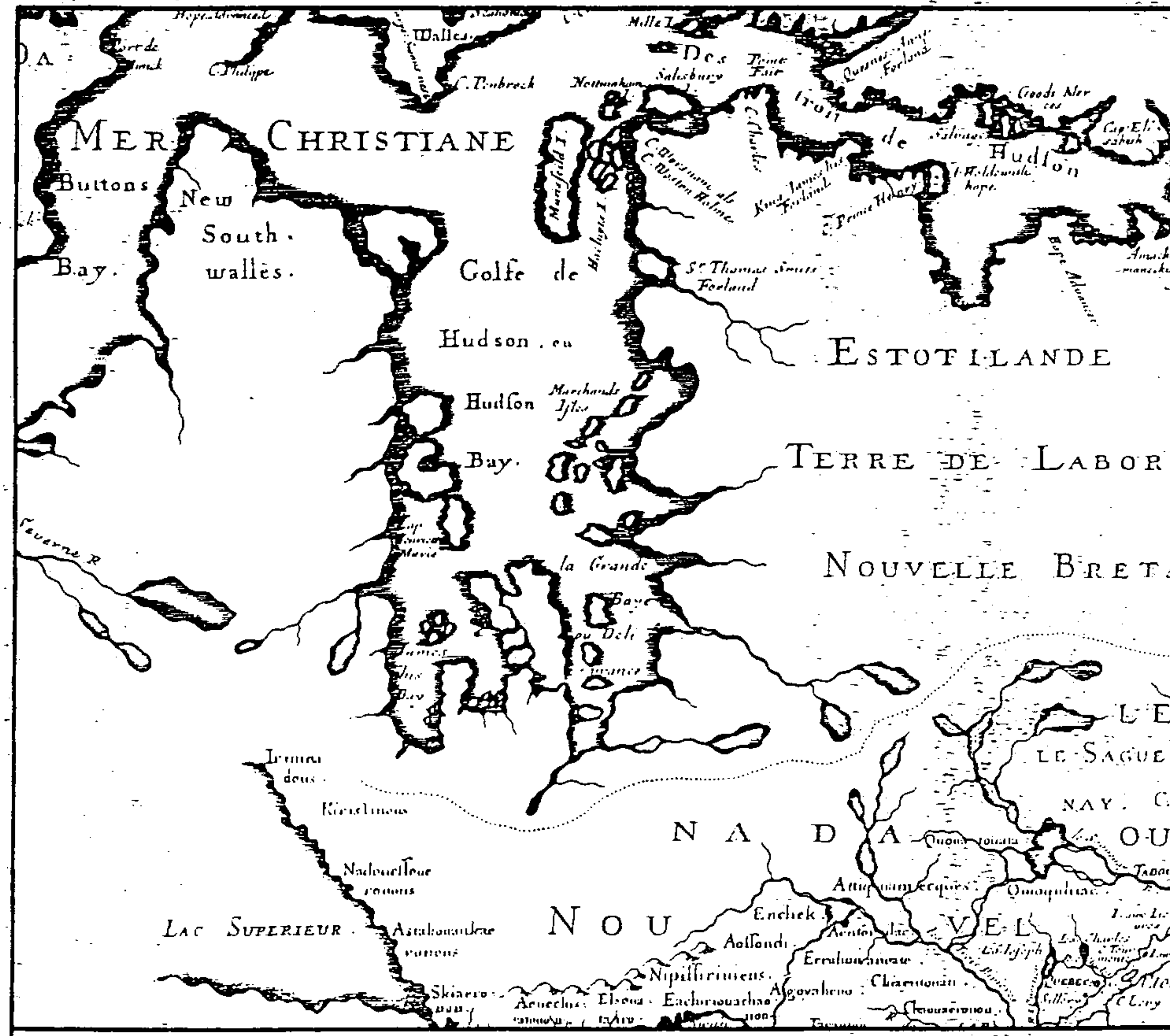
Misc Reports

ENVIRONMENTAL LITERATURE REVIEW
HUDSON BAY OFFSHORE PETROLEUM EXPLORATION

(3)



prepared for

Canadian Occidental Petroleum Limited

December 1983

THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED

CANADIAN OXY
Canadian
Occidental
Petroleum Ltd.

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Calgary, Alberta, Canada T2P 3Z1
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April 9, 1984

Dr. M. Ruel
Director General, Environmental Protection
Canada Oil & Gas Lands Administration
355 River Road
Tower B, Place Vanier
Ottawa, Ontario
K1A 0E4

Dear Dr. Ruel:

Re: Petroleum Exploration in Hudson Bay

Canadian Occidental is seeking "approval in principle" to proceed with petroleum exploration in Hudson Bay. Our Exploration Agreement calls for a one or two well program no later than the end of 1986. Surface conditions dictate that this program must begin no later than August of that year. Discontinuation of PIP grants after 1986 markedly affects the economics in this area and drilling past this date is unlikely.

In seeking approval in principle, Canadian Occidental is pleased to submit a draft copy of its Environmental Literature Review of Hudson Bay. This report forms only part of the studies undertaken by Canadian Occidental Petroleum Ltd. in its evaluation of environmental parameters affecting petroleum exploration in Hudson Bay. The report summarizes the current state of knowledge, evaluates the data base for operational planning, and identifies key areas for environmental protection and contingency planning considerations. The document was intended for "in house" use as a planning tool and is incomplete to the degree it complements other studies being undertaken by Canadian Occidental Petroleum Ltd. These studies include assimilation and analysis of extensive reports and data collections from Aquitaine's operations in 1969 and 1974 including wind, wave, and environmental data; evaluation of other summary reports for the region; wildlife observer programs in 1982 and 1983; and community information and discussion programs.

Canadian Occidental's evaluations and discussions to date support DOE/DFO findings in their report "A Summary of Environmental Concerns Associated with the Disposition of Lease Acreage in Hudson Bay with Recommendations" (1980). All indicated drilling locations are well within Area D where DOE/DFO found that exploration activities should be allowed to proceed with adequate safeguards. Wildlife observer programs recommended by the report were undertaken and indicate a low density of marine birds and mammals in the offshore region of Hudson Bay during the open water season. Oceanographic data was found to be adequate for operational planning. Further needs address real time operational requirements and the detailed studies required for the environmental protection and contingency plan.

On the basis of these findings, Canadian Occidental Petroleum Ltd. respectfully requests that approval be granted for petroleum exploration in Hudson Bay. Early resolution of this issue will allow Canadian Occidental Petroleum Ltd. to proceed with operational and contingency planning requirements in a timely and efficient manner.

Yours very truly,

R. T. Peirce
General Manager, Exploration

RTP/jmd
Enclosure

ENVIRONMENTAL LITERATURE REVIEW

HUDSON BAY OFFSHORE PETROLEUM EXPLORATION

DRAFT FINAL REPORT

PREPARED FOR

CANADIAN OCCIDENTAL PETROLEUM LIMITED

BY

THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED

TORONTO, ONTARIO

December, 1983

Revised

March, 1984

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EXECUTIVE SUMMARY

INTRODUCTION

Canadian Occidental Petroleum Ltd. and its partners are proposing a one or two well exploration drilling program in Hudson Bay for the open-water season of 1986. This report summarizes existing literature and data on the physical, chemical and ecological features of Hudson Bay relevent to environmental and operational project planning.

METEOROLOGY

Wind is the meteorological parameter of primary interest since it determines structural loadings, creates waves and currents, and affects aviation. Other variables affecting offshore operations include air temperature, precipitation, icing and fog.

A preferred track for intense storms crosses Hudson Bay from west to east in summer and northern James Bay in fall. Wind data are available from land stations, ship observations and geostrophic winds derived from pressure fields. Some wind, wave and temperature data were collected from 1968-1974 by Aquitaine and in 1969 a weather buoy was deployed during drilling.

During the open water (drilling) season, prevalent geostrophic winds are from the west through to north. Wind speed tends to be stronger and more persistant in October and November than in August and September. Few surface wind data are available. Annual wind roses for coastal stations and monthly wind roses for the open water season are included in this report. Calculation of surface winds from geostrophic winds is suitable for a first estimate of open water conditions but does not represent extreme wind conditions. The need for long term observations may be satisfied in part by the 1969 weather buoy data and should be sufficient for planning purposes.

Mean temperatures remain below freezing over the entire region until May. In the fall and early winter there are warm areas over open water. There are no precipitation records for central Hudson Bay although shore stations provide an indication of seasonal variability and suggest the precipitation regime over the Bay. West shore stations receive less precipitation than the east shore with heaviest precipitation occurring between June and October. Total annual precipitation is about 400 mm. Ice accretion on horizontal and vertical surfaces for each coast is summarized. Long term records for fog and visibility are available from land stations. Fog formation is most frequent in late summer. During open water months, the incidence of fog over the Bay will be higher than for the shore stations and the percentage of cloudiness over the Bay also increases, reaching 85% in October.

PHYSICAL OCEANOGRAPHY

Hudson Bay is a shallow water body within a gently sloping basin having a shoreline of low relief. It's area is about 760,000 km^2 with a mean depth of about 125 m and a maximum depth of about 235 m. Parameters of greatest relevence to the proposed exploratory programme include coastal physiography, ice conditions, currents and tides, and sea state.

Hudson Bay has three basic coastal types: low lying coasts associated with sedimentary formations (west James Bay and southwest Hudson Bay, etc.); coastal cliffs and headlands (northwest Hudson Bay, Southhampton Island, etc.); and intervening areas of complex coastline exhibiting numerous small bays, inlets, and headlands.

The thermal regime is important for planning and operations in that it determines the timing and rate of ice formation and disintegration and, to an extent, the seasonal variation of pycnocline depths. As the temperature of the surface waters decreases in the fall, density increases resulting in an unstable vertical stratification and consequent vertical mixing between the surface and lower layers. Density gradients are also affected by salinity. The average salinity is about 32 to $33^{o}/oo$, which will result in a freezing point between -1 and -2° C at less than maximum density. Ice formation may be expected near the end of November to early December.

The depth of the surface water layer is at a minimum during early summer and deepens in fall due to mixing processes. A typical temperature/salinity profile for early September is reported.

