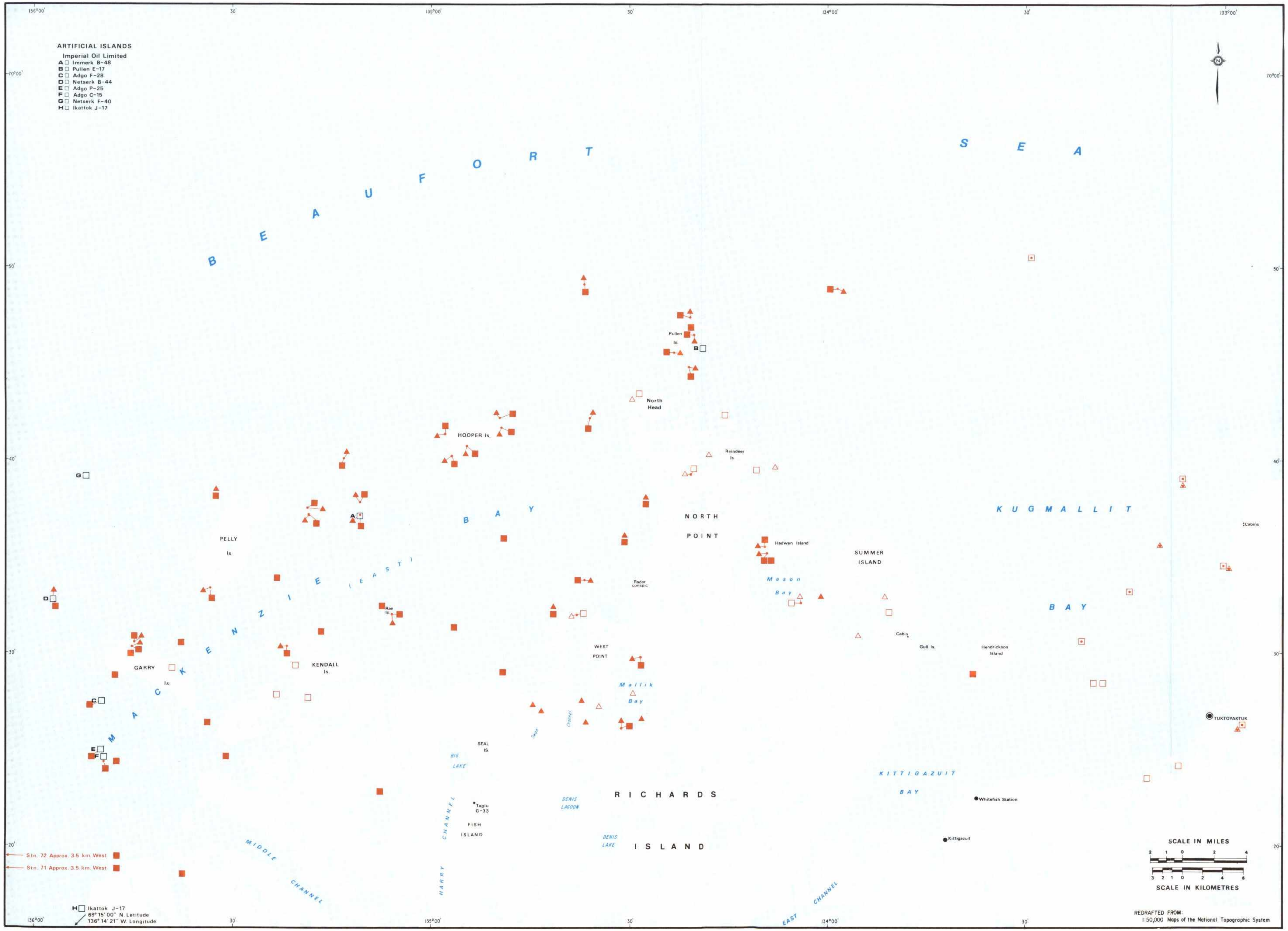


MAP 7.5
Distribution of Inconnu, Pacific Herring and Saffron Cod



LEGEND

▲ Fourhorn Sculpin
■ Boreal Smelt

▲ F.F. Slaney studies, 1972, 1973, 1974 and 1975
△ Percy *et al* studies, 1975 (locations approximate)
Galbraith & Fraser studies, 1974 (locations approximate)

MAP 7.6
Distribution of Fourhorn Sculpin and Boreal Smelt

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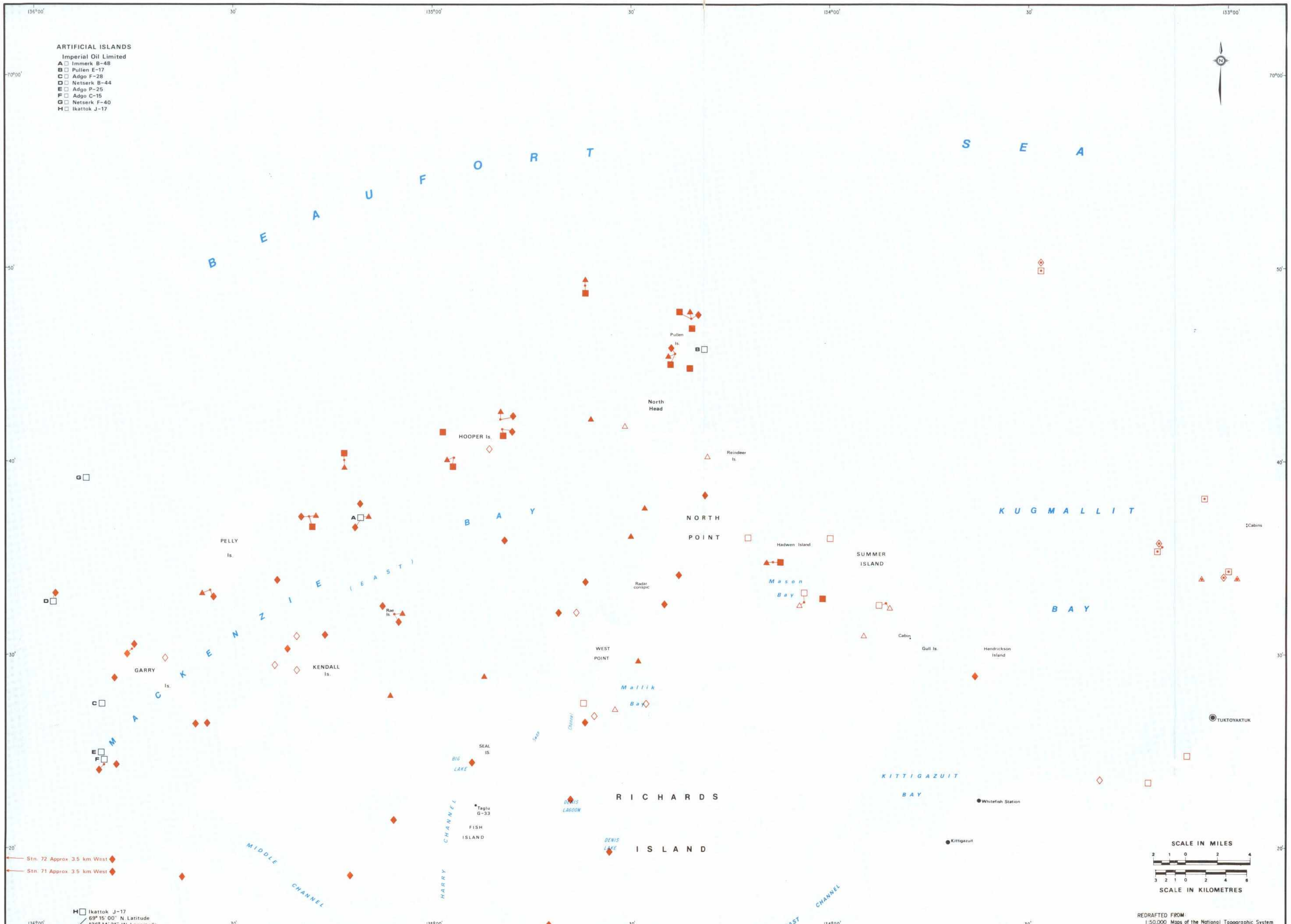

LEGEND

- ▲ Saffron Cod
- ■ Arctic Flounder
- ◆ Burbot

- ▲ F.F. Slaney studies, 1972, 1973, 1974 and 1975
- △ Percy *et al* studies, 1975 (locations approximate)
- ▲ Galbraith & Fraser studies, 1974 (locations approximate)

MAP 7.7

Distribution of Saffron Cod, Arctic Flounder and Burbot

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7.6 RESULTS OF THE STUDY

The following sections of this report present the results and discussion of the 1975 fisheries studies. Since both the 1974 and 1975 fish programs were nearly identical in scope and objectives, data obtained during both years of study have been discussed on a comparative basis. Information describing distribution, occurrence and relative abundance of fish in Kugmallit Bay has come largely from the interim results of the Beaufort Sea Study Projects in the eastern coastal Beaufort Sea (Galbraith and Fraser, 1974) and along the outer Mackenzie Delta (Percy et al, 1974; Percy, 1975).

7.6.1 Occurrence of Fish Species in the Study Area

Along the fringes of the outer Mackenzie Delta, turbid Mackenzie River waters empty into the coastal reaches of the southern Beaufort Sea where they form a large aquatic ecosystem inhabited by a diverse complement of freshwater, marine and anadromous fish species. Twenty-five species of fish have been identified along this coastline (Galbraith and Fraser, 1974; Percy, 1975; Slaney, 1975; Table 7.1).

Of the 25 species which have been identified in these waters, only 16 species were commonly taken in East Mackenzie Bay during the 1975 study. These included seven freshwater species: broad whitefish (Coregonus nasus), burbot (Lota lota), humpback whitefish (Coregonus clupeaformis complex), inconnu (Stenodus leucichthys nelma), longnose sucker (Catostomus catostomus), ninespine stickleback (Pungitius pungitius), northern pike (Esox lucius), six marine species: arctic cod (Boreogadus saida), arctic flounder (Liopsetta glacialis), sand lance (Ammodytes spp.), fourhorn sculpin (Myoxocephalus quadricornis quadricornis), pacific herring (Clupea harengus pallsi), saffron cod (Eleginus navaga), and four anadromous species: arctic cisco (Coregonus autumnalis), arctic lamprey (Lampetra japonica), boreal smelt (Osmerus eperlanus complex) and least cisco (Coregonus sardinella complex).

The eight remaining species which have been taken infrequently and in small numbers are: round whitefish (Prosopium cylindraceum), lake trout (Salvelinus namaycush), spoonhead sculpin (Cottus ricei), an unidentified sculpin (Cottidae spp.), snail fish (Liparidae spp.), arctic flounder (Liopsetta glacialis), starry flounder (Platichythys stellatus), blenny (Leptoclinus maculatus) and pricklebacks (Stichacidea spp.).

Species which were not collected during the 1975 field studies, but have been identified in previous work include the blenny (Leptoclinus maculatus), an unidentified snail fish (Liparidae spp.), starry flounder (Platichythys stellatus), and spoonhead sculpin (Cottus ricei) (Slaney, 1974a, 1975).

7.6.1.1 Diversity of Fish Species

Occurrence data from previous studies by F.F. Slaney & Company and the 1974 - 1975 Beaufort Sea Study Project (Percy, 1975) were grouped to demonstrate diversity of fish species which have been collected in the nearshore and inshore waters of the study area (Map 7.2).

Fish diversity was highest in the shallow waters surrounding the Barrier Islands, at channel mouths and in the deep brackish water bays and lagoons of Richards Island. In the nearshore reaches, diversity was highest in the Mallik Bay area where 12 species have been recorded (Slaney, 1974a; Percy, 1975). In Mason Bay and at the Langley Channel mouth, ten species have been collected. Along the shorelines of the Barrier Islands, fish diversity was also high with nine to 11 species commonly taken.

TABLE 7.1

FISH SPECIES IDENTIFIED IN

EAST MACKENZIE BAY, KUGMALLIT BAY AND MASON BAY

	East Mackenzie Bay	Kugmallit Bay	Mason Bay
FRESHWATER			
Broad whitefish	▲	△	▲
Burbot	▲	▲	
Humpback whitefish	▲	▲	▲
Inconnu	▲	△	▲
Lake trout	▲		
Longnose sucker	▲	◬	
Ninespine stickleback	▲		
Northern pike	▲		
Round whitefish		△	
Spoonhead sculpin	▲		
ANADROMOUS			
Arctic cisco	▲	▲	▲
Arctic lamprey	▲	▲	
Boreal smelt	▲	▲	▲
Least cisco	▲	▲	▲
MARINE			
Arctic cod		▲	
Arctic flounder	▲	△	▲
Blenney	▲		
Fourhorn sculpin	▲	▲	▲
Pacific herring	▲	◬	▲
Pricklebacks		◬	
Saffron cod	▲	◬	▲
Sand lance		▲	
Sculpin (unidentified)	▲		
Snailfish (unidentified)	▲		
Starry flounder	▲	△	

Legend:

▲ - F.F. Slaney 1974 and 1975 studies

◬ - Galbraith and Fraser, 1974

△ - Percy, 1975.

Species diversity dropped immediately beyond the influence of shoreline in nearly all areas except Mason Bay, where commonly collected species appeared to be distributed throughout the open waters. At inshore freshwater stations sampled in East Mackenzie Bay, diversity was low (<4 species) except at Immerk artificial island (Station 16) where seven species have been collected. Diversity increased slightly at inshore estuarine stations sampled in East Mackenzie Bay, where three to six species have been encountered. In the inshore estuarine waters, diversity was greatest at Station 2 in Kugmallit Bay, where eight species have been taken.