Hudson Bay is the largest body of water that freezes completely over in winter and becomes ice-free in the summer. The absence of stable ice cover in winter prevents stationary ice-based drilling so that drilling is limited to a floating platform in the ice-free period. Mean annual maximum ice thickness is about 1.5 m in April. In winter, only a pronounced shore lead and isolated other leads interrupt a continuous ice pack. Break-up begins in May near shore, with the last ice disappearing in August. Freeze-up begins along the northern shore in September and gradually extends southward and eastward. Aquitaine's experience suggests that data from Ice Forecasting Central of the Atmospheric Environment Service (AES) were useful and accurate in relation to the area of operations, and invaluable in relation to moving the drilling rig into and out of Hudson Bay. On average, there are about 3 months of open water. Information soon to be available from AES is sufficient for planning purposes and ice forecasts will form the core of ice information required for operational purposes.

Tidal information is collected from a number of coastal stations, and computer models have been developed to interpret tidal effects over the entire Bay. Tidal ranges are much greater on the west coast (up to 5.2 m) than on the east (as little as 0.5 m). Surface and near surface currents are dominated by the tidal component at all depths resulting in an overall counter-clockwise rotation. Average current speeds recorded at 20 m, 50 m, and 100 m depths in September/October, 1981 were about 30, 12 and 15 cm/sec, respectively. The oceanographic parameters are highly dependent on the wind stress and resulting currents.

Ship observations within Hudson Bay report a maximum wave height of 8.2 m and a maximum swell height of 23.5 m. During Aquitaine's work in 1970, sea state studies recorded mean wave heights of 0.7 to 2.0 m and a return period of 5 to 6 seconds. The maximum swell observed had a height of 4.0 m and a period of 8 seconds. An extreme wave hindcast study predicted greatest significant wave heights for the 1 in 10 and 1 in 100 year storms of 10.4 and 14.0 m, respectively.

CHEMICAL OCEANOGRAPHY

A series of oceanographic cruises in Hudson Bay during the 1970's has provided a much improved understanding of its chemical oceanography, particularly during the open-water season. Surface salinity ranges from 22.0 to 31.8% with highest values occurring inshore around Coats and Southampton Islands, and offshore near the middle of the Bay. Lowest salinity occurs close to shore near rivers. Waters below 50 m have temperatures between 0 and -1.86°C and salinities of 30 to 33.7 ‰. Little vertical mixing occurs in summer.

Hudson Bay is an oligotrophic body of water of low productivity, heavily influenced by freshwater runoff. During the summer, lack of vertical mixing appears to restrict the regeneration of nutrients, particularly nitrate, in the surface waters. Hudson Bay waters are generally well oxygenated. Few data regarding baseline concentrations of heavy metals or hydrocarbons are available. Secchi disc transparency exceeded 15 m in the open water of Hudson Bay in the few measurements made to date.

Sediments in shallow coastal regions and offshore shoals generally have a median particle diameter in the fine sand-silt range, whereas deeper basin areas are characterized by sediments with relatively high organic carbon content, having a median diameter in the clay range.

MARINE ECOLOGY

Clear inshore-offshore gradients in physico-chemical and biological variables occur in Hudson Bay. The offshore zone can clearly be delineated from six nearshore areas. Land runoff and associated coastal circulation appear to be the predominant factors influencing standing crop and likely productivity in the surface waters. Offshore waters in summer are comparatively oligotrophic.

No specific microbiological studies have been reported for Hudson Bay, although similarities in terms of oil-degrading bacteria might be expected with other northern waters. Recent cruises have greatly augmented the data base with respect to phytoplankton communities and primary productivity. Diatoms form the largest group, followed by dinoflagellates. A highly developed subsurface chlorophyll maximum layer has been noted which may significantly contribute to annual production. An area west of the Belcher Islands is thought to be particularly productive with respect to phytoplankton. However, in general, in spite of the enormous freshwater runoff, the biomass supported is low, perhaps due to limited return of nutrients from deep waters.

Estimates of zooplankton suggest production lower than the Atlantic Ocean but higher than the central Arctic Ocean, with extreme annual variation occurring. Ciliates occur in large numbers, at least in the Belcher Islands area and may be an important component of marine food chains. Amphipods, mysids, euphausiids and shrimp are prey for fish and marine mammals.

Hudson Bay benthic invertebrate communities have not been studied extensively, but just over 200 species are known to occur in James Bay. Few growth or production data are available. Due to the uniform mud substrata in the offshore region, exploitable numbers of commercial invertebrates are unlikely. Clams, snails and other organisms provide food for walrus and other animals in shallow waters. Marine plants are entirely seaweeds (algae) with the exception of "eel grass".

FISH AND FISHERIES

The Hudson Bay fish fauna is largely typical of Arctic regions and few species are present. Although few studies have examined offshore waters, the most diverse fish communities occur in nearshore areas, particularly around river mouths, where a wider range of habitats occur and nutrient concentrations are generally higher.

The true marine fish species have been described as small, obscure, bottom-dwelling forms of little economic value. Greenland cod and capelin are fished to a minor extent. The nearshore zone and estuaries attract marine and anadromous species to spawn and feed respectively. Sea-run brook trout, Arctic char and whitefishes are the most prized species by fishermen.

Fishery exploitation to date has been minimal and concentrated along the shorelines, mainly near river mouths where migration runs can be intercepted. Exploitable commercial fishery resources of any practical scale do not occur. Utilization of fish is principally for subsistence of the native populations where fishing is an important social as well as nutritional function. A modest fishery for Arctic char is centred at Rankin Inlet where a cannery was built, but escalating transportation costs have reduced marketability, so that only frozen char is supplied today.

BIRDS

Hudson Bay and James Bay coastal environments provide critical nesting, staging and migration habitat for large numbers of arctic and subarctic marine birds, waterfowl and shorebirds. Of particular note are colonies of lesser snow geese, Canada geese and thick-billed murres, and the migration-staging areas associated with coastal marshes and tidal flats of the Hudson and James Bay Lowlands. These latter areas support numerous transient geese, waterfowl and shorebirds. For several species, these areas represent significant proportions of their North American populations.

Among the notable physical features of the region are its great diversity of shoreline habitats, and the fact that these coastlines provide a direct link between southern wintering areas and summer breeding areas in the Canadian arctic. Most of the important areas of bird habitat are associated with shore zones and islands and are well removed from the area of exploration.

Waterfowl of the region are a noted resource of local and international importance. Large numbers of geese and ducks are taken annually by native hunters of the region, particularly in the James Bay area but also elsewhere. As well, ducks and particularly geese form an integral part of the waterfowl hunting resource throughout eastern and central North America. Economic benefits associated with this waterfowl hunting activity are measured in the millions of dollars.

SENSITIVE AREAS AND CONTINGENCY PLANNING

As a result of our review, we have identified areas in the Hudson Bay region which are particularly important to bird life and marine mammals. To a more general level, types of habitat which are more productive for fish are also noted. We stress that the identification of such areas relates entirely to the inherent importance of these areas to the organisms themselves and does not take into account any aspect of the probability of their disturbance by oil spills. The proposed drill site is located in the central portion of Hudson Bay and is well removed from all areas of biological interest.

Seven areas of noted biological importance to marine birds are identified and mapped in this report along with six areas of particular importance to marine mammals. Major river estuaries are most important to fish communities.

Real time and two types of scenario oil spill trajectory models are described. Sufficient data exist to run an oil spill trajectory model for spill contingency planning. The probability of an oil spill during the 1986 exploratory drilling is slight since there are no indications of overpressure zones.

As a first order estimate based on available data on oil spill trajectory analysis off the Hibernia oil field, such a spill could travel from 10 to 50 km per day. To cover the minmum 250 km distance to shore, the shortest time required would be about 5 days and on an average, probably longer than 10 to 15 days. Over this period of time, the spill is likely to be highly degraded and emulsified with over 90% of the volatiles evaporated.

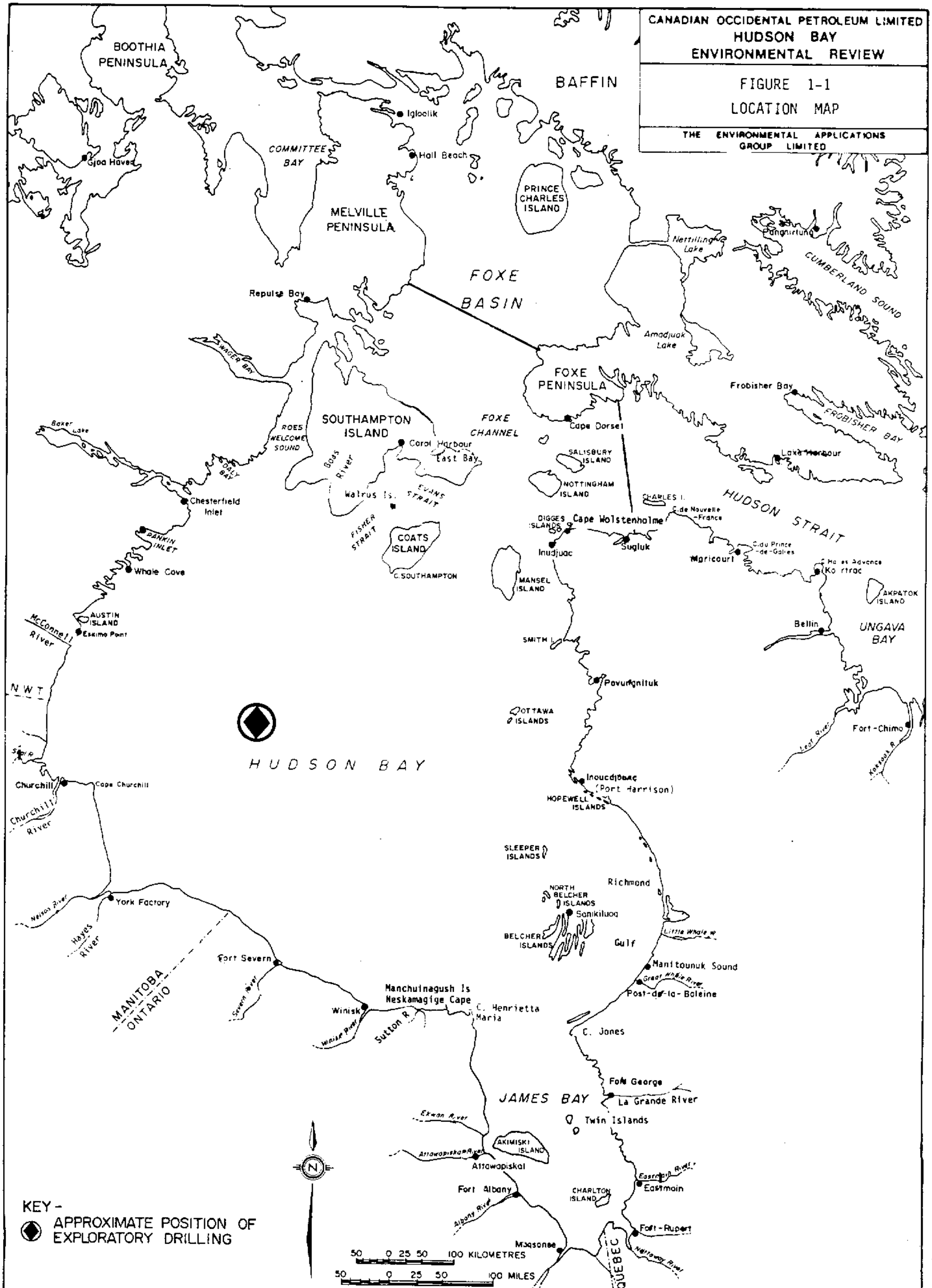
Adequate data are available to undertake the comprehensive trajectory modelling required for contingency planning.

1. INTRODUCTION

Canadian Occidental Petroleum Ltd. and its partners, Ontario Energy Corporation and Soquip are currently in the early exploration phase of searching for petroleum reserves in Hudson Bay. A one or two well drilling programme is planned to be completed during the open water season (approximately 3 months) of 1986. At present there are no plans for further drilling in other years. Figure 1-1 shows the probable location of drilling in central Hudson Bay: 89° W, 59° 40' N to 88° W, 59° 00' N. This map also identifies place names discussed in this report.

The Environmental Applications Group Limited was retained by Canadian Occidental to review the existing environmental literature and data base pertaining to offshore exploration in Hudson Bay. The present report will provide a basis for making informed project decisions regarding environmental and operational planning requirements. It provides a critical summary of the state of present knowledge rather than a listing of tabular data. In particular, this report concentrates on those parameters likely to affect or be affected by offshore petroleum exploration activities. Operational data requirements and potentially sensitive areas are identified wherever possible.

This study summarizes the major aspects relating to the physical and chemical oceanography, meteorology, marine ecology, fisheries and marine birds. Marine mammals were examined in a separate report by LGL (1983) in concert with wildlife observer programmes undertaken by Canadian Occidental in 1982 and 1983. Hudson Bay is a large and remote portion of the Canadian marine environment, where access and working conditions are difficult and expensive. As well, human population levels are sparse and known exploitable resources quite limited, so that some aspects of the existing environment are less well known than for other offshore areas.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HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 1-1
LOCATION MAP
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
BOOTHIA PENINSULA
BAFFIN
Igloolik
Hall Beach
COMMITTEE BAY
Gjoa Haven
MELVILLE PENINSULA
PRINCE CHARLES ISLAND
Nettilling Lake
Pangnirtung
CUMBERLAND SOUND
FOXE BASIN
Repulse Bay
WAGER BAY
Amadjuak Lake
FOXE PENINSULA
Frobisher Bay
FROBISHER BAY
Baker Lake
ROES WELCOME SOUND
SOUTHAMPTON ISLAND
Coral Harbour
East Bay
FOXE CHANNEL
Cape Dorset
Lake Harbour
SALISBURY ISLAND
NOTTINGHAM ISLAND
CHARLES I.
DALY BAY
Boas River
EVANS STRAIT
Walrus Is.
Chesterfield Inlet
HUDSON STRAIT
C. de Nouvelle-France
DIGGES ISLANDS
Cape Wolstenholme
RANKIN INLET
FISHER STRAIT
COATS ISLAND
Sugluk
Inoudjuac
C. du Prince-de-Galles
Maricourt
C. Hopes Advance
Koartrac
Whale Cove
C. SOUTHAMPTON
MANSEL ISLAND
AKPATOK ISLAND
AUSTIN ISLAND
Eskimo Point
McConnell River
Bellin
UNGAVA BAY
SMITH I.
N W T
Povungnituk
OTTAWA ISLANDS
Fort-Chimo
Leaf River
Koksoak R.
Seal R.
HUDSON BAY
Churchill
Cape Churchill
Inoucdjouac
(Port Harrison)
HOPEWELL ISLANDS
Churchill River
SLEEPER ISLANDS
Richmond
NORTH BELCHER ISLANDS
Sanikiluaq
York Factory
Nelson River
Hayes River
BELCHER ISLANDS
Little Whale R.
Gulf
Fort Severn
Manitounuk Sound
Great Whale River
Post-de-la-Baleine
MANITOBA
ONTARIO
Severn River
Manchuinagush Is
Neskamagige Cape
Winisk
C. Henrietta Maria
Winisk River
Sutton R.
C. Jones
Fort George
JAMES BAY
La Grande River
Ekwan River
Twin Islands
AKIMISKI ISLAND
Attawapiskat River
Attawapiskat
N
Eastmain River
Eastmain
Fort Albany
CHARLTON ISLAND
Albany River
Fort-Rupert
Moosonee
QUEBEC
Nottaway River
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES
KEY -
APPROXIMATE POSITION OF EXPLORATORY DRILLING

2. METEOROLOGY

2.1 INTRODUCTION

The meteorological variables of particular concern for this study are the ones which are related to the conditions of drilling operations and structural design. Because meteorology has influence on the physical oceanography, the two sciences cannot be analysed separately. Consequently cross-references between the two chapters (meteorology and physical oceanography) are frequently used in this report.

2.2. METEOROLOGICAL VARIABLES RELEVANT TO OFFSHORE OPERATIONS

Wind is the meteorological parameter of primary interest, as it determines structural loadings, creates waves and water currents, and also affects aviation.

Meteorological variables of secondary importance affecting offshore operations include air temperature, precipitation, icing and fog.

COGLA (1983) recommends the following meteorological variables be observed:

wind	barometric pressure	air temperature
dew point	sky condition	precipitation
visibility	ice accretion	

Additionally, two types of weather forecast services are required for the drilling operation. The Site-specific Forecast Service is provided by the drilling operator. This is intended to supply more accurate forecasts than regional government forecasts and to supply up dated forecasts during emergency conditions. The Aviation Weather Forecast Service is normally provided by the Atmospheric Environment Service (AES) and supports weather information for flying conditions.

At the end of the drilling programme a data analysis is required by COGLA. The report should include such sections as forecast verifications. data analysis of storms encountered, and statistical summaries of meteorological observations.

Meteorological data are also needed to formulate contingency plans for possible emergency situations such as oil spills or evacuation procedures. The following sections of this chapter address the current knowledge of the Hudson Bay climatology in light of the data requirements.

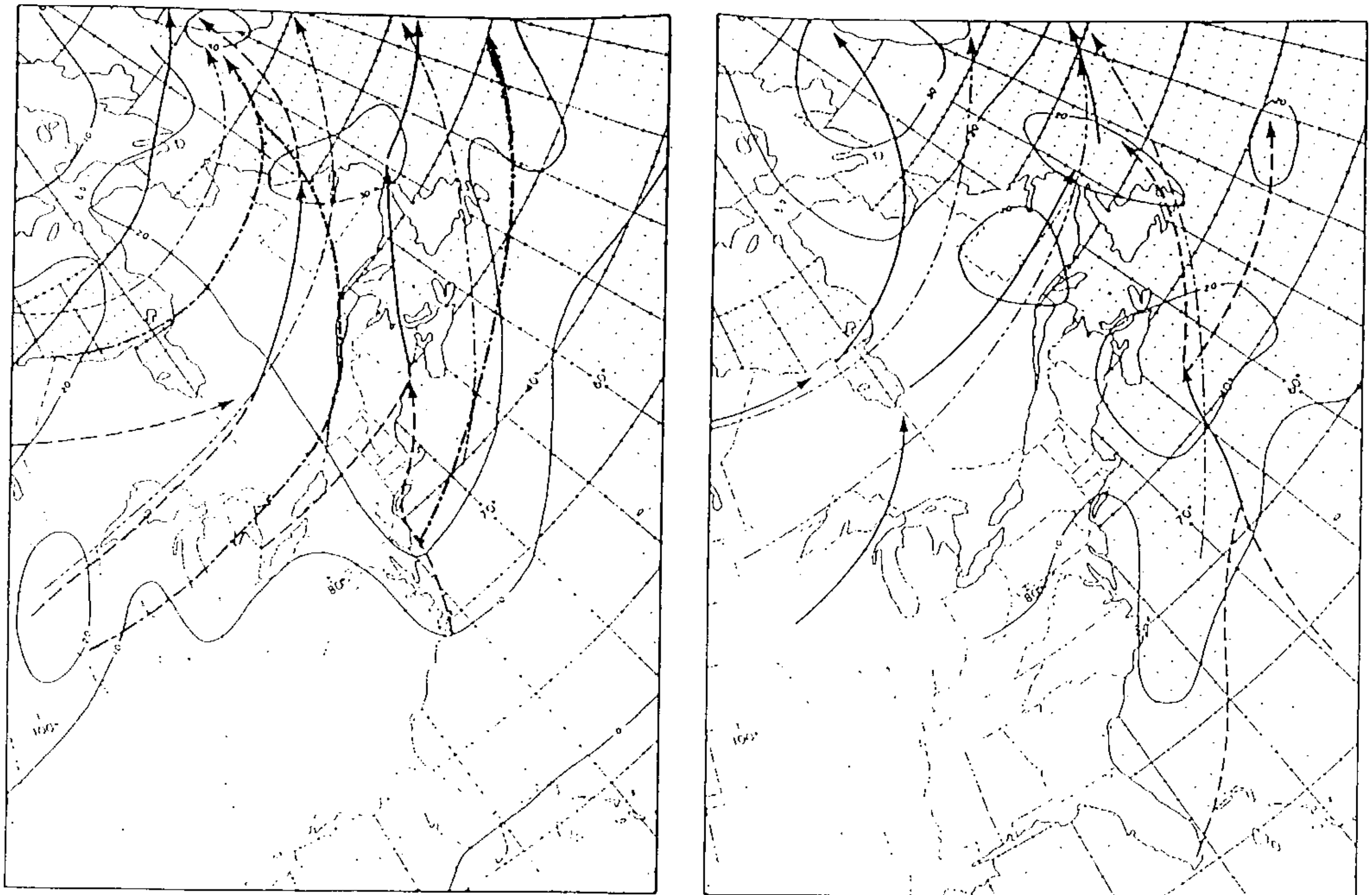
2.3 SYNOPTIC SYSTEMS

One of the prime objectives in providing site specific forecasts is the identification and prediction of movement of intense storms or cyclones. Reitan (1974), among others, has shown that one of the preferred cyclone tracks crosses central Hudson Bay from west to east in summer and northern James Bay in the fall (Figure 2-1). Archibald's (1969) analyses of intense storm tracks over Hudson Bay reveals the same seasonal pattern. Based on analysis of storms for a 5-year period (1963-1967), Archibald found that for July, August and September, the greatest frequency of intense storms lies across Hudson Bay with a less frequent track to the north of Hudson Bay. During October, November and December, a primary (i.e. well defined cyclones) but less frequent track still exists across Hudson Bay and through southern James Bay.