Although a function of many factors, fish diversity in the coastal waters appears to be largely influenced by the tolerance of fish to saline or brackish water, and feeding habits. Along the Barrier Islands for example, or in the saline bays of Richards Island, marine species as well as euryhaline freshwater species are found. Diversity is further increased in these areas by the preference of whitefish and ciscoes to remain along edges of natural island shorelines rather than in the inshore waters.

7.6.2 Distribution of Fish in the Study Area

The distribution of the most frequently occurring fish species collected in the study area are shown (Maps 7.3, 7.4, 7.5, 7.6, and 7.7). Distribution data obtained during previous Slaney & Company studies were combined with the 1975 information to provide updated distribution maps which include Kugmallit Bay. Selected data from Percy (1975) and Galbraith and Fraser (1974) were included to aid in describing fish distributions, particularly in Kugmallit Bay for which little data was obtained during the 1975 Slaney studies.

7.6.2.1 Arctic Cisco and Least Cisco

Arctic cisco and least cisco were widely distributed throughout the study area (Map 7.3). Both species demonstrated nearly identical distribution, and were collected at all nearshore stations sampled in 1974 and 1975. Arctic cisco and least cisco were not commonly found at the inshore freshwater and inshore estuarine stations sampled. These species generally remained along the edge of the Barrier Islands and in coastal lagoons and embayments. In Kugmallit Bay, arctic cisco and least cisco were taken at nearly all stations sampled by Percy et al (1974) and Galbraith and Fraser (1974).

Young-of-the-Year

Cisco young-of-the-year (fry) were widely distributed throughout the nearshore coastal reaches of the outer Mackenzie Delta. Young-of-the-year have been collected at nearly all the nearshore Barrier Island seining stations sampled in East Mackenzie Bay during 1974 and 1975, and in Mason Bay in 1975. Low catches of young-of-the-year in the inshore freshwater and inshore estuarine waters by trawl indicated little utilization of these waters by this size class. Young-of-the-year were captured along the shoreline of Immerk artificial island in 1974. Percy (1975) reported unidentified cisco fry have been taken along the coastline of Richards Island.

7.6.2.2 Broad whitefish and Humpback Whitefish

Broad whitefish and humpback whitefish are freshwater species which were typically found along coastal reaches and in the vicinity of channel mouths (Map 7.4). Adult and large juvenile whitefish were only rarely found in the nearshore Barrier Islands areas and the inshore freshwater areas which were subjected to intrusions of saline Beaufort Sea water.

Whitefish were not found to venture far into the inshore waters of Kugmallit Bay. Humpback whitefish were frequently taken in the coastal reaches along the Tuktoyaktuk Peninsula in Kugmallit Bay, but were absent from the inshore stations sampled (Galbraith and Fraser, 1974; Percy, 1975). Broad whitefish did not appear in any catches along that coastline.

Whitefish young-of-the-year (fry) and small juveniles (<100 mm) demonstrated nearly opposite behaviour to the adults and were frequently collected by beach seine in the nearshore areas along the Barrier Islands. The only whitefish collected in the inshore estuarine waters were young-of-the-year taken at Station 11.

7.6.2.3 Inconnu

During the 1974 studies, inconnu were rarely collected beyond the coastal reaches of Langley and Richards Islands (Slaney, 1975). In the nearshore of the Barrier Islands, a single catch was recorded at Hooper Island. During the same period, Percy et al (1974) noted inconnu catches at Pelly and Garry Islands and along the shoreline of Kendall Island. In 1975, inconnu were collected on both the leeward and seaward sides of Pullen Island and at two artificial island sites (Stations 62 and 72) located within the influence of the Mackenzie River outflow (Map 7.5). Although this species occasionally appears along the outer fringes of the Barrier Islands, inconnu appear to remain within close proximity of the coastal reaches and in the large bays and lagoons which occur along Richards Island.

Young-of-the-Year

Inconnu young-of-the-year were not collected at any station sampled in the study area. Sampling conducted by Percy et al (1974) in the outer Mackenzie Delta produced only one inconnu fry.

7.6.2.4 Burbot

Burbot were found throughout the nearshore and inshore freshwater areas of East Mackenzie Bay (Map 7.7). This species was collected at one inshore estuarine location (Station 8) during the 1974 field sampling. Burbot were absent from catches reported by Percy (1975) along the NE coast of Richards Island where salinities greater than 5 $^{o}/oo$ were recorded. Galbraith and Fraser (1974) collected burbot by gillnet at Tibjak Point on Tuktoyaktuk Peninsula, and by bottom trawl at stations located off that point. Salinity was recorded as less than 1 $^{o}/oo$.

Young-of-the-Year

In the two years of sampling conducted in East Mackenzie Bay, only seven juvenile burbot (ranging 44 to 71 mm in length) were collected. All were captured in the vicinity of Garry Island. It is not known if any of the specimens were young-of-the year. Those in the lower size class, however, may represent fry.

7.6.2.5 Fourhorn Sculpin

Fourhorn sculpin were common throughout the estuarine waters of the study area and in those inshore freshwater areas subject to intrusions of saline Beaufort Sea water (Map 7.6). Sculpins were absent from catches made at stations located in the freshwater outflow of the Mackenzie River. Galbraith and Fraser (1974) and Percy (1975) found fourhorn sculpin widely distributed along the NE coastline of Richards Island. In the Kugmallit Bay region, fourhorn sculpin have been taken off Tibjak Point and along nearshore areas of Tuktoyaktuk Peninsula.

Young-of-the-Year

Fourhorn sculpin young-of-the-year were collected by beach seine in the nearshore of Garry Island, Pelly Island and Pullen Island. Infrequent catches were made at some inshore stations (Stations 2, 6 and 11) by bottom trawl. Percy (1975) found fry near the outlet of Mallik Bay and on the seaward side of Pelly Island.

7.6.2.6 Boreal Smelt

The most widespread species collected along the outer Mackenzie Delta was the boreal smelt (Map 7.6). This species has been taken at every station sampled during both years of study in East Mackenzie Bay, and at most stations sampled by Percy et al (1974) along the coastline of Richards Island. Galbraith and Fraser (1974) found boreal smelt throughout Kugmallit Bay, except in regions of high salinity at Drift Point and Atkinson Point.

Young-of-the-Year

Boreal smelt young-of-the-year were collected throughout the nearshore Barrier Islands, and were infrequently taken by bottom trawl in the inshore waters of the study area.

7.6.2.7 Saffron Cod

The distribution of saffron cod in the study area appears to be limited to the inshore estuarine waters and along the outer edge of the inshore freshwater areas (Map 7.7). This species has been infrequently taken as far south as the lower tip of Pelly Island, near Harry Channel and in Mallik Bay (Slaney, 1974a). Saffron cod were taken in Mason Bay during the 1975 nearshore sampling, and were reported by Galbraith and Fraser (1975) to be distributed along the southern Beaufort Sea.

Young-of-the-Year

Despite considerable trawling effort conducted in East Mackenzie Bay during the 1974 and 1975 studies and sampling by Galbraith and Fraser (1974) in Kugmallit Bay, no saffron cod young-of-the-year have been collected.

Saffron cod fry were also absent from all beach seining catches in the nearshore of the Barrier Islands. Percy (1975) reports negative catch results along the coast of Richards Island.

7.6.2.8 Arctic Cod

Arctic cod, all of which were young-of-the-year, were taken for the first time in the study area at Station 2 (Map 7.5). Arctic cod fry were frequently collected by Galbraith and Fraser (1974) in bottom trawls off Tibjak Point in Kugmallit Bay, and adults were taken by onshore gillnets. None have been collected in the inshore waters of the Delta.

7.6.2.9 Arctic Flounder

Arctic flounder were distributed primarily along nearshore Barrier Islands and in the inshore estuarine waters (Map 7.7). This species has been collected in the large saline bays of Richards Island (Percy, 1975) and along the western coastline of the Tuktoyaktuk Peninsula (Galbraith and Fraser, 1974).

Young-of-the-Year

Although arctic flounder were commonly collected in the brackish water regions of the study area, no young-of-the-year were collected in either East Mackenzie Bay or Mason Bay. Galbraith and Fraser (1974) and Percy (1975) did not report catches of arctic flounder fry in Kugmallit Bay.

7.6.2.10 Pacific Herring

Pacific herring were only rarely found in East Mackenzie Bay during the two years of study (Map 7.5). In 1975, a single catch was made at Station 12. This species was commonly collected in the lagoons and embayments along the NE coast of Richards Island (Percy, 1975) and were taken by gillnet in Mason Bay (Stations 67 and 68). Percy (1975) caught pacific herring under ice in Mallik Bay in March, 1975. In Kugmallit Bay, Galbraith and Fraser (1974) reported pacific herring at most inshore stations sampled, but they were absent from nearshore seining stations along the Tuktoyaktuk Peninsula.

Young-of-the-Year

Young-of-the-year (fry) were not collected in the study area. Percy (1975) was also unsuccessful in collecting age 0 fish in the nearshore reaches of Richards Island. Young larvae, presumably young-of-the-year, have been reported along the Tuktoyaktuk Peninsula (Hunter, 1974; and Galbraith and Fraser, 1974).

7.6.2.11 Other Species

Sand lance were collected for the first time in the study area by bottom trawl at Station 2. Sand lance have also been identified in the vicinity of Herschel Island (McAllister, 1962).

7.7 RELATIVE ABUNDANCE OF FISH IN THE STUDY AREA

During the 1975 field sampling program, a total of 2,169 fish were collected in the study area by beach seine, gillnet and trawl (Appendices 7.2, 7.3, and 7.4). Of the total fish caught, least cisco (N=797), boreal smelt (N=349), arctic cisco (N=282) and four-horn sculpin (N=231) were the most abundant and comprised 76 percent of the total catch. In 1974, these four species accounted for 81 percent of the total catch (Slaney, 1975).

The relative abundance of fish taken by all methods of capture are discussed in terms of the catch per unit of effort (numbers of fish caught per standard net length) and percent composition of fish taken in the inshore and nearshore areas sampled.

7.7.1 Catch Per Unit of Effort Comparisons

A comparison of the gillnet catch results expressed in terms of catch per unit of effort at inshore freshwater, inshore estuarine and nearshore stations sampled in the study area are presented (Table 7.2). Data from both years of study and only nets of standard length (76.2 m) are compared.

Within the study area, fish appeared to concentrate in the nearshore areas of the Barrier Islands. The greatest percentage of fish taken were collected in a very narrow band of intertidal and shallow subtidal waters along shorelines of spits. At two stations located on Pullen Island (Stations 39 and 64), gillnets placed on the leeward and seaward sides of Pullen spit caught a mean of 37.6 fish per hour soaked. An additional gillnet placed at the abandoned island site, Pullen E-17 (Station 65), located approximately 100 m from Station 64, caught 5.2 fish per hour soaked. Although only two gillnets were placed in the nearshore of Pullen Island, the numbers of fish collected at those stations are considered representative of fish abundance along the shorelines of Hooper Island and the northern tip of Pelly Island. Beach seining results for stations sampled on Hooper Island and Pullen Island are also suggestive of the high numbers of fish encountered in this region of the study area (Appendix 7.2).

The low gillnet catch at the abandoned artificial island of Pullen E-17, however, represented the highest for all inshore stations sampled. In 1974 a gillnet placed between Pullen Island and North Head caught only four fish. Soak time was not recorded for that set.

TABLE 7.2

COMPARISONS OF GILLNET CATCH PER UNIT OF EFFORT (CPUE)*
AMONG INSHORE AND NEARSHORE STATIONS
SAMPLED IN EAST MACKENZIE BAY

Station	Date	Soak Time (Hrs)	Numbers Fish Caught	CPUE
NEARSHORE BARRIER ISLANDS				
39	July 11, 1975	10.0	228	22.8
64	July 11, 1975	7.0	367	52.4
			Mean CPUE = 37.6 fish per hour	
INSHORE FRESHWATER (<3m in depth)				
16	Sept. 6, 1974	7.0	3	0.4
16	Sept. 7, 1974	15.0	2	0.1
16	July 12, 1975	14.5	11	0.8
21	Aug. 4, 1974	3.0	4	0.8
22	Aug. 4, 1974	4.0	0	0.0
22	Aug. 7, 1974	7.5	19	2.5
62	July 27, 1975	13.0	3	0.2
62	Aug. 5, 1975	16.5	14	0.8
63	July 27, 1975	12.0	5	0.4
62	Aug. 13, 1975	3.0	1	0.3
71	Aug. 19, 1975	20.0	9	0.4
72	Aug. 19, 1975	20.0	8	0.4
65	July 11, 1975	11.0	57	5.2
			Mean CPUE = 0.95 fish per hour	
INSHORE ESTUARINE (>3m in depth)				
8	Aug. 6, 1974	23.5	24	1.0
12	July 31, 1975	29.0	22	0.8
12	July 12, 1975	25.5	18	1.4
61	July 12, 1975	14.0	16	1.1
			Mean CPUE = 1.08 fish per hour	

*CPUE = catch per unit of effort (numbers of fish caught per standard net length per hour).

The catch per unit of effort for gillnets placed in the inshore freshwater and inshore estuarine areas sampled indicate that the numbers of fish which occur in these waters are low in comparison to those which are found in the nearshore reaches.