Danard's review (1980) of the meteorological influences of Hudson and James Bays includes a discussion of storm intensification. He indicates that in the fall and early winter, prior to freeze-up (see Section 3.3) the modifying influence of Hudson Bay on cyclones is similar to the influence of the Great Lakes. When an extratropical cyclone crosses the Great Lakes, the fluxes of heat and water vapour cause a deepening of the low pressure. Higher winds also result from storm intensification. This effect becomes less important during winter and summer seasons, when the temperature difference between land and sea water surface is less.

Due to the large expanse of Hudson Bay, the intensification of a storm may not be identified and the weather forecasts may be subsequently in error. However in recent years the Atmospheric Environment Service (AES) has deployed a drifter

FIGURE 2-1
CYCLONE TRACKS



JULY

OCTOBER

LEGEND: - - → secondary
—— → primary Klein (1957), —·—→ 7iskha and Smith (1980), —··—→ Reitan (1974),

isopleths indicate the number of cyclone events in 20 months (Klein 1957) buoy transmitting information on atmospheric pressure, water temperature and location to demonstrate enhanced forecasting capabilities in Hudson Bay. The additional data collected were found to improve the weather analysis and hence improve the weather forecasts (M. Stauder, AES, personal communications).

The Atmospheric Environment Service (AES) has received funding for one further year for operational deployment of a drifter buoy in 1984. Combined with previous years (1979 to 1982), this programme will provide useful data in hindcasting and operational forecasting.

2.4 WINDS

There are currently three sources of wind data for the Hudson Bay area: land stations, ship observations, and geostrophic winds derived from pressure fields. Some additional data (i.e. winds, waves and temperature) were collected between 1968 and 1974 by Aquitaine during a drilling campaign located in the triangular area of 18E-19E-22E (see Figure 2-2). In 1969, Aquitaine deployed a weather buoy, "Data Well" continuous recording wave meter buoy and a current meter with readings every 6 hours at sea level, half water depth, and sea bottom.

The land stations surrounding Hudson Bay are shown in Figure 2-2 along with the grid points at which geostrophic winds are calculated. (The geostrophic wind is the horizontal wind velocity for which the coriolis acceleration exactly balances the horizontal pressure force in the free atmosphere i.e. removed from the surface). Winds computed from pressure data have the advantage of a long continuous record which may be used to infer a surface wind climatology over Hudson Bay. The Atmospheric Environment Service (AES) has derived a geostrophic wind climatology for marine areas, including Hudson Bay area, (Sauleslega, personal communication) and is currently looking at methods of improving surface wind hindcasts based on pressure data.

Annual wind roses for selected stations around Hudson Bay are presented in Figure 2-3. Monthly wind roses for August, September, October, and November are given in Figure 2-4 (a,b,c,d). Only mean wind speeds are given for these stations; however, standard processing packages available at AES may be utilized to determine the frequency and persistence of specified wind speed and direction classes. The

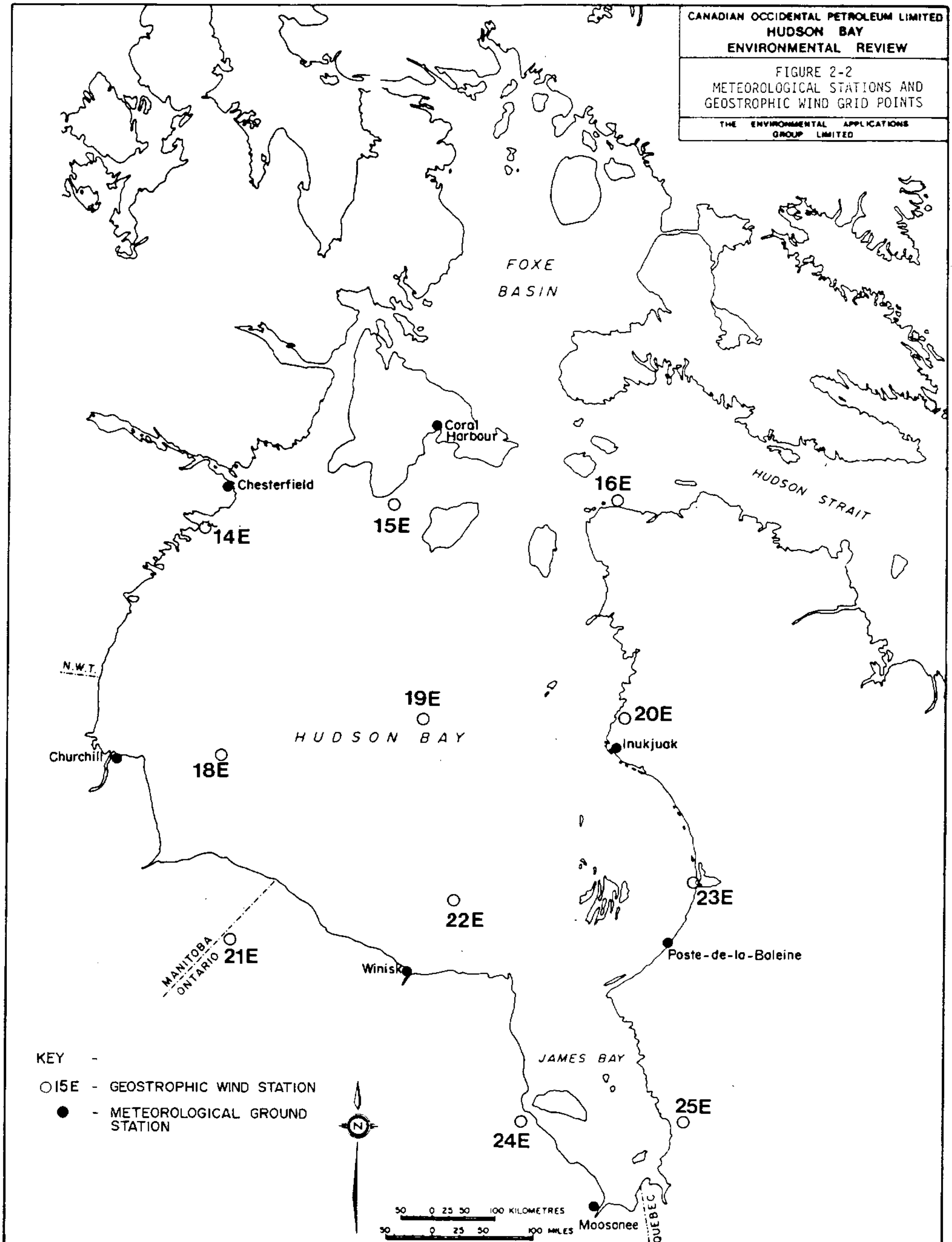


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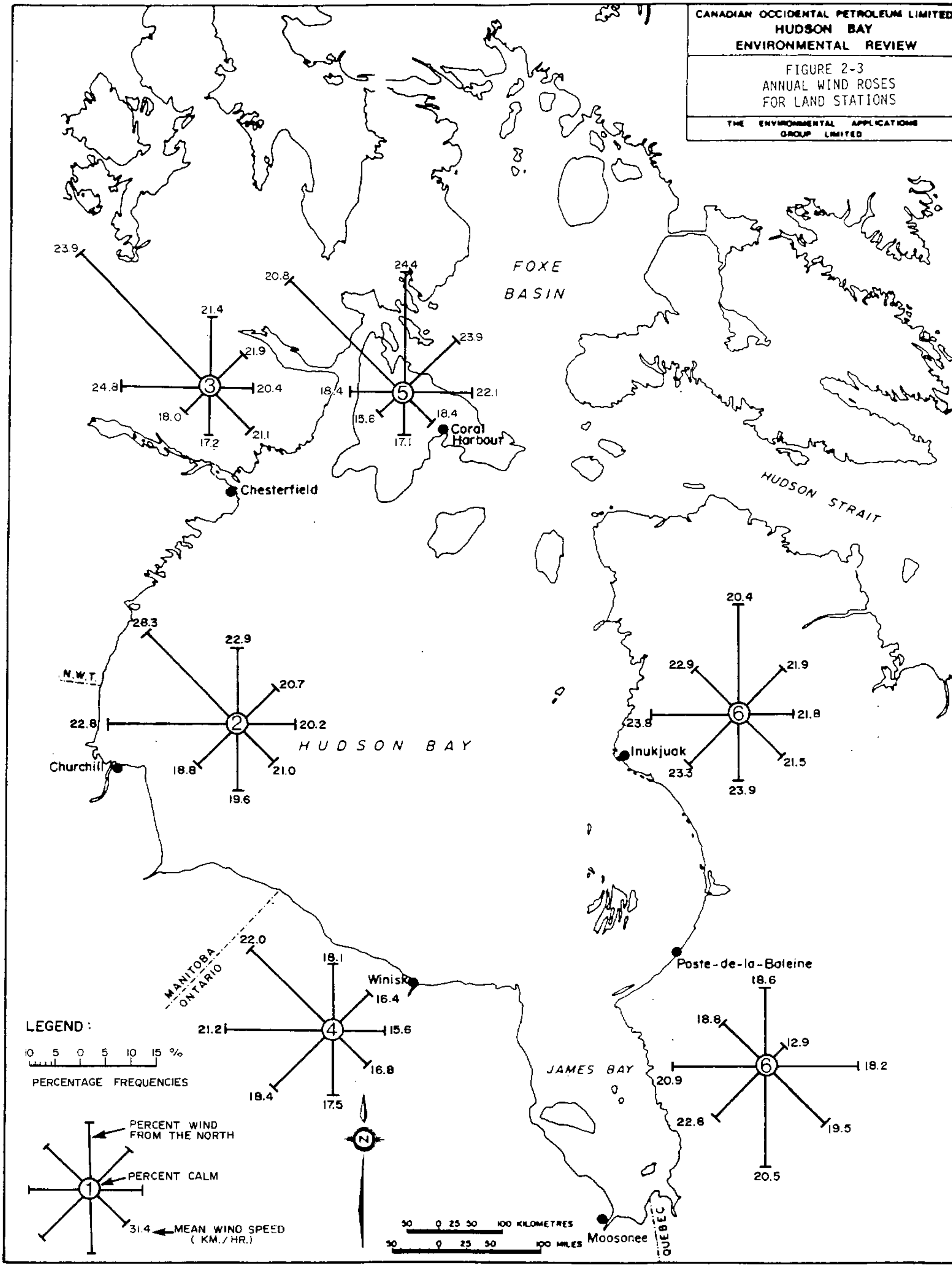
FIGURE 2-2
METEOROLOGICAL STATIONS AND
GEOSTROPHIC WIND GRID POINTS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
Coral Harbour
Chesterfield
16E
15E
14E
HUDSON STRAIT
N.W.T.
19E
20E
HUDSON BAY
Inukjuak
Churchill
18E
23E
22E
Poste-de-la-Baleine
MANITOBA
ONTARIO
21E
Winisk
JAMES BAY
25E
24E
Moosonee
QUEBEC
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES
KEY -
○15E - GEOSTROPHIC WIND STATION
● - METEOROLOGICAL GROUND STATION
N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HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 2-3
ANNUAL WIND ROSES
FOR LAND STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE
BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
Chesterfield
Coral Harbour
Churchill
Inukjuak
Winisk
Poste-de-la-Baleine
Moosonee
23.9
21.4
21.9
24.8
20.4
18.0
21.1
17.2
20.8
24.4
23.9
18.4
22.1
15.6
17.1
18.4
28.3
22.9
20.7
22.8
20.2
18.8
21.0
19.6
20.4
22.9
21.9
23.8
21.8
23.3
21.5
23.9
22.0
18.1
16.4
21.2
15.6
18.4
16.8
17.5
18.6
18.8
12.9
20.9
18.2
22.8
19.5
20.5
LEGEND:
10 5 0 5 10 15 %
PERCENTAGE FREQUENCIES
PERCENT WIND FROM THE NORTH
PERCENT CALM
31.4
MEAN WIND SPEED (KM./HR.)
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

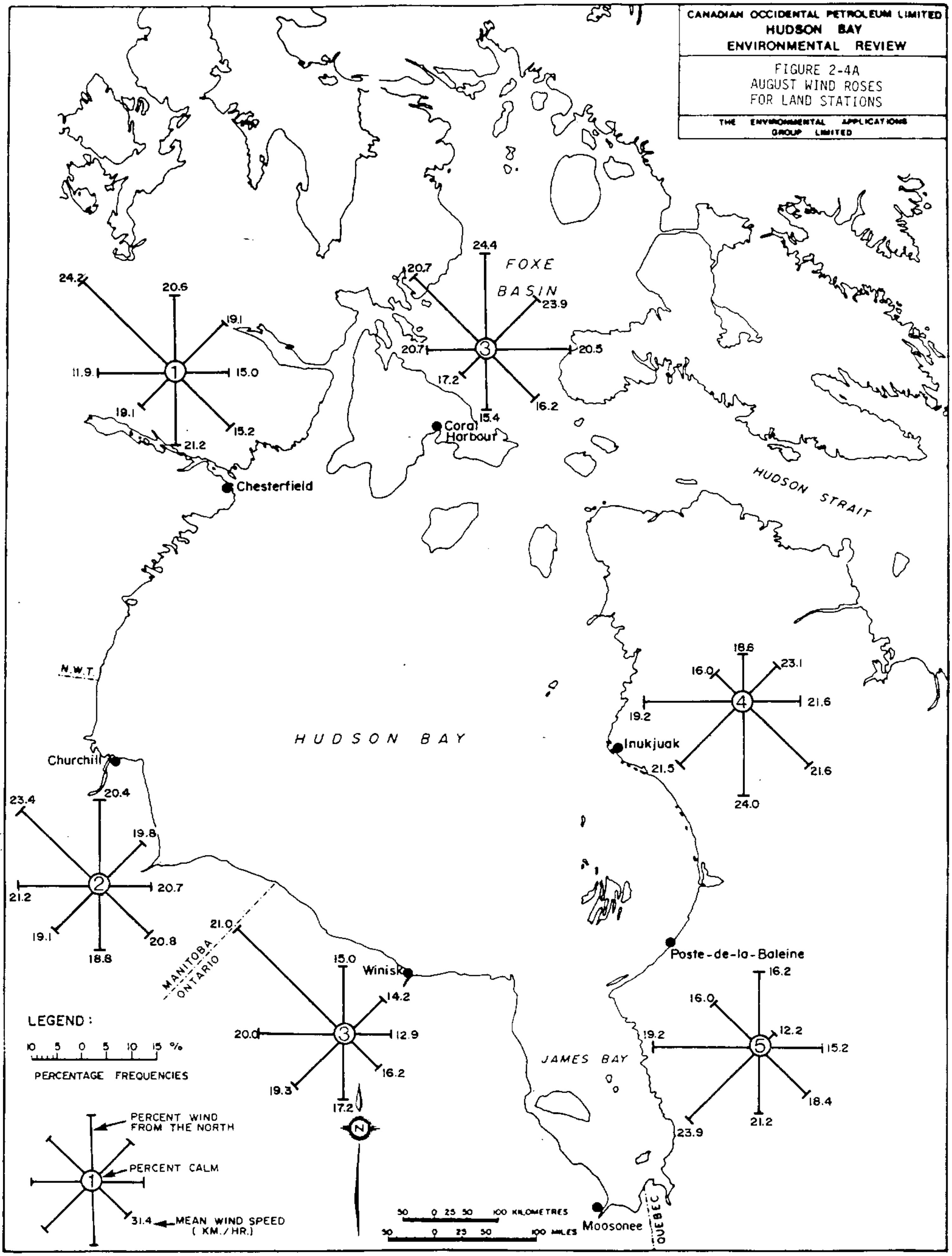
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FIGURE 2-4A
AUGUST WIND ROSES
FOR LAND STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
Coral Harbour
Chesterfield
Churchill
Winisk
Inukjuak
Poste-de-la-Baleine
Moosonee
N.W.T.
MANITOBA
ONTARIO
QUEBEC
24.2
20.6
19.1
11.9
15.0
19.1
15.2
21.2
24.4
20.7
23.9
20.7
20.5
17.2
16.2
15.4
18.6
16.0
23.1
19.2
21.6
21.5
21.6
24.0
23.4
20.4
19.8
21.2
20.7
19.1
20.8
18.8
21.0
15.0
14.2
20.0
12.9
19.3
16.2
17.2
16.2
16.0
12.2
19.2
15.2
23.9
21.2
18.4
LEGEND:
10 5 0 5 10 15 %
PERCENTAGE FREQUENCIES
PERCENT WIND FROM THE NORTH
PERCENT CALM
31.4
MEAN WIND SPEED (KM./HR.)
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