At three inshore estuarine stations sampled in 1974 and 1975, a mean catch per unit effort for four gillnets was 1.08 fish caught per hour soaked. Using identical gillnets, inshore freshwater stations sampled in 1974 and 1975 produced only 0.95 fish per hour soaked. Low to nil bottom trawl catches in the inshore waters during both years of study further suggests that the overall abundance of fish in the inshore waters of the study area is low (Appendix 7.4).

The abundance of fish which occur in the deeper marine waters north of the Barrier Islands is virtually unknown. There is, however, evidence that larval forms of marine fish may be found in abundance. In a single bottom trawl taken at Station 2 in Kugmallit Bay, 106 sand lance and 92 arctic cod young-of-the-year were collected. This sample represented 79 percent of the entire July trawl catch. In eastern Kugmallit Bay, Galbraith and Fraser (1974) also found arctic cod young-of-the-year in great numbers. In a single trawl off Tibjak Point, 1,468 arctic cod young-of-the-year were collected.

Gillnets were placed in Mason Bay to provide a basis for comparing the numbers of fish which are typically collected by gillnet in East Mackenzie Bay to those which may be taken in a productive estuary along the NE coastline of Richards Island. The mean catch per unit of effort for two surface nets placed in the open waters at Stations 67 and 68 was 18.6 fish per hour soaked. Fish numbers were also high along the shoreline of Mason Bay where 20.6 fish were caught per seine haul at Station 66. These catches were comparable to the numbers which were commonly found in the nearshore reaches of the Barrier Islands in East Mackenzie Bay. Percy et al (1974) encountered large populations of fish residing in Mason Bay throughout the summer period.

7.7.2 Percent Composition of Catch

The percent composition (Figures 7.1 and 7.2) and length frequencies (Figures 7.3, 7.4, 7.5 and 7.6) of the four most abundant fish species taken at stations sampled within the study area demonstrate the marked differences in abundance among species.

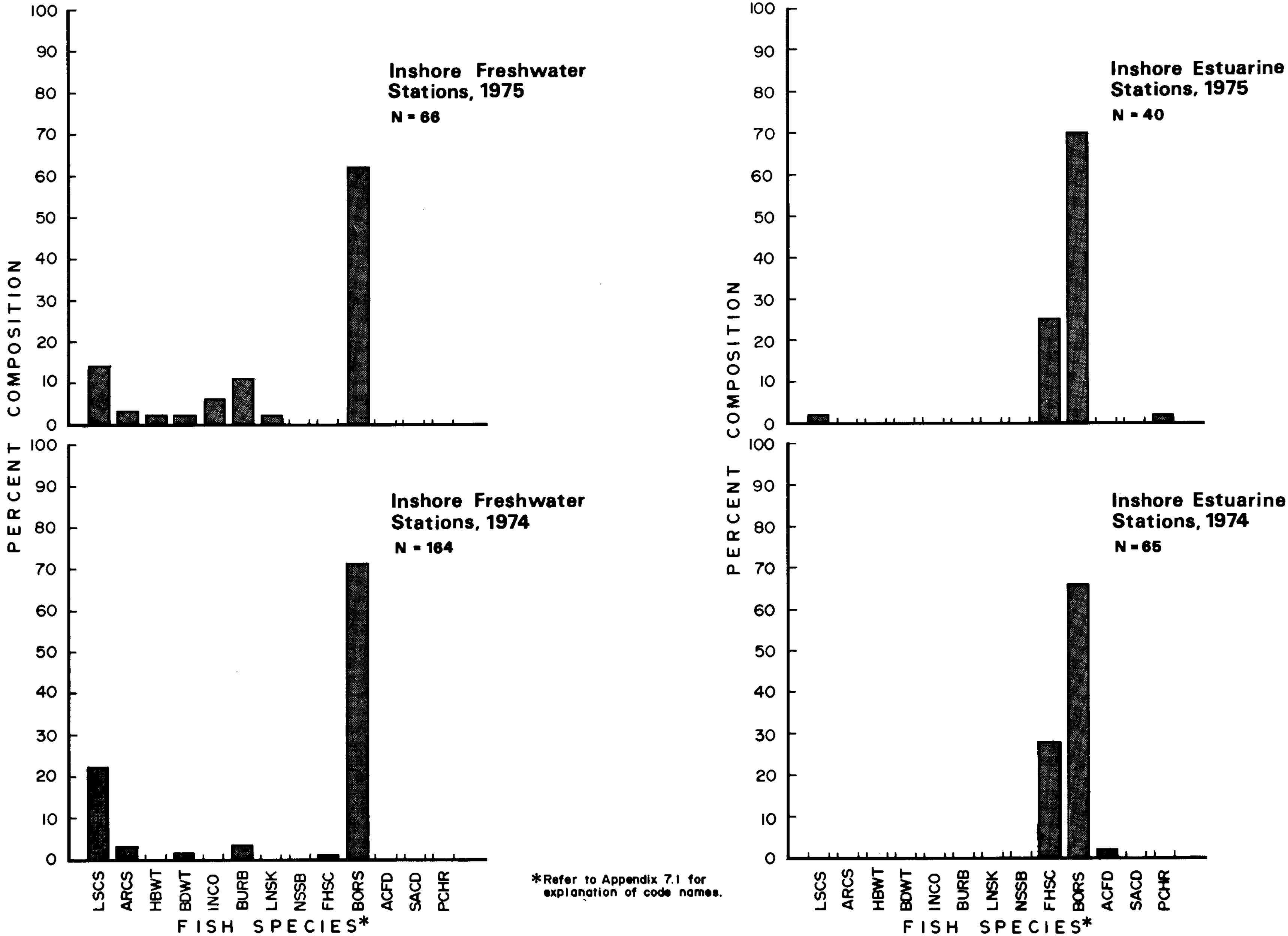
In the inshore freshwater and inshore estuarine waters, boreal smelt was the most abundant species collected and comprised 62 and 70 percent, respectively, of the gillnet catch (Figures 7.1 and 7.3). Fourhorn sculpin, although relatively common in the inshore estuarine areas (25 percent of the gillnet catch), were not collected at the inshore freshwater stations by gillnet (Figures 7.1 and 7.4). Trawl results of 1974 also indicated low densities of fourhorn sculpin in these areas, representing less than two percent of the trawl catch.

In the inshore freshwater areas, least cisco were taken in considerably fewer numbers than found in the nearshore reaches (Figure 7.5). Least cisco accounted for 14 percent of the gillnet catch in the inshore freshwater areas sampled as compared to 42 percent in the nearshore reaches (Figure 7.1).

The percent composition of fish collected by gillnet at the inshore sampling stations was compared for both study years by chi-square analysis. No significant difference could be demonstrated between the 1974 and 1975 inshore freshwater (x^2 = 27.27, P = 0.05) and inshore estuarine (x^2 = 5.20, P = 0.05) catch compositions.

FIGURE 7.1

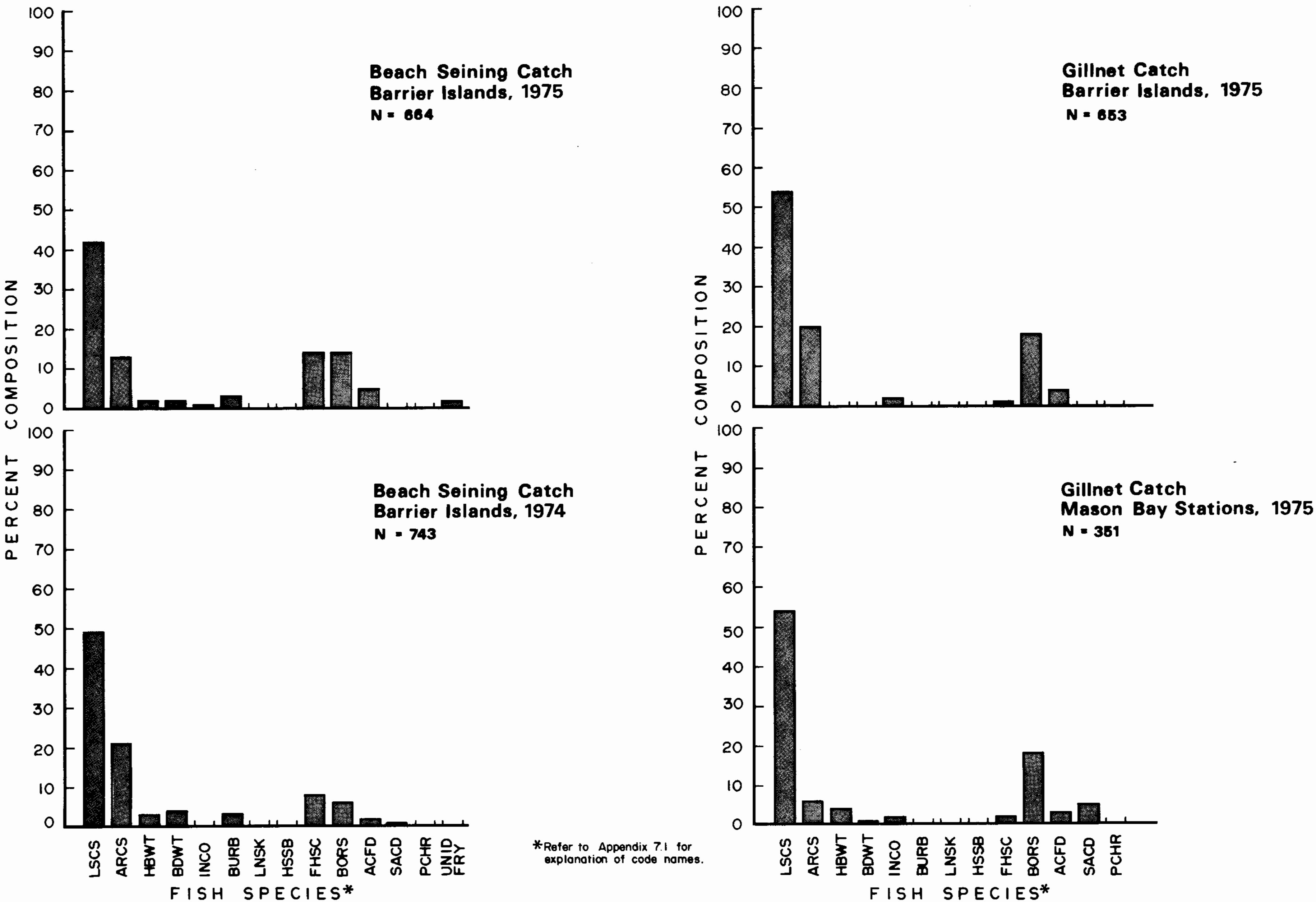
Comparison of 1974 and 1975 Gillnet Catch Composition in East Mackenzie Bay



*Refer to Appendix 7.1 for explanation of code names.

FIGURE 7.2

Comparison of 1974 and 1975 Catch Composition at Nearshore Barrier Islands and Mason Bay Stations



*Refer to Appendix 7.1 for explanation of code names.

FIGURE 7.3

Length – Frequency Comparisons of Boreal Smelt Taken by Gillnet and Seine in East Mackenzie Bay and Mason Bay, 1975

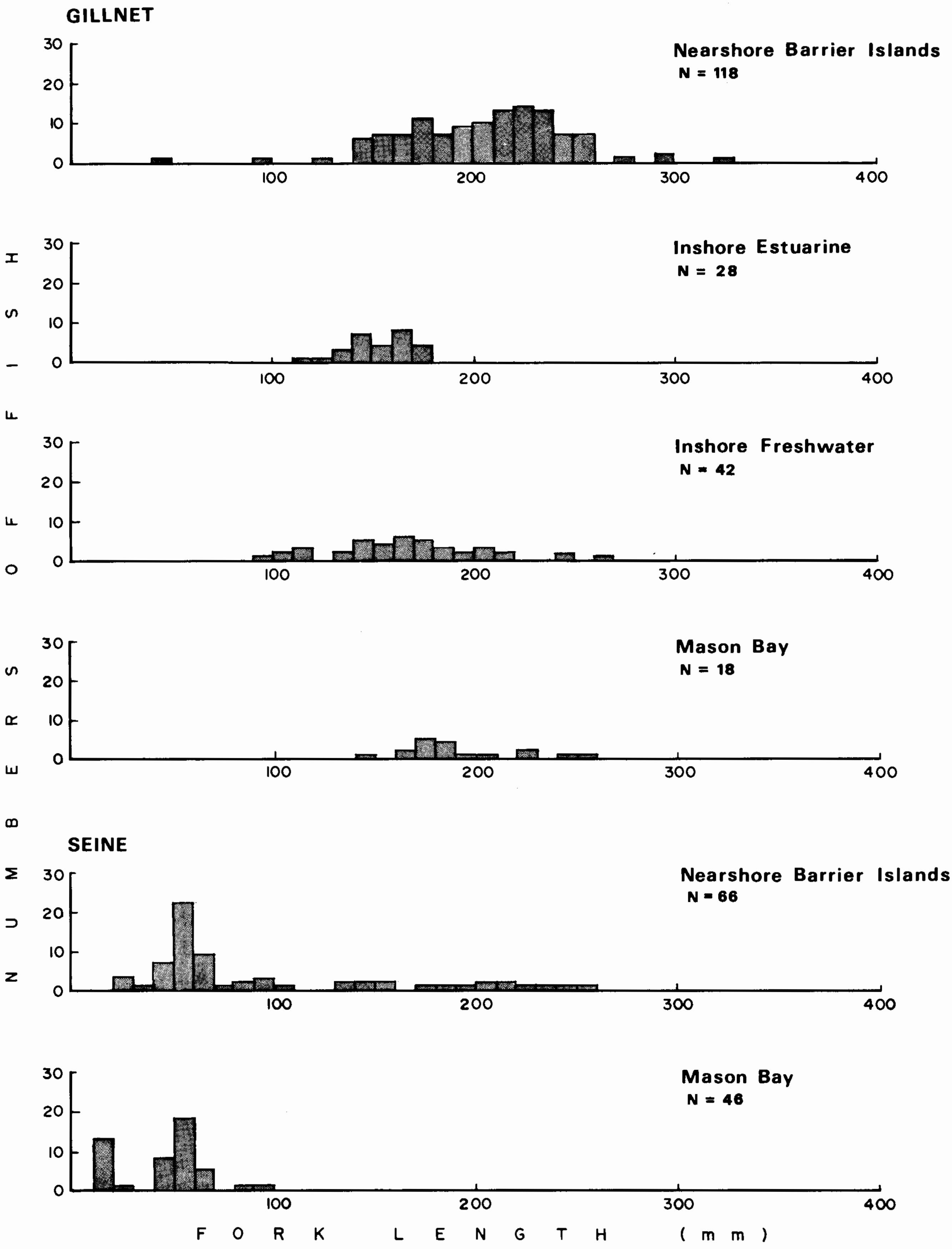


FIGURE 7.4

Length - Frequency Comparisons of Fourhorn Sculpin Taken by Gillnet and Seine in East Mackenzie Bay and Mason Bay, 1975