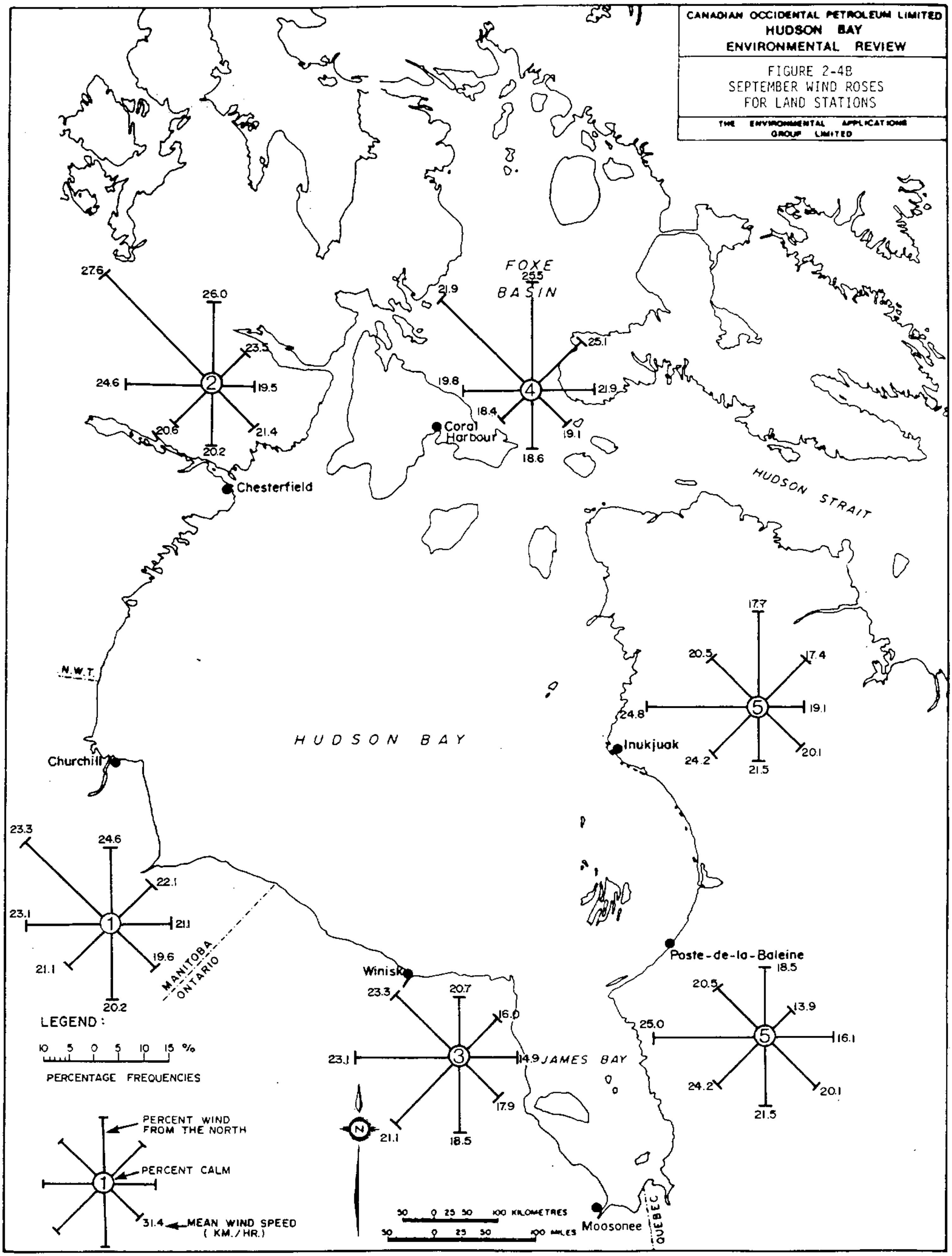
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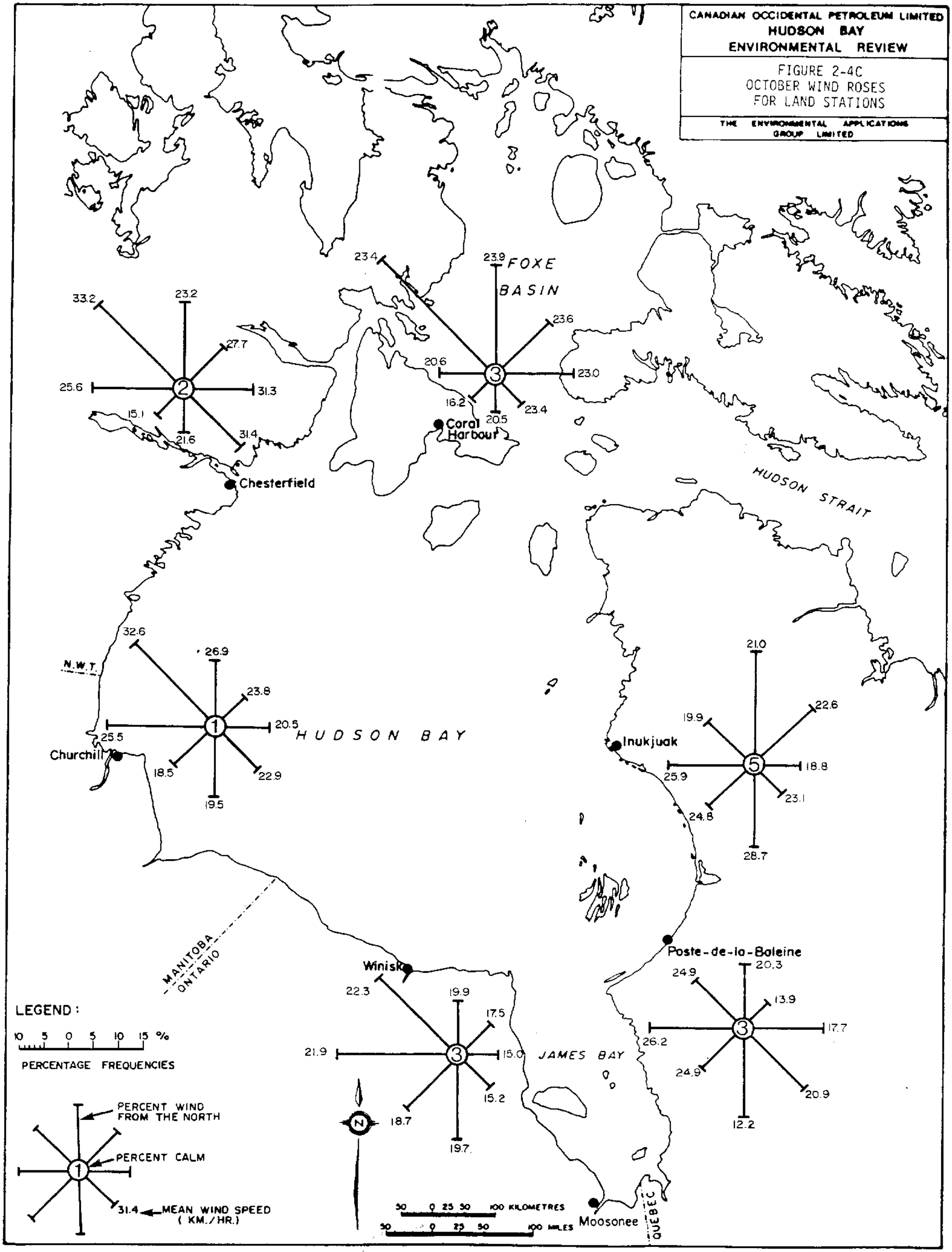
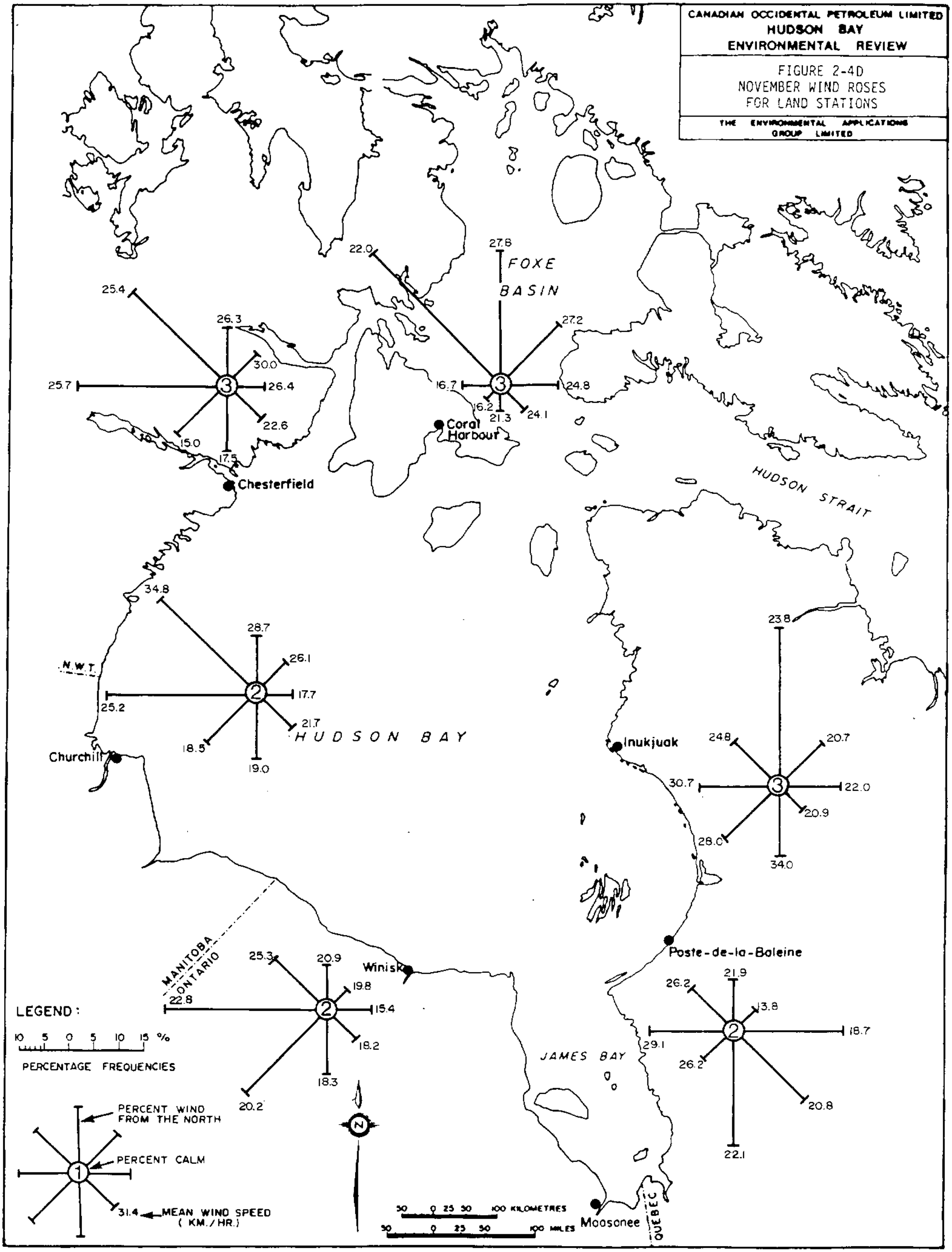
FIGURE 2-4B
SEPTEMBER WIND ROSES
FOR LAND STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
Chesterfield
Coral Harbour
Churchill
Inukjuak
Poste-de-la-Baleine
Winisk
Moosonee
27.6
26.0
23.5
24.6
19.5
20.6
20.2
21.4
21.9
25.5
25.1
19.8
21.9
18.4
19.1
18.6
17.7
20.5
17.4
24.8
19.1
24.2
21.5
20.1
23.3
24.6
22.1
23.1
21.1
21.1
19.6
20.2
23.3
20.7
16.0
23.1
14.9
21.1
17.9
18.5
18.5
20.5
13.9
25.0
16.1
24.2
20.1
21.5
LEGEND:
10 5 0 5 10 15 %
PERCENTAGE FREQUENCIES
PERCENT WIND FROM THE NORTH
PERCENT CALM
31.4 MEAN WIND SPEED (KM./HR.)
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES



CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 2-4C
OCTOBER WIND ROSES
FOR LAND STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
Chesterfield
Coral Harbour
Churchill
Inukjuak
Poste-de-la-Baleine
Winisk
Moosonee
N.W.T.
MANITOBA
ONTARIO
QUEBEC
33.2
23.2
27.7
25.6
31.3
15.1
21.6
31.4
23.4
23.9
23.6
20.6
23.0
16.2
20.5
23.4
32.6
26.9
23.8
25.5
20.5
18.5
22.9
19.5
21.0
22.6
19.9
18.8
25.9
23.1
24.8
28.7
22.3
19.9
17.5
21.9
15.0
18.7
15.2
19.7
24.9
20.3
13.9
26.2
17.7
24.9
20.9
12.2
LEGEND:
10 5 0 5 10 15 %
PERCENTAGE FREQUENCIES
PERCENT WIND FROM THE NORTH
PERCENT CALM
31.4 MEAN WIND SPEED (KM./HR.)
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 2-4D
NOVEMBER WIND ROSES
FOR LAND STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
Coral Harbour
Chesterfield
Churchill
Inukjuak
Poste-de-la-Baleine
Winisk
Moosonee
22.0
27.6
27.2
16.7
24.8
16.2
21.3
24.1
25.4
26.3
30.0
25.7
26.4
22.6
15.0
17.5
34.8
28.7
26.1
25.2
17.7
21.7
18.5
19.0
23.8
24.8
20.7
30.7
22.0
20.9
28.0
34.0
25.3
20.9
19.8
22.8
15.4
18.2
18.3
20.2
21.9
26.2
13.8
29.1
18.7
26.2
20.8
22.1
LEGEND:
10 5 0 5 10 15 %
PERCENTAGE FREQUENCIES
PERCENT WIND FROM THE NORTH
PERCENT CALM
31.4 MEAN WIND SPEED (KM./HR.)
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

major difference between west and east coast winds is the more frequent northwest and west winds on the west coast compared with the east coast, especially during October and November. For example, during November winds are from the west through north-northwest at Poste de la Baleine only 23.5% of the time. The corresponding figure for Churchill is 52% (AES, 1980). Danard (1980) suggests that the difference in part may be due to a land-sea breeze circulation associated with the relatively warm open water. He also indicates that another factor affecting Poste de la Baleine's and Inukjuak's winds is the tendency for decelerating air (from the relatively smooth Bay surface to the increased roughness of the shore) to deflect to the left. Thus a northwest wind could acquire a component from the south. For all locations around the Bay shore based land stations will underestimate the wind speeds over the Bay due to increased roughness over land.

The geostrophic wind roses are shown in Figure 2-5 for the annual case. Figure 2-6 illustrates the monthly variation (August through November) for two grid points in the middle of the Bay. It must be remembered that these winds are derived using the geostrophic approximation and must be corrected before being representative of winds over the sea surface. However, due to low friction over the sea surface, the correction is less important than over land. The geostrophic wind is predominantly northwest over the Bay over the year. During the months of open water, the prevalent directions are from the west through to north.

Data on the persistence of geostrophic winds are also available in the AES geostrophic wind climatology. Partial data are presented in Table 2-1 for the months of August to November. They represent the number of cases when wind was observed above a certain speed (6 speed classes, from 5 m/s to 30 m/s) for a certain duration (10 of the 60 duration classes are presented in the table). Duration class 1 represents wind persistence lasting from 6 to 11 hours, and class 2 from 12 to 17 hours, and so on. The table indicates that wind speed tends to be stronger and more persistent during the fall months (i.e. October and November)

The last data base for winds is ship observations during the navigation season. For the period 1895-1979 only 3202 observations of wind on the Bay have been recorded or estimated. This data base is less adequate than the geostrophic wind data base and no meaningful statistics can be derived from it.

FIGURE 2-5

ANNUAL GEOSTROPHIC WIND ROSES FOR HUDSON BAY GRID POINTS

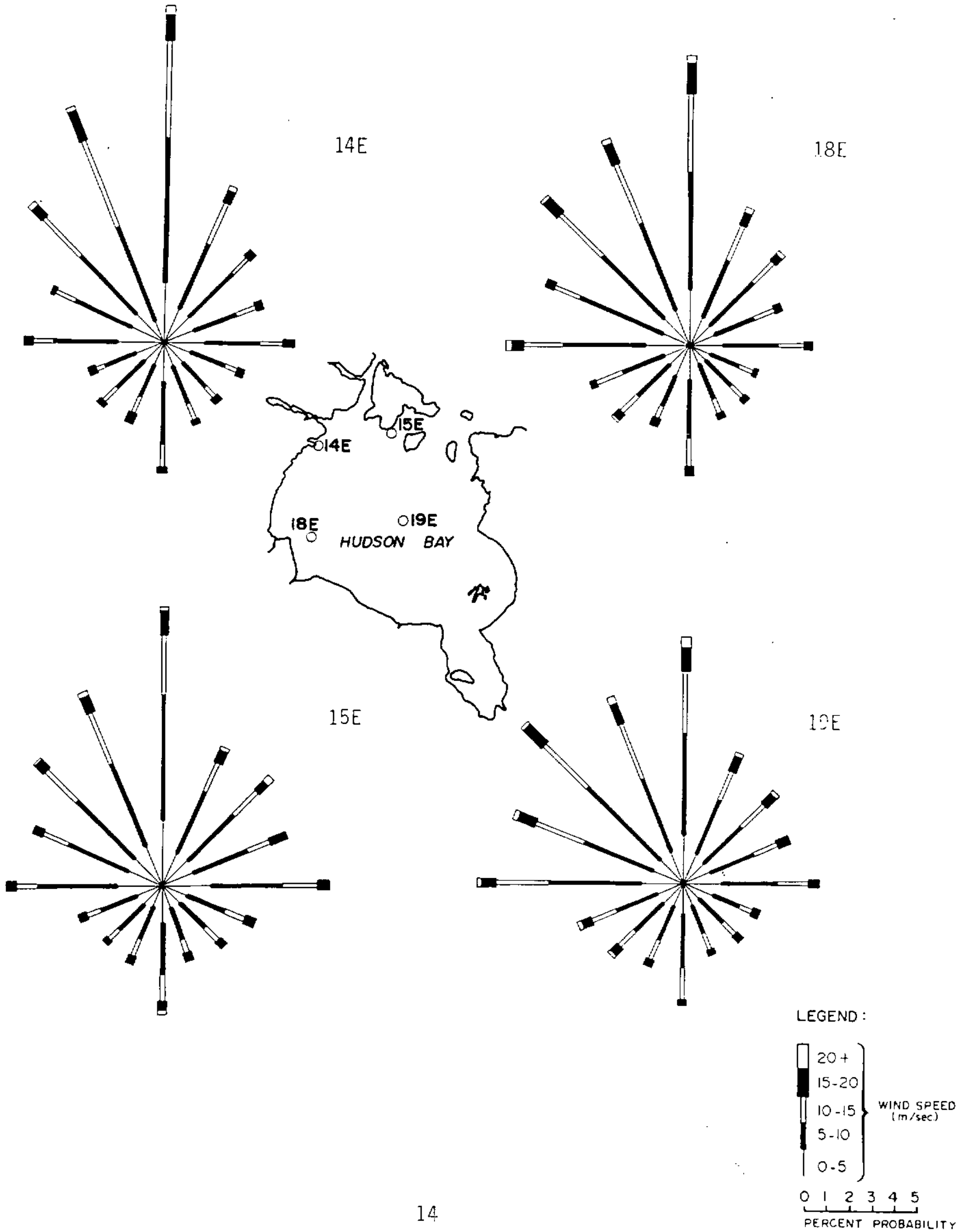


FIGURE 2-5 (cont'd)