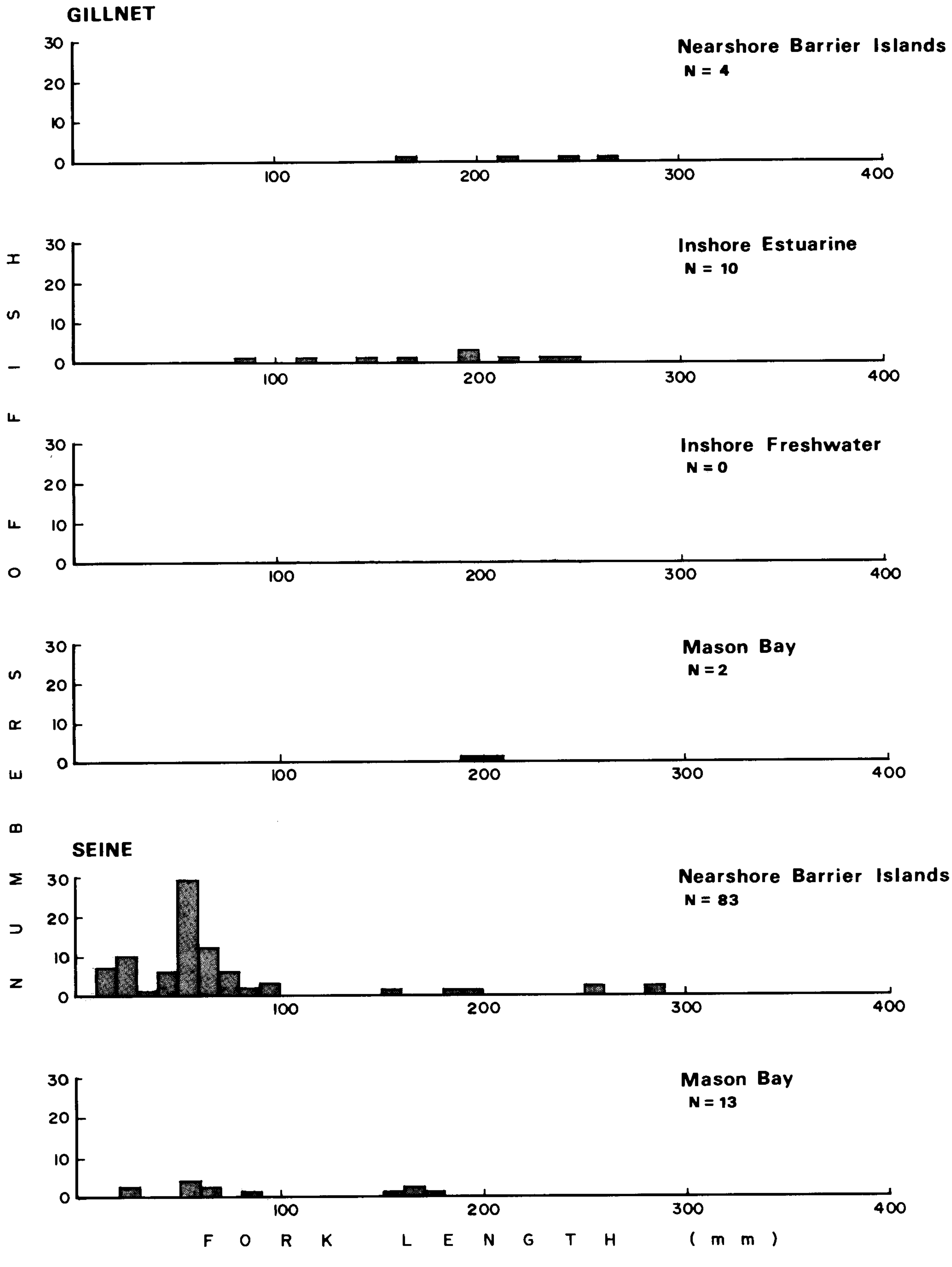


FIGURE 7.5

Length - Frequency Comparisons of Least Cisco Taken by Gillnet and Seine in East Mackenzie Bay and Mason Bay, 1975

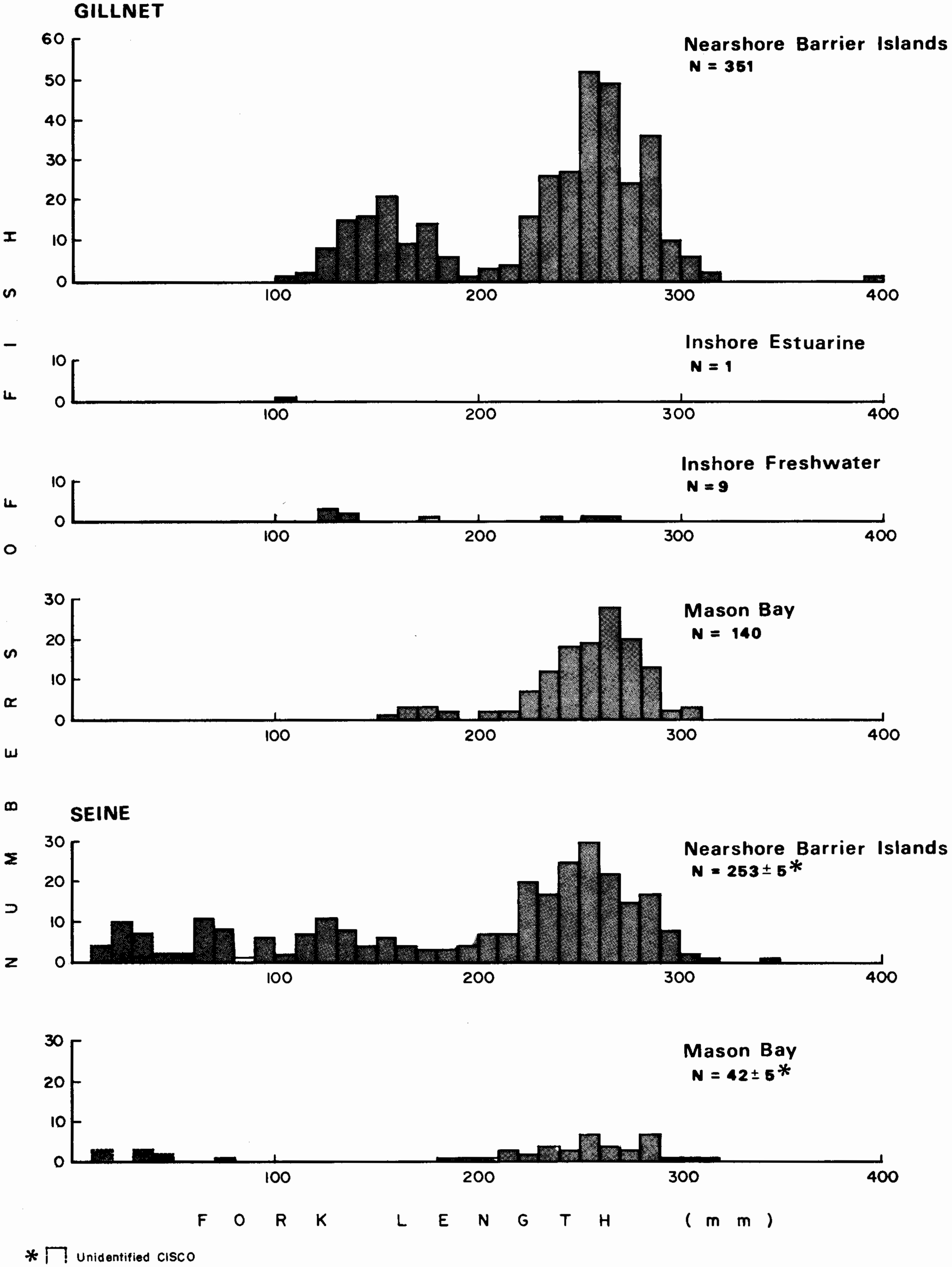
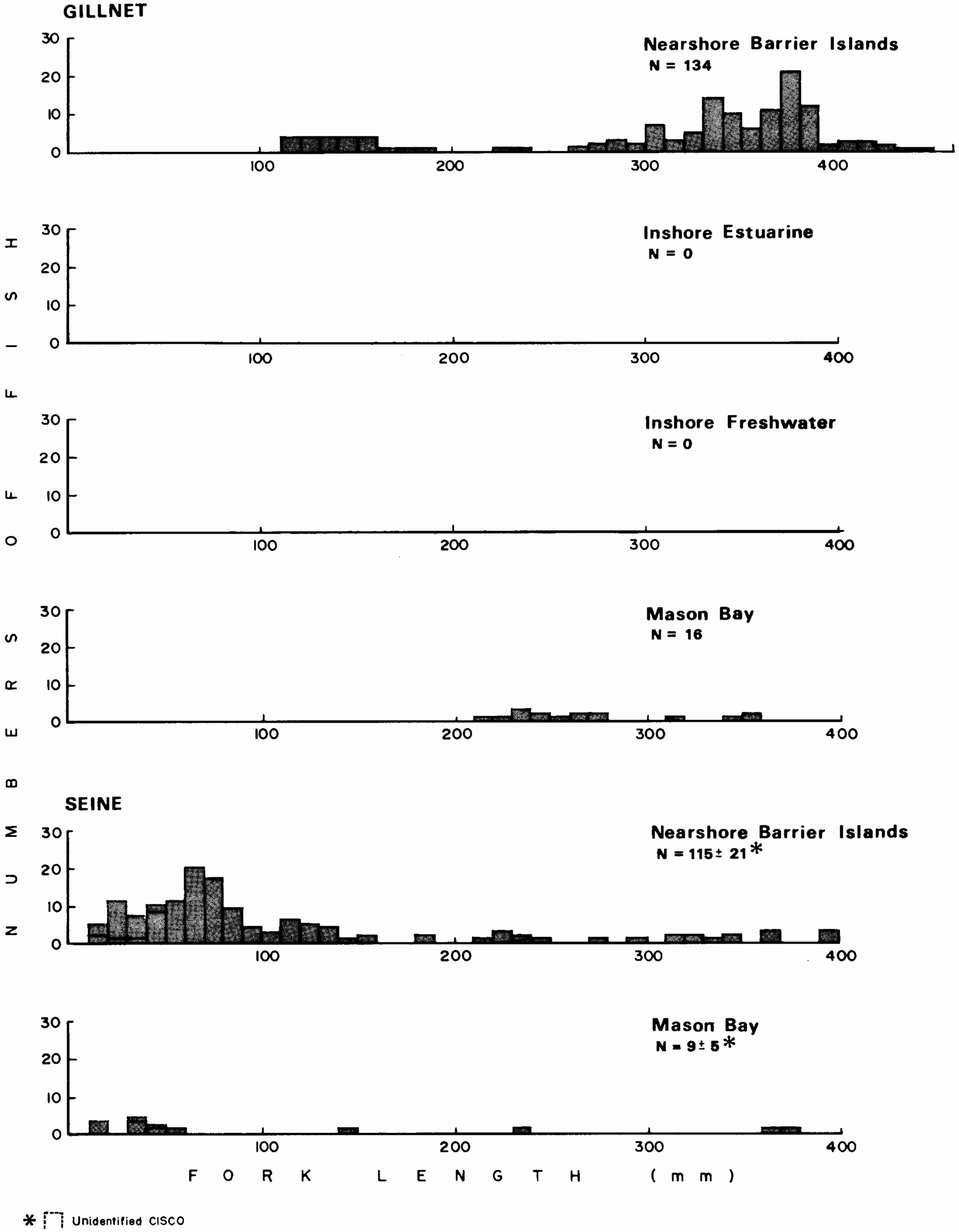


FIGURE 7.6

Length – Frequency Comparisons of Arctic Cisco Taken by Gillnet and Seine in East Mackenzie Bay and Mason Bay, 1975



Although no significant difference could be demonstrated between the 1974 and 1975 gillnet catch compositions in the inshore estuarine areas, trawl catches in Kugmallit Bay indicate considerable variability in abundance and species occurrence of post-larval forms in the estuarine and offshore marine waters.

Least cisco, arctic cisco, fourhorn sculpin and boreal smelt were the most abundant species collected in the nearshore reaches of the Barrier Islands and Mason Bay (Figure 7.2). These species accounted for 83 percent of the beach seining catch and 93 percent of the nearshore gillnet catch. In 1974, these species made up 84 percent of the beach seining catch. Gillnets were not set in the nearshore of the islands during the 1974 studies.

The percent composition of the 1975 beach seining catch was compared to the 1974 catch data using chi-square analysis. The ratio of fish collected in both years of study was not significantly different (x^2 = 13,43, p = 0.05).

Least cisco was the most common fish collected in shallow waters along island shorelines and were taken in large numbers. Least cisco accounted for 49 and 42 percent of the beach seining catches in 1974 and 1975, respectively. Gillnet results indicate similar levels of abundance, as 54 percent of the nearshore gillnet catch was comprised of least cisco. The greatest percentage of the least cisco taken in the nearshore were juveniles greater than two years of age, or adults. Of the least cisco collected by seine, only 19 percent were juveniles less than two years of age.

Arctic cisco comprised 13 and 21 percent of the beach seining catches in 1974 and 1975, respectively (Figure 7.1). Of those taken, 76 percent were juveniles less than two years of age. Similarly, boreal smelt juveniles less than two years of age, comprised the greatest portion (76 percent) of the nearshore smelt catches.

7.8 UTILIZATION OF HABITAT BY FISH IN THE STUDY AREA

The following sections of this report discuss the utilization of the coastal waters of the study area by fish populations as spawning, rearing, feeding and wintering areas. Since detailed analyses of some of the life history data compiled during the 1975 field program was not possible within the scope of this report, the following discussions are based on life history data presented in Slaney (1975), selected 1975 data and literature review.

Many fish species which are commonly found in the study area do not complete their life cycles in the coastal estuarine waters, but are freshwater fish which are living at the extremes of their salinity tolerance ranges or are anadromous fish which spend variable amounts of time in the marine environment but return to freshwater to spawn. In order to provide an understanding of the life cycles of these fish, a summary of the available information identifying spawning, rearing, feeding and wintering areas outside of the coastal waters is provided (Table 7.3).

7.8.1 Spawning Timing and Location

Life history data compiled on fish collected in the study area suggest that none of the species taken utilize the coastal waters as spawning grounds during the ice-free period. During this period no mature spawners in ripe condition of any species were collected.

Craig and McCart (1975) suggest that most of the arctic cisco inhabiting the nearshore coastal waters between the Colville and Mackenzie Rivers are either immature fish which have never spawned

TABLE 7.3

UTILIZATION OF THE COASTAL WATERS BY FISH SPECIES COMMONLY TAKEN ALONG THE MACKENZIE DELTA

Species Classification	Approximate Spawning Period: Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Location	Nursery Areas	Feeding Areas	Wintering Areas
ANADROMOUS SPECIES																
Arctic cisco					■	■	■						Tributaries of the Mackenzie River including the Arctic Red, Peel, and Great Bear Rivers are suspected spawning areas (Stein et al, 1973).	Embayments, lagoons, and shallow nearshore waters along the coastline of the outer Mackenzie Delta and Barrier Islands.	Nearshore reaches of the outer Mackenzie Delta,and along the Alaska-Yukon Beaufort Sea coastline (Craig and Mann, 1974).	Arctic cisco are suspected to winter in the deep brackish water areas along the outer Mackenzie Delta. Wintering fish have been collected in Mallik Bay (Percy, 1975) and along the northern Yukon coastline at Shingle Pt. (Kendal et al, 1974).
Boreal smelt	■	■											The Arctic Red River is a suspected spawning area (Stein et al, 1973).	Shallow nearshore and inshore coastal waters along the Mackenzie Delta and Beaufort Sea coastline.	Widespread throughout the brackish and freshwater regions of the outer Mackenzie Delta, and Beaufort Sea coastline.	Deep water regions beyond the Barrier Islands, Kugmallit Bay and waters along the Beaufort Sea coastline.
Least cisco						■	■						Spawning may take place in some delta lakes (Mann, 1975), Peel Channel, Husky Channel, Red River, and in the Mackenzie River near Arctic Red River (Stein et al, 1973).	Lower delta streams and lakes and along the shallow nearshore coastal waters of the outer Mackenzie Delta.	Shallow nearshore coastal waters of the outer Mackenzie Delta including the Barrier Islands, and freshwater lakes and streams in the lower Delta.	Wintering least cisco have been taken in Delta lakes and channels (Mann, 1975; Jessop and Lilley, 1975), Mallik Bay and Kugmallit Bay (Percy, 1975).
MARINE SPECIES																
Arctic cod									■	■	■		Unknown, likely the offshore marine waters of the Beaufort Sea.	Inshore waters of Kugmallit Bay and the Beaufort Sea.	Unknown, likely the deeper offshore marine waters of the Beaufort Sea.	Unknown, likely the deeper offshore marine waters of the Beaufort Sea.
Arctic flounder	■										■	■	Unknown, spawning likely takes place in the inshore brackish and offshore marine waters of Mackenzie Bay.	Brackish coastal waters of the Outer Mackenzie Delta.	Brackish waters along the northeast coastline of Richards Island, Mallik Bay (Percy, 1975) and the Barrier Islands.	Likely throughout the inshore and offshore marine waters of East Mackenzie Bay, and Kugmallit Bay, and the deepwater embayments of Richards Island. Arctic flounder have been taken under ice in Mallik Bay (Percy, 1975).
Fourhorn sculpin										■	■	■	Likely widespread over winter range; ripe and spent fish were collected under ice cover in Mallik Bay (Percy, 1975).	Nearshore brackish water of the outer Mackenzie Delta, Barrier Islands, and along the Beaufort Sea coastline.	Widespread throughout the brackish water regions of the outer Mackenzie Delta, and Beaufort Sea coastline.	Deep water embayments and inshore marine waters along the outer Mackenzie Delta and Beaufort Sea coastline. Wintering sculpins were taken in Mallik and Mason Bays (Percy, 1975), and at Shingle Pt. (Kendal et al, 1974).
Pacific herring		■	■										Unknown. Along Tuktoyaktuk Peninsula Pacific herring are reported to spawn in spring in shallow brackish water bays and at river mouths (Riske, 1960).	Young-of-the-year have not been taken in the inshore and nearshore coastal waters of the Mackenzie Delta, but are reported to have been found along the Tuktoyaktuk Penninsula (Hunter, 1975).	Brackish water bays and lagoons along the northeast coastline of Richards Island. Principal feeding area is likely the offshore marine waters of the Beaufort Sea.	Pacific herring are suspected to congregate during winter in the vicinity of spawning grounds nearshore (Riske, 1960). Herring have been taken under ice in Mallik Bay (Percy, 1975).
Saffron cod									■	■	■		Unknown, likely the offshore marine waters of the Beaufort Sea.	Unknown, young-of-the-year have not been collected in the inshore or nearshore coastal reaches of the Mackenzie Delta.	Limited utilization of nearshore brackish waters along the Barrier Islands and Richards Island.	The offshore marine waters of the Beaufort Sea likely serve as wintering areas.
FRESHWATER SPECIES																
Broad whitefish					■	■							Broad whitefish are suspected to spawn within the vicinity of the mouth of the Arctic Red River and near Horseshoe Bend on the Main Channel (Jessop et al, 1974).	Whitefish (unidentified to species) young-of-the-year utilize delta lakes (Percy, 1975), lagoons and shallow nearshore coastal waters of the Mackenzie Delta and Barrier Islands as nursery areas.	Lakes and channels of the outer Mackenzie Delta (Percy, 1975). In the coastal areas adult broad whitefish remain within close proximity to river and channel mouths.	Freshwater lakes and channels in the lower and upper Mackenzie Delta (Mann, 1975; Jessop and Lilley, 1975).
Humpback whitefish					■	■							Spawning is suspected to take place within the vicinity of the Arctic Red River (Stein et al, 1973).	Same as above.	Lakes and channels of the outer Mackenzie Delta (Percy, 1975). Like broad whitefish, adults of this species remains within close proximity to river and channel mouths.	Lakes and channels in the lower Mackenzie Delta (Mann, 1975).
Inconnu						■	■						Spawning is suspected to occur in tributaries of the Peel and Arctic Red River (Stein at al, 1973).	The coastal waters of the outer Mackenzie Delta do not serve as nursery area for this specie.	Coastal shoreline within close proximity to river and channel mouths. Principally lake and channels of the lower Delta and Mallik and Mason Bays (Percy, 1975).	Inconnu have been taken in lakes and channels (Mann, 1975) in the lower Mackenzie Delta, and at Mallik Bay under ice (Percy, 1975).

before, or mature non-spawners in the interval between spawning years. This situation appears to exist with arctic cisco in the outer Mackenzie Delta. Egg diameters of mature arctic cisco taken in East Mackenzie Bay ranged from 0.5 to 1.5 mm. Only seven specimens had eggs greater than 1.0 mm in diameter. Based on an estimated egg size of greater than 1.7 mm in diameter at the time of spawning (Craig and McCart, 1975), it is likely that only a small portion of the arctic cisco found in the study throughout the open water period are fish which would spawn during the coming spawning season.

Populations of least cisco residing in the nearshore coastal waters were also dominated by immature fish and mature non-spawners. Egg size of mature least cisco taken in the study area ranged from 0.5 to 1.4 mm. Ripe least cisco taken just prior to freeze-up in Harry Channel on September 27 ranged from 1.1 to 1.6 mm (average 1.3 mm) in diameter (L. Martin, unpublished data, 1975). It is highly probable that least cisco from the coastal water with egg diameters 1.0 mm and greater would have gained sufficient development within the summer period to spawn in the coming season.

Potential spawners from freshwater and anadromous fish populations which inhabit the coastal waters during summer migrate from the coastal areas to spawning grounds located in tributaries of the Mackenzie River or lake and stream systems in the Delta region. Although little is known of the spawning habits of the marine species which occur in the study area, all are suspected to spawn under ice cover during winter. Winter spawning areas for some marine fish populations likely include the deeper, inshore estuarine waters that do not freeze during winter and the deep-water embayments such as Mallik and Mason Bay on Richards Island.

Winter fisheries surveys conducted by Percy (1975) collected ripe and spawned-out fourhorn sculpin under ice in Mallik Bay in March, 1975. Pacific herring also taken during that survey were sexually developed but had not spawned at that time. Herring are reported to spawn in spring in shallow brackish water bays and at river mouths (Riske, 1960). Although access to coastal inshore waters from Mallik Bay appears possible through under ice channels (Slaney, 1974d), it is likely that pacific herring populations found in March remain there to spawn.

7.8.2 Nursery Areas

The nearshore coastal waters of the outer Mackenzie Delta serve as an important nursery area for young-of-the-year and juvenile fish. Within the study area, the shallow nearshore waters of the Barrier Islands are utilized extensively by young-of-the-year and small juveniles of arctic cisco, least cisco, boreal smelt and, along the outer islands, fourhorn sculpin. Whitefish young-of-the-year were taken in large numbers in protected, shallow lagoons on Garry Island, but were not abundant throughout the rest of the study area.

Percy et al (1974) found large populations of whitefish and cisco young-of-the-year along the NE shore of Richards Island and in the Mallik Bay area. Of the total young-of-the-year collected throughout the lower Delta, including lake and channel studies, 61 percent of the young-of-the-year collected by Percy et al (1974) were taken in the coastal area.

Cisco and whitefish young-of-the-year have been taken at Garry Island as early as July 8, and were found throughout the open water period. Key migratory periods for young-of-the-year which were spawned in freshwater but migrate to the coastal waters are not well known.

Studies conducted on Harry Channel (Slaney, 1976) indicated coregonid (whitefish and cisco) young-of-the-year catches were low to nil following break-up, then peaked in July and dropped again in August. Fry were not collected in September.

7.8.3 Feeding

The nearshore coastal waters of the outer Mackenzie Delta provide anadromous and marine fish populations with an opportunity to exploit the productive nature of an estuarine system. Estuaries act as nutrient sinks and are typically richer with a higher annual production of organic matter than the sea or freshwater drainages on either side (Odum, 1970).

Situated along the outer extremes of the inshore freshwater zone, the Barrier Islands form an important protective feeding area for juveniles and adults of anadromous arctic cisco, least cisco, and boreal smelt. Food items identified in the stomach content of these species were dominated by the Amphipoda orders Crustacea and Cumacea (Table 7.4).

Marine fish populations of fourhorn sculpin, saffron cod and arctic flounder tended to avoid the inshore freshwater zone and remained in areas subject to frequent intrusions of marine water. The diets of these species consisted principly of organisms in the orders Isopoda, Amphipoda and Mysidacea-Euphauscacea.

7.8.4 Wintering Areas

During winter, many of the shallow water areas within East Mackenzie Bay freeze solid to the bottom (Slaney, 1974c; 1974d), forcing summer resident fish populations to emigrate to areas where water depths are sufficient to maintain oxygen levels throughout the winter period.

Anadromous and marine species which inhabit the nearshore areas of the Barrier Islands likely move further offshore into the deeper, more saline waters of the study area. In the only winter fishery investigations conducted to date along the coastal reaches of East Mackenzie Bay and Richards Island, Percy (1975) reported significant wintering populations of fish were collected under ice cover in Mallik and Mason Bays on Richards Island.

7.9 POSSIBLE ENVIRONMENTAL EFFECTS

The following sections of the report discuss the possible environmental effects arising from artificial island construction and their implications to existing fisheries resources.

7.9.1 Effects of Artificial Island Construction

Construction of artificial islands for use as exploratory drilling pads involves a number of activities, some of which have the potential for creating varying degrees of environmental perturbations which can affect fish populations. The most apparent forms of environmental disturbance associated with artificial island construction which may directly or indirectly affect fish are:

1. Excessive turbidity and siltation resulting from removal of borrow material from submarine sources by suction and/or clamshell dredges, or by mixing of surface sediments by boat prop wash in shallow waters;

2. Habitat degradation as a result of concentrated construction activity near or in the vicinity of artificial islands;

3. Localized reduction of fish food organisms caused by smothering from island fill or excessive siltation at dredge sites;

TABLE 7.4

FREQUENCY OF OCCURRENCE OF FOOD ITEMS IN STOMACH CONTENT OF FISH COLLECTED IN EAST MACKENZIE BAY, 1972, 1974 AND 1975

	LSCS*		ARCS		FHSC		BORS		BURB		HBWF		BDWF		INCO		LNSK		PIKE		ARFD		SACO	
	NO.+	(%)++	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)	NO.	(%)
Amphipoda	22	(32)	5	(11)	26	(41)	46	(43)	16	(43)	1	(50)	-	-	-	-	-	-	-	-	3	(60)	3	(15)
Annelida	-	-	1	(2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cumacea	2	(3)	10	(18)	-	-	2	(2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	(10)
Isopoda	2	(3)	-	-	44	(52)	13	(12)	20	(54)	1	(50)	-	-	-	-	-	-	-	-	1	(20)	2	(10)
Mysidacea - Euphausiacea	6	(9)	6	(13)	11	(13)	31	(29)	11	(30)	-	-	-	-	1	(4)	-	-	-	-	1	(20)	10	(50)
Copepoda	-	-	1	(2)	-	-	-	-	1	(3)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	-	-	-	-	2	(2)	-	-	-	-	1	(50)	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified Crustacea	15	(22)	9	(20)	1	(1)	4	(4)	-	-	-	-	2	(12)	-	-	-	-	-	-	-	-	1	(5)
Plecoptera Larvae	-	-	1	(2)	-	-	-	-	-	-	-	-	-	-	2	(9)	-	-	-	-	-	-	-	-
Dipteran Larvae	2	(3)	7	(15)	4	(5)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified Insect Parts	5	(7)	5	(11)	1	(1)	1	(1)	1	(3)	-	-	5	(31)	-	-	-	-	-	-	1	(20)	-	-
Coleoptera	-	-	-	-	1	(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish	1	(1)	-	-	4	(5)	14	(13)	12	(32)	-	-	-	-	21	(91)	-	-	4	(100)	-	-	-	-
Plant Material	8	(12)	17	(40)	8	(10)	6	(6)	1	(3)	1	(50)	14	(88)	1	(4)	-	-	-	-	-	-	1	(5)
Unidentified Debris	11	(16)	5	(11)	13	(15)	9	(8)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No. of Stomachs Containing Food	68		46		84		107		37		2		16		23		0		4		5		19	
No. of Empty Stomachs	155		115		61		164		10		16		13		34		2		3		8		1	
Total Stomachs Sampled	223		161		145		271		47		18		29		57		2		7		13		20	

* See Appendix 7.1 for explanation of code names
\+ Number of times food items appeared in those stomachs which contained food
++ Percent occurrence of food items in those stomachs which contained food

4. Loss of habitat by the physical presence of islands and/or in turbidity plume created by dredging.

The detrimental effects of excessive turbitidy and siltation upon fish populations inhabiting clearwater streams in southern latitudes have been well documented. Little is known, however, of the effects of increased sediment loading on arctic fish species which are found naturally in highly turbid river systems such as the Mackenzie.

Most of the freshwater and anadromous fish populations which migrate to the coastal waters of the Mackenzie Delta during their early stages of development or adult life are subjected to high levels of natural turbidity. Turbidity levels measured during the open water period in the study area have been recorded as high as 800 ppm and ranged from 150 to 600 ppm (Slaney, 1975).

Natural turbidity levels are generally maintained at high levels throughout the open water period by frequent summer storms which generate currents wave action that mix sediments in the shallow waters. Coastal waters do not usually begin to clear until late September. Water under ice cover remains sediment-free until the onset of the spring Mackenzie River freshet in June.

The principal source of increased suspended sediments created by artificial island construction result from suction dredging for borrow material. Surface turbidities generated by an active dredge operation near Garry Island in 1974 ranged from 305 to 370 ppm (Slaney, 1975). Although such values are within natural ranges which are likely to occur during summer, sustained turbidities as high as 300 ppm at a dredge site would likely affect fish by:

1. Creating turbidity barriers which may disrupt localized fish movement causing fish to move into less turbid water and thereby concentrating fish numbers and possibly increasing intraspecific competition for food and space;

2. Smothering localized populations of benthic organisms utilized as fish food, thereby increasing predation upon other food sources.

The effects of dredging would likely have greatest consequences where turbidity plumes extend along the shorelines of the Barrier Islands. Juveniles and adults of arctic cisco and least cisco concentrate along these edges to feed. These same areas are also the principal nursery areas for cisco young-of-the-year found in East Mackenzie Bay.

However, although a minimal amount of inshore habitat at island locations is lost to the fishery as a result of island construction, it does not appear that the waters surrounding an artificial island are rendered unsuitable to fish during construction activities.

A comparison of the gillnet catch results (Table 7.5) was made between stations sampled at an artificial island site where construction activities were ongoing (Ikattok), at two sites where the islands had been completed but were still centers of heavy support activity (Immerk and Adgo C-15), and with stations located outside of known traffic lanes (approximately one quarter mile from the artificial islands) in undisturbed waters.

TABLE 7.5

COMPARISON OF THE CATCH PER UNIT OF EFFORT
AND CATCH COMPOSITION FOR GILLNETS
PLACED INSIDE AND OUTSIDE OF ACTIVE CONSTRUCTION ZONES
AT IMMERK, IKATTOK AND ADGO C-15 ARTIFICIAL ISLANDS

Stations		Date	INSIDE CONSTRUCTION ZONE – Fish Caught								OUTSIDE CONSTRUCTION ZONE – Fish Caught							
			ARCS	LSCS	BURB	LNSK	INCO	BDWT	BORS	CPU	ARCS	LSCS	BURB	LNSK	INCO	BDWT	BORS	CPU
16	(Immerk)	12 July 75		4		1			6	0.8	1						15	1.1
62	(Ikattok)	27 July 75	1		2				2	0.3			2			1	2	0.4
71	(Adgo C-15)	19 Aug. 75		2	1				6	0.4		2	3		1		2	0.4
										$\bar{x}$=0.5								$\bar{x}$=0.6

Although only three sites were sampled, it is apparent from the catch results that little difference can be demonstrated between the numbers of fish caught inside construction zones to those caught outside of construction zones in undisturbed waters. Slight differences in the catch compositions were noted, but it is suspected that repeated sampling would have resulted in nearly identical compositions. The low catch results obtained in both the disturbed and undisturbed waters are typical of those found throughout the inshore waters of the study area.

Increased suspended sediments during fish spawning periods have been shown in other studies to influence spawning success of adults and the post spawning success of egg and alevins in gravel.

Because the coastal waters along the outer Mackenzie Delta are not suspected to be utilized as spawning grounds by any of the fish populations sampled during the open water period, and that dredge operations are concluded prior to freeze-up, no interference with spawning fish is anticipated. By the time dredge operations are initiated in early summer, eggs deposited by fourhorn sculpin over winter would have hatched as larval fish. Eggs deposited by other winter spawning fish such as arctic cod, saffron cod and arctic flounder in all likelihood would have also been hatched prior to summer dredge operations.

7.9.2 Overall View of Artificial Island Construction

Based upon data collected during the 1974 and 1975 fishery investigations, it is concluded that the extent by which fish are likely affected by presented artificial island construction practices is minimal, and that they do not pose threat to the maintenance and preservation of the existing fisheries resources of East Mackenzie Bay. Artificial islands are presently being constructed with minimal loss to the existing habitat in areas where fish populations are widely dispersed. Waters surrounding artificial islands, although centers of considerable activity and ship traffic, do not appear to be avoided by fish which normally occur in the inshore waters.

Within the study area there are two major concerns which will require adequate protection planning for future development:

1. Nursery areas
2. Feeding areas

Along the nearshore of the Barrier Islands, adult arctic cisco, least cisco, fourhorn sculpin and, to a lesser extent boreal smelt, concentrate to feed. These areas are also important nursery areas for cisco juveniles and young-of-the-year. Whitefish young-of-the-year are found in the nearshore of Garry Island but infrequently throughout the rest of the study area. During 1975, dredge operations took place at Garry Island and on the seaward side of Hooper Island. Both operations occurred within close proximity to shoreline in areas of heavy fish utilization.

7.10 SUMMARY OF IMPORTANT POINTS

1. Within the coastal waters of the Mackenzie Delta, as many as 25 species of freshwater, anadromous and marine fishes have been collected.

2. Sixteen of those collected were common to the inshore and nearshore coastal waters of East Mackenzie Bay.

3. Fish diversity as well as fish abundance was greatest in the large estuarine embayments on Richards Island and along the shorelines of Barrier Islands.

4. Anadromous fish species including least cisco, arctic cisco and boreal smelt were widely distributed throughout the coastal waters.

5. Important domestic and commercial fish species such as broad whitefish, humpback whitefish and inconnu, although present in the study area, remained within close proximity to channel and river mouths, and were not frequently taken at stations sampled in the inshore waters or nearshore of the Barrier Islands.

6. Although adult whitefish were not common in the study area, young-of-the-year were frequently taken in low numbers in the nearshore of the Barrier Islands.

7. Least cisco, boreal smelt, arctic cisco and fourhorn sculpin, representing 81 percent of the total catch in 1974, were the most abundant fish collected in 1975 and accounted for 76 percent of the total catch.

8. Within the study area, fish concentrations were found along the shorelines of the Barrier Islands, particularly the northern tip of Pelly Island, Hooper Island and Pullen Island, and in Mason Bay on Richards Island.

9. Comparisons of the fish numbers taken by gillnet in the near-shore ($\bar{x}$ = 37.6 fph, N=2) to those in the inshore freshwater areas ($\bar{x}$ = 0.63 fph, N=10) or inshore estuarine areas ($\bar{x}$ = 1.06 fph, N=15) suggests that fish abundance drops markedly beyond the influence of natural island shoreline.

10. No significant difference could be demonstrated between the 1974 and 1975 gillnet catch compositions in any of the major study regions.

11. Within the nearshore reaches of the Barrier Islands, the greatest percentage (76 percent) of arctic cisco and boreal smelt collected by beach seine were less than two years of age.

12. Unlike arctic cisco and boreal smelt, only 19 percent of the nearshore beach seining catch was comprised of least cisco.

13. The lack of ripe or spent fish being collected during two years of intensive summer study along the coastal reaches of East Mackenzie Bay, strongly suggests that this region does not serve as spawning ground during the ice-free period.

14. The coastal waters of East Mackenzie Bay are important feeding and rearing areas for the anadromous species such as arctic cisco, least cisco and boreal smelt. Marine species include fourhorn sculpin and arctic flounder. Other deepwater marine species such as arctic cod, saffron cod and sandlance are taken infrequently but, at times, in large numbers in the inshore waters.

15. Further information is required before the wintering potential of the coastal waters can be assessed with some degree of certainty. At present, the only confirmed wintering area which has been identified in the vicinity of East Mackenzie Bay is Mallik Bay.

16. Based on a site-specific assessment of the existing baseline information, other than loss of habitat to artificial island location, no discernible detrimental effects have been observed to fish populations during the summer period as a result of artificial island construction.

17. Subtle effects not easily detected at the level of baseline study which may affect fish populations as a consequence of artificial island construction are:

a. Creating turbidity barriers which may disrupt localized fish movement causing fish to move into less turbid water and thereby concentrating fish numbers and possibly increasing intraspecific competition for food and space; and,

b. Smothering localized populations of benthic organisms utilized as fish food, thereby increasing predation upon other food sources.

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APPENDIX 7.1

COMMON, SCIENTIFIC AND CODE NAMES* OF FISH COLLECTED IN EAST MACKENZIE BAY, 1972, 1974, AND 1975; AND KUGMALLIT BAY, 1975

Family CATOSTOMIDAE - Suckers		
Catostomus catostomus	longnose sucker	LNSK
Family CLUPEIDAE - Herrings		
Clupea harengus pallasi[1]	herring	HERR
Family COREGONIDAE - Whitefish Ciscoes		
Stenodus leucichthys nelma	inconnu	INCO
Coregonus autumnalis	arctic cisco	ARCS
C. sardinella complex	least cisco	LSCS
C. nasus	broad whitefish	BDWF
C. clupeaformis complex	humpback whitefish	HBWF
Family COTTIDAE - Sculpins		
Myoxocephalus quadricornis quadricornis	fourhorn sculpin	FHSC
Cottus ricei	spoonhead sculpin	SHSC
Cottidae spp. - unidentified	sculpin	
Family ESOCIDAE - Pike		
Esox lucius	northern pike	PIKE
Family GADIDAE - Cods		
Lota lota	burbot	BURB
Boreogadus saida	arctic cod	ARCD
Eleginus navaga	saffron cod	SACD
Family GASTEROSTEIDAE - Sticklebacks		
Pungitius pungitius	ninespine stickleback	NSSB
Family LIPARIDAE - Snailfish		
Liparidae spp. - unidentified	snailfish	SNFH
Family OSMERIDAE - Smelt		
Osmerus eperlanus complex	boreal smelt	BORS
Family PETROMYZONIDAE - Lampreys		
Lampetra japonica	arctic lamprey	ARLM
Family PLEURONECTIDAE - Flatfish		
Liopsetta glacialis	arctic flounder	ARFD
Platichthys stellatus	starry flounder	STFD
Family SALMONIDAE - trout		
Salvelinus namaycush	lake trout	LAKT
Family STICHAEIDAE - Pricklebacks		
Leptoclinus maculatus[1]	blenney	BLEN
Family AMMODYTIDAE		
Ammodytes spp. - unidentified	sand lance	SDLC-23 sp

* As used in McPhail & Lindsay (1970), with the esception of *Clupea harengus* and *Leptoclinus maculatus*

[1] As listed in Wilimovsky (1968)

APPENDIX 7.2

BEACH SEINING RESULTS AND CALCULATED CATCH PER UNIT EFFORT AT NEARSHORE STATIONS SAMPLED IN EAST MACKENZIE BAY, KUGMALLIT BAY AND MASON BAY, 1975*

STATION	DATE	NO. OF HAULS	SEINE LENGTH (FEET)	NUMBERS OF FISH CAUGHT: LSCS	ARCS	HBWT	BDWT	INCO	BURB	LNSK	NSSB	FHSC	BORS	ACFD	SACD	PCHR	COR FRY	UNID WHIT	LOST	TOTAL	CATCH PER UNIT EFFORT
29	Jul. 8	3	100	8	1	-	1	1	-	-	-	-	20	-	-	-	-	1	-	32	10.6
29	Aug. 7	3	100	2	2	1	1	2	1	-	-	-	2	-	-	-	-	-	-	11	3.6
30	Jul. 8	3	100	15	3	-	-	-	2	-	-	-	-	-	-	-	2	6	-	28	9.3
30	Aug. 1	3	100	20	6	1	-	-	9	-	1	1	-	-	-	-	-	-	-	38	12.6
31	Aug. 1	3	100	2	-	-	-	-	-	-	-	11	2	-	-	-	-	-	-	15	5.0
31	Aug. 10	3	100	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.7
31	Aug. 12	3	100	11	4	1	1	-	-	-	-	2	2	-	-	-	-	-	-	21	7.0
32	Aug. 11	3	100	3	14	-	-	-	1	-	-	-	-	-	-	-	-	-	-	18	6.0
33	Jul. 9	3	100	14	11	-	-	-	2	-	-	6	7	-	-	-	-	-	-	40	13.3
34	Jul. 9	3	100	40	13	-	-	1	-	-	-	2	3	-	-	-	1	1	-	61	20.3
38	Jul. 12	3	100	54	7	-	-	-	-	-	-	8	1	1	-	-	-	-	5	76	25.3
39	Jul. 11	3	100	62	11	1	-	-	-	-	-	49	13	17	-	-	-	-	-	153	51.0
57	Jul. 8	1	100	6	2	2	-	-	2	-	-	-	12	-	-	-	-	-	-	26	26.0
58	Jul. 17	3	100	1	-	3	7	-	1	-	-	-	1	-	-	-	-	-	-	13	4.3
58	Aug. 12	3	100	1	3	-	2	1	-	-	-	1	-	-	-	-	-	-	-	8	2.6
59	Aug. 12	3	100	2	5	-	-	-	-	-	-	-	1	-	-	-	-	-	-	8	2.6
66	Jul. 16	3	100	30	3	4	-	1	-	-	-	9	1	11	3	-	-	-	-	62	20.6
69	Jul. 13	2	100	3	-	1	-	-	-	-	-	1	-	2	-	-	2	-	-	9	4.5
70	Jul. 14	3	100	5	4	3	-	-	4	-	-	-	29	-	-	-	-	-	-	45	15.0
TOTAL				281	89	17	12	7	22	-	1	90	94	31	3	-	6	8	5	666	
PERCENT COMPOSITION				42	13	2	2	1	3	-	-	14	14	5	-	-	1	1	-	98	

STATION	DATE	NO. OF HAULS	SEINE LENGTH (FEET)	LSCS	ARCS	HBWT	BDWT	INCO	BURB	LNSK	NSSB	FHSC	BORS	ACFD	SACD	PCHR	COR FRY	UNID WHIT	LOST	TOTAL	CATCH PER UNIT EFFORT
29	Jul. 8	1	30	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	2	
29	Aug. 7	1	30	-	2	-	-	-	-	-	-	11	2	-	-	-	-	-	-	15	
30	Jul. 8	2	30	6	14	-	-	-	-	-	-	1	-	-	-	-	16	8	-	45	
30	Aug. 11	1	30	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	2	
31	Aug. 12	1	30	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	3	
32	Aug. 11	1	30	-	12	-	-	-	1	-	-	1	-	-	-	-	-	-	-	14	
34	Jul. 9	1	30	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	
38	Jul. 12	1	30	1	2	-	-	-	-	-	-	1	-	-	-	-	-	1	-	5	
39	Jul. 11	1	30	+	-	-	-	-	-	-	-	100	-	+	-	-	-	-	-	100	
58	Jul. 17	1	30	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	3	
59	Aug. 12	1	30	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	
66	Jul. 16	1	30	4	-	-	-	-	-	-	-	3	13	-	-	-	-	-	-	20	
70	Jul. 14	1	30	-	2	-	-	-	1	-	-	-	3	-	-	-	3	-	-	9	
TOTAL				16	35	-	-	-	5	-	1	120	20	+	-	-	19	10	-	227	
PERCENT COMPOSITION				7	15	-	-	-	2	-	-	53	9	+	-	-	8	4	-	98	

* See Appendix 7.1 for explanation of code names
Catch per Unit Effort (Number of fish caught per haul per standard net length) not calculated for 30 feet seine since effort was not standardized
\+ Taken, not counted (<5)

APPENDIX 7.3

GILLNET RESULTS AND CALCULATED CATCH PER UNIT OF EFFORT AT
NEARSHORE AND INSHORE STATIONS SAMPLED IN EAST MACKENZIE BAY, KUGMALLIT BAY AND MASON BAY, 1975*

STATION	DATE	SOAK TIME	NET LENGTH (FEET)	NUMBERS OF FISH CAUGHT															CATCH PER UNIT EFFORT+
				LSCS	ARCS	HBWT	BDWT	INCO	BURB	LNSK	PIKE	FHSC	BORS	ACFD	SACD	PCHR	UNID WHIT	TOTAL	
12	Jul. 31	29	250	-	-	-	-	-	-	-	-	9	12	-	-	1	-	22	0.8
12	Jul. 12	26.5	250	1	-	-	-	-	-	-	-	1	16	-	-	-	-	18	1.4
16	Jul. 12	14.5	250	4	-	-	-	-	-	1	-	-	6	-	-	-	-	11	0.8
23	Jul. 8	13	250	-	-	3	-	4	-	-	1	-	-	-	-	-	-	8	0.6
23	Aug. 14	4	250	-	1	1	-	3	-	-	-	-	-	-	-	-	-	5	1.3
39	Jul. 11	10	250	86	45	2	-	4	-	-	-	3	66	16	-	-	6	228	22.8
61	Jul. 12	14	250	1	-	-	-	-	-	-	-	-	15	-	-	-	-	16	1.1
62	Jul. 27	13	250	-	-	1	-	2	-	-	-	-	-	-	-	-	-	3	0.2
62	Aug. 5	16.5	250	1	1	-	-	1	1	-	-	-	10	-	-	-	-	14	0.8
62	Aug. 13	3	250	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	0.3
63	Jul. 27	12	250	-	-	-	1	-	2	-	-	-	2	-	-	-	-	5	0.4
64	Jul. 11	7	250	235	75	1	-	6	-	-	-	-	39	8	-	-	3	367	52.4
65	Jul. 11	11	250	30	13	-	-	-	-	-	-	1	13	-	-	-	-	57	5.2
67	Jul. 16	7	250	43	7	10	2	6	-	-	-	2	1	41	3	2	-	117	16.7
68	Jul. 16	7	250	97	9	1	-	-	-	-	-	-	17	5	4	10	-	143	20.4
71	Aug. 19	20	250	2	-	-	-	-	1	-	-	-	6	-	-	-	-	9	0.4
72	Aug. 19	20	250	1	-	-	-	1	3	-	-	-	2	-	-	-	-	7	0.4
TOTAL				501	152	19	3	27	7	1	1	16	205	70	7	13	9	1031	
PERCENT COMPOSITION				48	15	2	-	3	1	-	-	2	20	7	1	1	1	101	

*See Appendix 7.1 for explanation of code names

+Catch per Unit of Effort (number of fish caught per hour per standard net length)

APPENDIX 7.4

OFFSHORE TRAWL RESULTS IN EAST MACKENZIE BAY AND KUGMALLIT BAY, 1975*

NUMBERS OF FISH CAUGHT

STATION	DATE	TRAWL	LSCS	ARCS	HBWT	BDWT	INCO	BURB	LNSK	NSSB	FHSC	BORS	ACFD	SACD	ARCD	PCHR	SDLC	ARLM	COR FRY	UNID FRY	TOTAL
1	Jul. 31	BT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Jul. 17	BT	-	-	-	-	-	-	-	-	3	-	-	-	106	-	92	-	-	1	202
4	Jul. 31	BT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
7	Jul. 29	BT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
11	Jul. 13	BT	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	5
11	Jul. 31	BT	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
12	Jul. 11	BT	-	-	-	-	-	-	-	-	1	7	-	-	-	-	-	-	-	-	8
12	Jul. 30	BT	-	2	-	-	-	-	-	-	-	1	-	-	-	-	-	2	-	-	5
16	Jul. 10	BT	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	4	19
16	Jul. 30	BT	1	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	6
62	Jul. 26	BT	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	1	-	3
TOTAL			1	6	-	-	-	1	-	-	4	29	-	+	106	-	92	3	3	6	251
PERCENT COMPOSITION			-	2	-	-	-	-	-	-	2	12	-	+	42	-	37	1	1	2	99

STATION	DATE	TRAWL	LSCS	ARCS	HBWT	BDWT	INCO	BURB	LNSK	NSSB	FHSC	BORS	ACFD	SACD	ARCD	PCHR	SDLC	ARLM	COR FRY	UNID FRY	TOTAL
1	Jul. 31	ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
4	Jul. 31	ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
8	Jul. 27	ES	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	3
11	Jul. 13	ES	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	+	1
12	Jul. 11	ES	-	-	-	-	-	-	-	-	1	7	-	-	-	-	-	-	-	-	8
12	Jul. 30	ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Jul. 10	ES	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	1	4
16	Jul. 30	ES	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	3
62	Jul. 26	ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL			-	-	-	-	-	1	-	-	5	12	-	-	-	-	-	-	-	3	21
PERCENT COMPOSITION			-	-	-	-	-	5	-	-	24	57	-	-	-	-	-	-	-	14	100

* See Appendix 7.1 for explanation of code names

\+ Taken, not counted

BT - Bottom Trawl

ES - Epibenthic Sled

APPENDIX 3.1

OPERATING CONDITIONS ANNEXED TO LAND-USE PERMITS FOR CONSTRUCTION OF ARTIFICIAL ISLANDS

CONTENTS:

Annex to Land Use Permit
Number N74A795

OPERATING CONDITIONS

The Operator, IMPERIAL OIL LIMITED
Shall conduct the ARTIFICIAL ISLAND CONSTRUCTION AND WELL DRILLING IMP NETSERK NORTH E-30 land use operation authorized by this Land Use Permit in accordance with the following operating conditions:

GENERAL CONDITIONS

1. The operator shall adhere to all conditions stated in Part 1 (General) of the Territorial Land Use Regulations.

2. The operator's field supervisor shall contact the Inuvik (Shell Lake) Office of the Northwest Lands and Forest Service phone number 979-2938 48 hours prior to the commencement of this Land Use Operation.

3. (A) All machinery and equipment associated with this operation shall operate within those routes or areas designated in the preliminary plan.

   (B) Should deviation from the preliminary plan be required while conducting this operation, the operator must obtain written approval from the engineer.

4. The obligation of the operator with respect to clean-up and restoration of the area of Land Use does not cease until he is in possession of a letter of clearance from the engineer.

5. Prior to completion, suspension or abandonment of the well, the Land Use Inspector shall be advised by the operator of the planned schedule for removal of equipment and materials by land from the drilling site and for the final clean-up.

6. The detonation of explosives on or in any water body in the N.W.T. requires authorization from the Fisheries and Marine Service, Department of Environment, Yellowknife.

7. The Land Use Permit and Annexed Operating Conditions shall be posted on the site of operations.

8. The operator shall adhere to all applicable provisions of the "Navigable Waters Protection Act." For matters pertaining to this act, contact - District Manager, Marine Services, Ministry of Transport, P.O. Box 155, Hay River N.W.T.

WASTE DISPOSAL

9. The disposal, treatment and testing of drilling wastes shall conform to the standards described in the publication "Interim Guidelines for Waste Management in Exploratory Drilling in the Canadian North" and, in addition, the following shall be adhered to:

   (A) All oil free drilling wastes and drill cuttings shall be diluted with receiving waters prior to discharge such that:

      (1) The diluted waste will cause no mortality of fish in the standard 96-hour static bio-assay test,

      (11) The dilution rate will be a minimum of 25 parts receiving water to one part waste,

      (111) The pH of the diluted waste shall be between 6.0 to 9.5

   (B) The pH of the diluted drilling waste shall be recorded daily, during periods of discharge, in the Daily Drilling Report.

(C) All oil stained cuttings and oil contaminated waste shall be segregated and disposed of at an approved on-shore disposal site.

(D) Steam and/or water only shall be employed for normal rig washing.

(E) All waste drilling fluid in the mud tanks at the completion of the drilling operation shall be disposed of by removal to a sump at an approved disposal site on shore or by other methods acceptable to the engineer.

(F) The operator shall endeavor to recycle rig wash water in order to minimize waste volume.

(G) (1) The operator shall take samples of the drilling wastes prior to dilution or neutralization at or about the following depths of hole:

1,300 feet
3,500 feet
10,000 feet
15,000 feet or total depth

(11) The samples shall be collected, transported, stored and subjected to bio-assay testing to determine the LC50 of the waste in accordance with the method specified in the report, "Interim Guidelines for Waste Management in Exploratory Drilling in the Canadian North." Bio-assay testing of the waste at concentrations normally found in the actual on-site diluted waste discharge shall also be carried out.

(111) The volume of sample required shall be specified by the independent laboratory carrying out the bio-assay testing.

(IV) The samples taken for bio-assay testing shall be analyzed for the following effluent quality parameters using methods specified in the 13th edition of "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association:

Oil and grease
Total alkalinity
pH
Dissolved chemical oxygen demand
Total chemical oxygen demand
Dissolved organic carbon
Dissolved chromium
Extractable chromium (at pH2)
Dissolved lead
Extractable lead (at pH2)
Dissolved zinc
Extractable zinc (at pH2)

(V) The results of the bio-assay tests, the effluent quality analyses and the dilution ratio being used at the time when the undiluted sample was taken shall be reported to the engineer within 30 days of the date of sampling.

10. The operator shall accurately measure and make available to the engineer within two (2) months of the completion of the drilling operation, the following:

(A) A summary report of the daily volume of water used for mud make-up.

(B) The types and quantities of mud additives used during the operation.

(C) A summary report of the daily volume of drilling waste discharged to the ocean prior to dilution.

(D) A summary report of the daily volume of receiving water used to dilute the drilling waste prior to discharge.

(E) A summary report of the dilution used during the operation.

11. The following materials shall not be used during the drilling operation without prior approval of the engineer:

    Chlorinated phenols (Dowicide B etc.)
    Compounds composed primarily of heavy metals
    (Weighing agents with high concentrations of galena etc.)
    Asbestos

12. All other waste petroleum products and toxic chemicals shall be disposed of by burning, burial or removal to a disposal site approved by the Land Use Inspector.

13. (A) Camp sewage shall be treated with an extended aeration, activated sludge treatment plant, capable of achieving 85 to 90 percent B.O.D. removal.

    (B) The operator shall ensure that the treatment plant is maintained and operated according to the schedule recommended by the manufacturer.

14. Garbage and debris shall be incinerated at least daily in a fuel-fired, forced-air incinerator.

15. The operator shall bury all residue from incinerated garbage and all non-combustible debris in a pit beneath three feet of compacted soil at an approved disposal site on shore.

FUEL AND STORAGE CONTINGENCY PLANNING

16. The operator shall locate and place fuel storage containers so that any spilled or leaked fuel will be totally contained.

17. Each fuel container or group of fuel containers shall be surrounded by a dyke. The net capacity of the dyked area shall be greater than the volume of the largest container placed therein.

18. The enclosed dyked area including the interior dyke walls shall be lined with impermeable material.

19. Fuel outlets excepting the outlet currently in use, shall be sealed to prevent leakage.

20. All stationary fuel storage facilities shall be clearly marked with flags, posts or similar device so they are plainly visible to local vehicle traffic regardless of snow cover, weather or daylight conditions.

21. The operator shall take all possible precaution to prevent fuel spillage from fuel barges.

22. The operator shall report any fuel spill resulting from his operation to the Northwest Lands and Forest Service by the speediest available means of communication.

WILDLIFE

23. The operator shall not use machinery or otherwise conduct the operation so as to harass or unnecessarily disturb wildlife or damage wildlife habitat.

24. The operator shall cooperate at all times with the game officials in regard to the protection of wildlife and wildlife habitat.

25. (A) One firearm shall be allowed in the camp and under the direct control of supervisory personnel to be used only for the purpose of protection.

(B) The presence of a wild animal that may potentially create a hazard to persons or property is to be reported immediately to the nearest Game Management Officer or R.C.M.P. detachment.

(C) The feeding of wildlife is prohibited.

26. (A) Prolonged movement by aircraft below elevations of 2,000 feet from the ground is to be avoided.

(B) Support aircraft shall avoid flights over the Kendall Island Migratory Bird Sanctuary during the period May 15 to August 15.

27. There shall be no marine traffic, including air cushion vehicles, over or through waters within the boundaries of the Kendall Island Migratory Bird Sanctuary between May 15 and September 1 without first obtaining the approval of the Canadian Wildlife Service.

28. Marine traffic, including air cushion vehicles, travelling to and from the program area through other waters in Mackenzie Bay and Kugmallit Bay shall avoid approaching closer than one half mile to the shore of all islands and the mainland, except upon entering ports, the navigable channels of the Mackenzie River in emergencies, or when in distress, between June 1 and August 15.

SUMPS AT APPROVED ONSHORE DISPOSAL SITES

29. Sumps and pits shall be constructed in such a manner that the fluids contained therein cannot spread to the surrounding land.

30. Originally excavated material shall be compacted over the entire sump or pit area. This area shall include an overlap of six feet beyond the existing sump wall.

31. The fluid contained in the sump shall be frozen to the extent that it will support the originally excavated material during placement and compaction over the sump contents.

Annex to Land Use Permit
Number N75A080

OPERATING CONDITIONS

The operator, IMPERIAL OIL LIMITED
shall conduct the IMP. OLIVIER C-56 ARTIFICIAL ISLAND CONSTRUCTION AND DRILLING Land Use Operation authorized by this Land Use Permit in accordance with the following operating conditions:

GENERAL CONDITIONS

1. The operator shall adhere to all conditions stated in Part 1 (General) of the Territorial Land Use Regulations.

2. The operator's field supervisor shall contact the Inuvik Dist. Office of the Northwest Lands and Forest Service phone number 979-2938 48 hours prior to the commencement of this Land Use Operation.

3. (A) All machinery and equipment associated with this operation shall operate within those routes or areas designated in the preliminary plan.

   (B) Should deviation from the preliminary plan be required while conducting this operation, the operator must obtain written approval from the engineer.

4. The obligation of the operator with respect to clean-up and restoration of the area of land use does not cease until he is in possession of a letter of clearance from the engineer.

5. The operator shall immediately notify the nearest office of the Northwest Lands and Forest Service of any petroleum or chemical pollution of the surrounding lands, directly, or indirectly resulting from this Land Use Operation.

6. The operator shall adhere to all applicable provisions of the "Navigable Waters Protection Act." For matters pertaining to this act, contact - District Manager, Marine Services, Ministry of Transport, P.O. Box 155, Hay River, N.W.T.

7. The Land Use Permit and annexed Operating Conditions shall be posted on the site of operations.

WASTE DISPOSAL - ARTIFICIAL ISLAND - DRILLING

8. The disposal, treatment and testing of drilling wastes shall conform to the standards described in the publication "Interim Guidelines for Waste Management in Exploratory Drilling in the Canadian North" and, in addition, the following shall be adhered to:

(A) All oil free drilling wastes and drill cuttings shall be diluted with receiving waters prior to discharge such that:

(1) The diluted wasted will cause no mortality of fish in the standard 96-hour static bio-assay test,

(11) The dilution rate will be a minimum of 25 parts receiving water to one part waste,

(111) The pH of the diluted waste shall be between 6.0 to 9.5.

(B) The pH of the diluted drilling waste shall be recorded daily, during periods of discharge, in the Daily Drilling Report.

(C) All oil stained cuttings and oil contaminated waste shall be segregated and disposed of at an approved on-shore disposal site.

(D) Steam and/or water only shall be employed for normal rig washing.

(E) All waste drilling fluid in the mud tanks at the completion of the drilling operation shall be disposed of by removal to a sump at an approved disposal site on shore or by other methods acceptable to the engineer.

(F) The operator shall endeavor to recycle rig wash water in order to minimize waste volume.

(G) (I) The operator shall take samples of the drilling wastes prior to dilution or neutralization at or about the following depths of hole:

1,300 feet
3,500 feet
10,000 feet
15,000 feet or total depth

(II) The samples shall be collected, transported, stored and subjected to bio-assay testing to determine the LC50 of the waste in accordance with the method specified in the report, "Interim Guidelines for Waste Management in Exploratory Drilling in the Canadian North." Bio-assay testing of the waste at concentrations normally found in the actual on-site diluted waste discharge shall also be carried out.

(III) The volume of sample required shall be specified by the independent laboratory carrying out the bio-assay testing.

(IV) The samples taken for bio-assay testing shall be analyzed for the following effluent quality parameters using methods specified in the 13th edition of "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association:

Oil and grease
Total alkalinity
pH
Dissolved chemical oxygen demand
Total chemical oxygen demand
Dissolved organic carbon
Dissolved chromium
Extractable chromium (at pH2)
Dissolved lead
Extractable lead (at pH2)
Dissolved zinc
Extractable zinc (at pH2)

(V) The results of the bio-assay tests, the effluent quality analyses and the dilution ratio being used at the time when the undiluted sample was taken shall be reported to the engineer within 30 days of the date of sampling.

9. The operator shall accurately measure and make available to the engineer within two (2) months of the completion of the drilling operation, the following:

(A) A summary report of the daily volume of water used for mud make-up.

(B) The types and quantities of mud additives used during the operation.

(C) A summary report of the daily volume of drilling waste discharged to the ocean prior to dilution.

(D) A summary report of the daily volume of receiving water used to dilute the drilling waste prior to discharge.

(E) A summary report of the dilution used during the operation.

10. The following materials shall not be used during the drilling operation without prior approval of the engineer:

Chlorinated phenols (Dowicide B etc.)
Compounds composed primarily of heavy metals
(Weighing agents with high concentrations of galena etc.)
Asbestos

11. All other waste petroleum products and toxic chemicals shall be disposed of by burning, burial or removal to a disposal site approved by the Land Use Inspector.

(A) Camp sewage shall be treated with an extended aeration, activated sludge treatment plant, capable of achieving 85 to 90 percent B.O.D. removal.

(B) The operator shall ensure that the treatment plant is maintained and operated according to the schedule recommended by the manufacturer.

12. Garbage and debris shall be incinerated at least daily in a fuel-fired, forced-air incinerator.

13. The operator shall bury all residue from incinerated garbage and all non-combustible debris in a pit beneath three feet of compacted soil at an approved disposal site on shore.

FUEL STORAGE AND HANDLING

14. The operator shall locate and place fuel storage containers so that any spilled or leaked fuel will be totally contained within the immediate area of the storage containers.

15. Each stationary fuel container or group of stationary fuel containers shall be surrounded by a dyke. The net capacity of the dyked area shall be greater than the volume of the largest container placed therein.

16. The enclosed dyked area including the interior dyke walls shall be lined with impermeable material.

17. All stationary fuel storage facilities shall be clearly marked with flags, posts or similar device so they are plainly visible to local vehicle traffic regardless of snow cover, weather or daylight conditions.

18. Fuel outlets excepting the outlet currently in use, shall be sealed to prevent leakage.

19. The operator shall take all possible precautions to prevent fuel spillage from fuel barges.

WILDLIFE

20. The operator shall not use machinery or otherwise conduct the operation so as to harass or unnecessarily disturb wildlife or damage wildlife habitat.

21. The operator shall cooperate at all times with the Game Officials in regard to the protection of wildlife and wildlife habitat.

22. (A) One firearm shall be allowed in the camp and under the direct control of supervisory personnel to be used only for the purpose of protection.

(B) The presence of a wild animal that may potentially create a hazard to persons or property is to be reported immediately to the nearest Game Management Officer or R.C.M.P. detachment.

(C) The feeding of wildlife is prohibited.

23. (A) Prolonged movement by aircraft below elevations of 2,000 feet from the ground is to be avoided.

    (B) Support aircraft shall avoid flights over the Kendall Island Migratory Bird Sanctuary during the period May 15 to August 15.

24. There shall be no marine traffic, including air cushion vehicles, over or through waters within the boundaries of the Kendall Island Migratory Bird Sanctuary between May 15 and September 1, without first obtaining the approval of the Canadian Wildlife Service.

SUMPS AT APPROVED ONSHORE DISPOSAL SITES

25. Sumps and pits connected with any operation on land shall not be constructed within 300 feet of any stream.

26. Sumps and pits shall be constructed large enough to contain all fluids to a level at least four feet below the lowest elevation of the immediate surrounding ground surface.

27. The operator shall maintain sump or pit wall stability.

28. Sumps and pits shall be contructed in such a manner that the fluids contained there cannot spread to the surrounding land.

29. All sumps and pits shall be restored by compacting the originally excavated material over the entire sump or pit area. This area shall include an overlap of six feet beyond the existing sump wall.

30. The fluid contained in the sump shall be frozen to the extent that it will support the originally excavated material during placement and compaction over the sump contents.

31. Restoration of the sumps and pits shall be completed prior to the spring shut-down date for overland vehicle movement.

F. F. SLANEY & COMPANY LIMITED
402 West Pender Street,
Vancouver, British Columbia, Canada