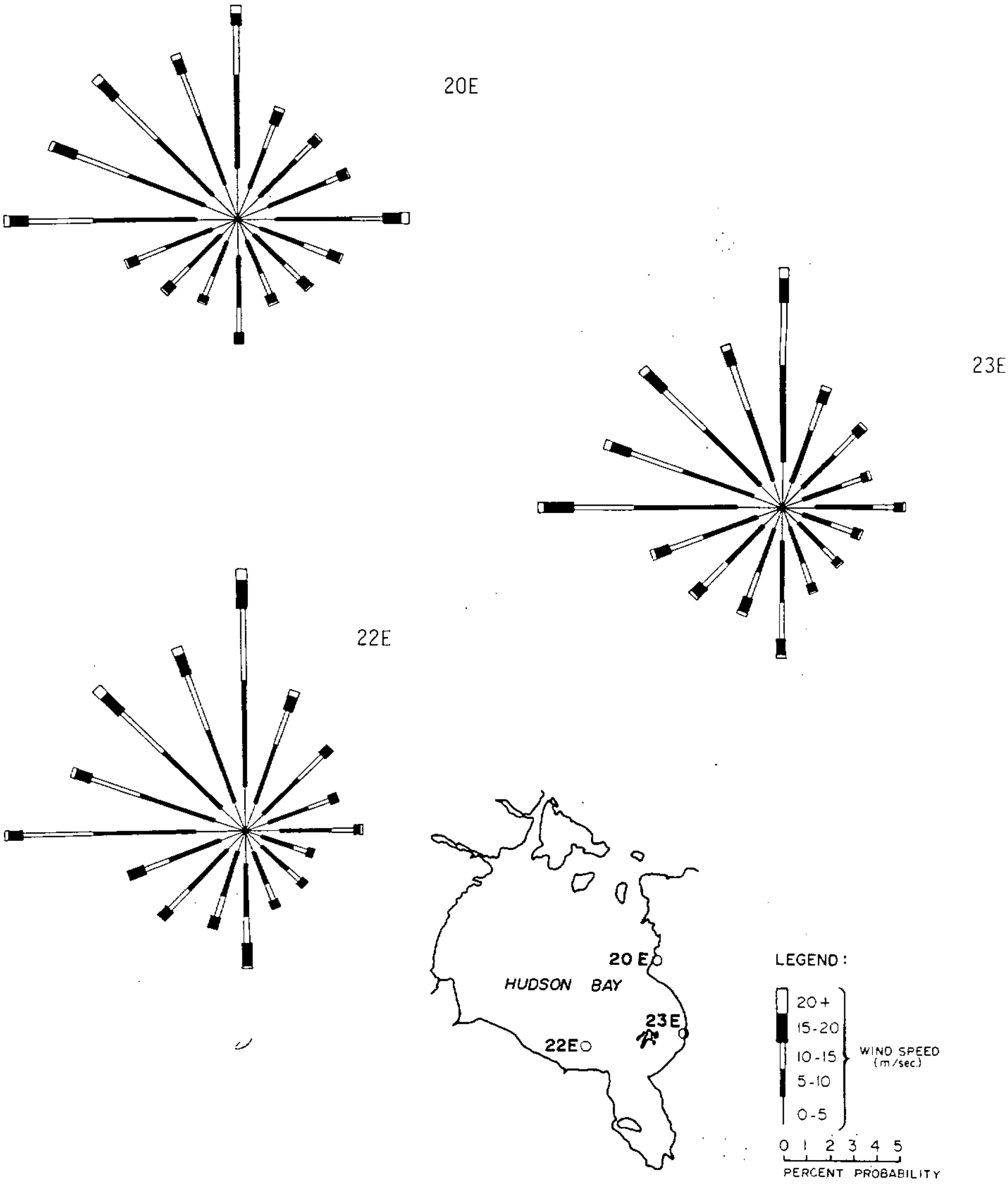


FIGURE 2-6

MONTHLY WIND ROSES (AUGUST THROUGH NOVEMBER) FOR TWO SELECTED GRID POINTS OVER HUDSON BAY

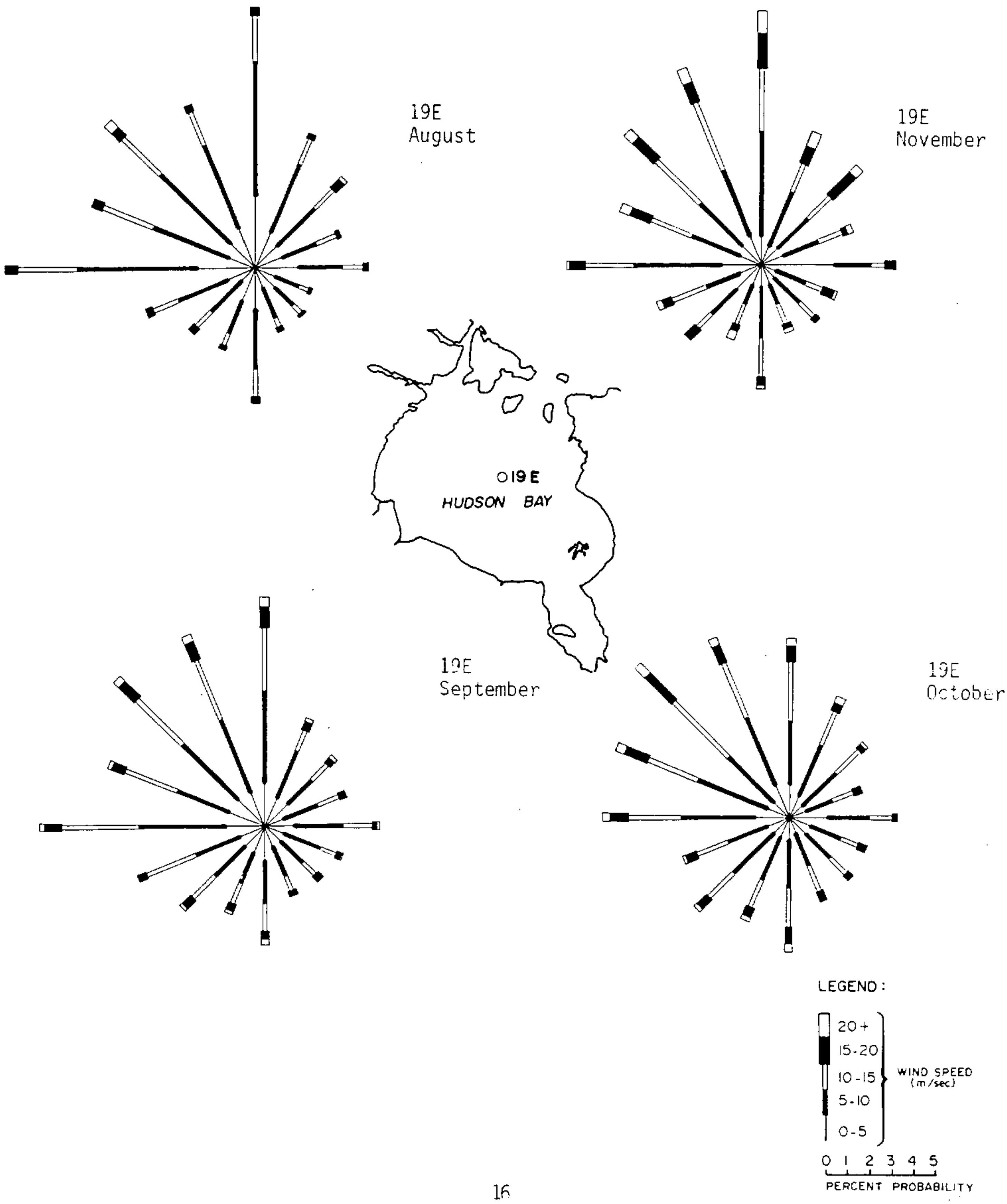


FIGURE 2-6 (cont'd)

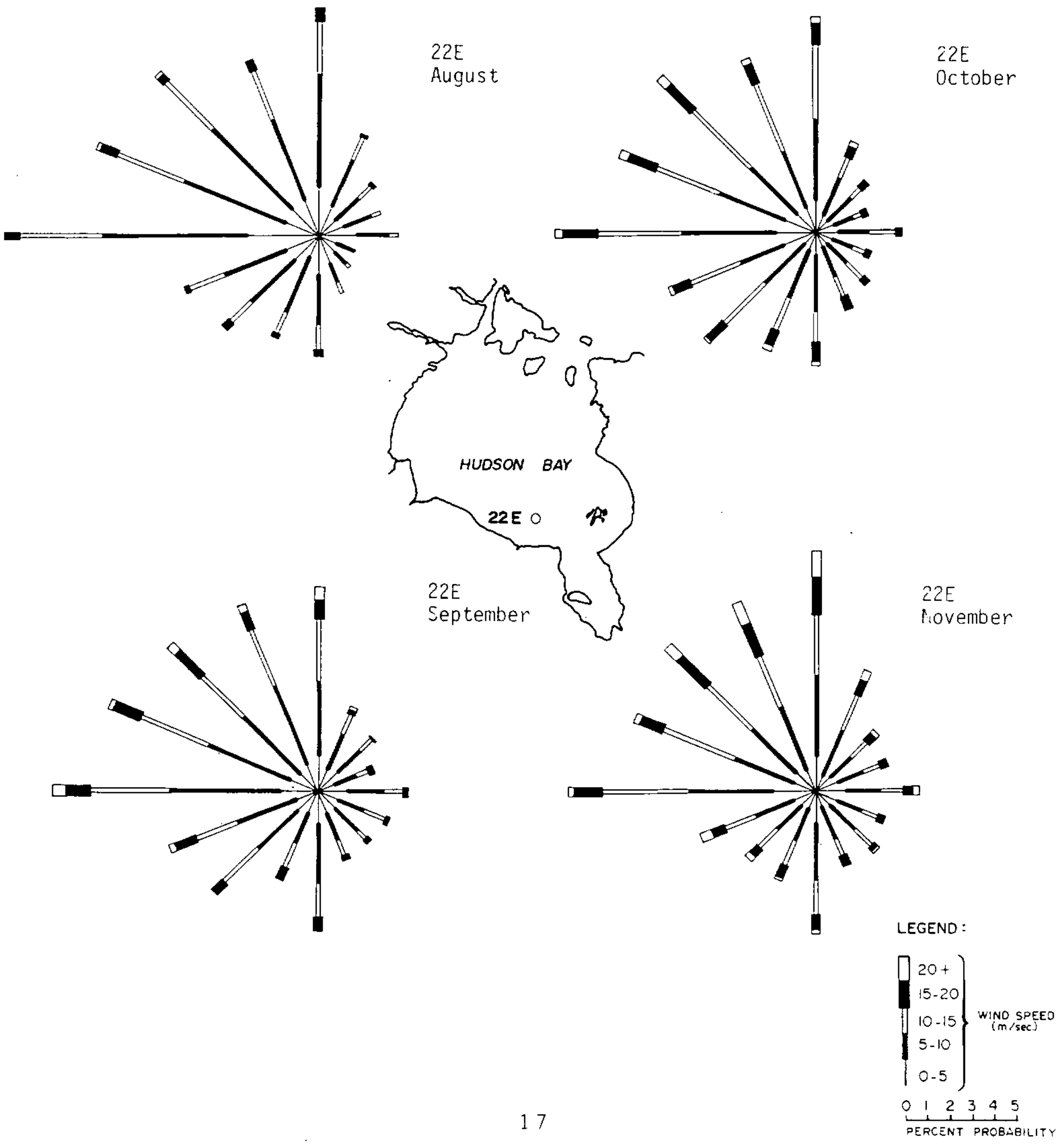


TABLE 2-1
FREQUENCY OF WIND SPEED OBSERVATIONS BY DURATION CLASS

STATION: 19E (59.5 N, 83.4 W) (AES Marine Geostrophic Wind Climatology)

MONTH: AUGUST

Duration (6-hr. Periods)	Wind Speed (m/s) >5	>10	>15	>20	>25	>30
1	36	52	19	1	0	0
2	12	38	17	0	0	0
3	19	32	5	2	1	0
4	22	25	6	0	0	0
5	20	17	2	1	0	0
6	17	11	4	0	0	0
7	14	11	2	0	0	0
8	19	8	1	0	0	0
9	7	7	0	0	0	0
10	8	7	0	0	0	0

MONTH: SEPTEMBER

Duration (6-hr. Periods)	>5	>10	>15	>20	>25	>30
1	25	43	29	9	3	1
2	11	37	27	8	2	0
3	17	39	22	6	0	0
4	19	31	8	4	0	0
5	16	25	13	1	0	0
6	11	14	8	1	0	0
7	14	33	4	0	0	0
8	7	12	1	0	0	0
9	13	12	1	0	0	0
10	23	7	0	0	0	0

MONTH: OCTOBER

Duration (6-hr. Periods)	>5	>10	>15	>20	>25	>30
1	23	52	25	20	5	0
2	10	32	40	9	4	1
3	15	33	37	12	1	0
4	18	35	25	8	0	0
5	19	30	11	1	0	0
6	19	25	12	1	0	0
7	8	18	3	0	0	0
8	6	17	1	0	0	0
9	17	10	2	1	0	0
10	13	5	3	0	0	0

TABLE 2-1 (continued)

MONTH: NOVEMBER

Duration (6-hr. Periods)	Wind Speed (m/s) >5	>10	>15	>20	>25	>30
1	25	38	34	16	4	0
2	19	33	24	16	2	1
3	11	31	23	10	0	0
4	19	28	23	4	1	0
5	18	34	13	2	1	0
6	14	12	8	3	0	0
7	18	18	11	0	1	0
8	18	13	6	0	0	0
9	9	7	0	1	0	0
10	9	11	2	1	0	0

There is a sparse data base for surface winds although some valuable data may be available from a weather buoy operated during the 1969 drilling campaign. There is an inadequate data base to correct land-based data to offshore conditions. However, the geostrophic winds corrected to the surface would provide, as a first estimate, an indication of the wind conditions over the Bay. These estimates should be verified by observations on the Bay as they do not represent extreme wind conditions. Long term wind observations would offer an acceptable verification of the calculated winds. This may be satisfied in part by the 1969 weather buoy data and should be sufficient for planning purposes.

2.5 OTHER METEOROLOGIC PARAMETERS

The source of information on meteorologic parameters other than wind are land-based stations and ship observations. Although ship observations are of limited use due to the sparse amount of data, some reference will be made to this data-set where warranted. Danielson (1969), who used ship as well as land data, has carried out a thorough climatological study except for precipitation.

2.5.1 Air Temperature

Figure 2-7 shows the patterns of monthly air temperatures throughout the year (Danielson, 1969). Mean temperatures remain below freezing over the entire region until May when they rise above 0 C south of about 55 degrees north. In the fall and early winter, there are warm areas over open water (i.e. see November and December in Figure 2-7).

For comparison to over water temperatures, the mean air temperatures are provided for Churchill and Inukjuak in Table 2-2.

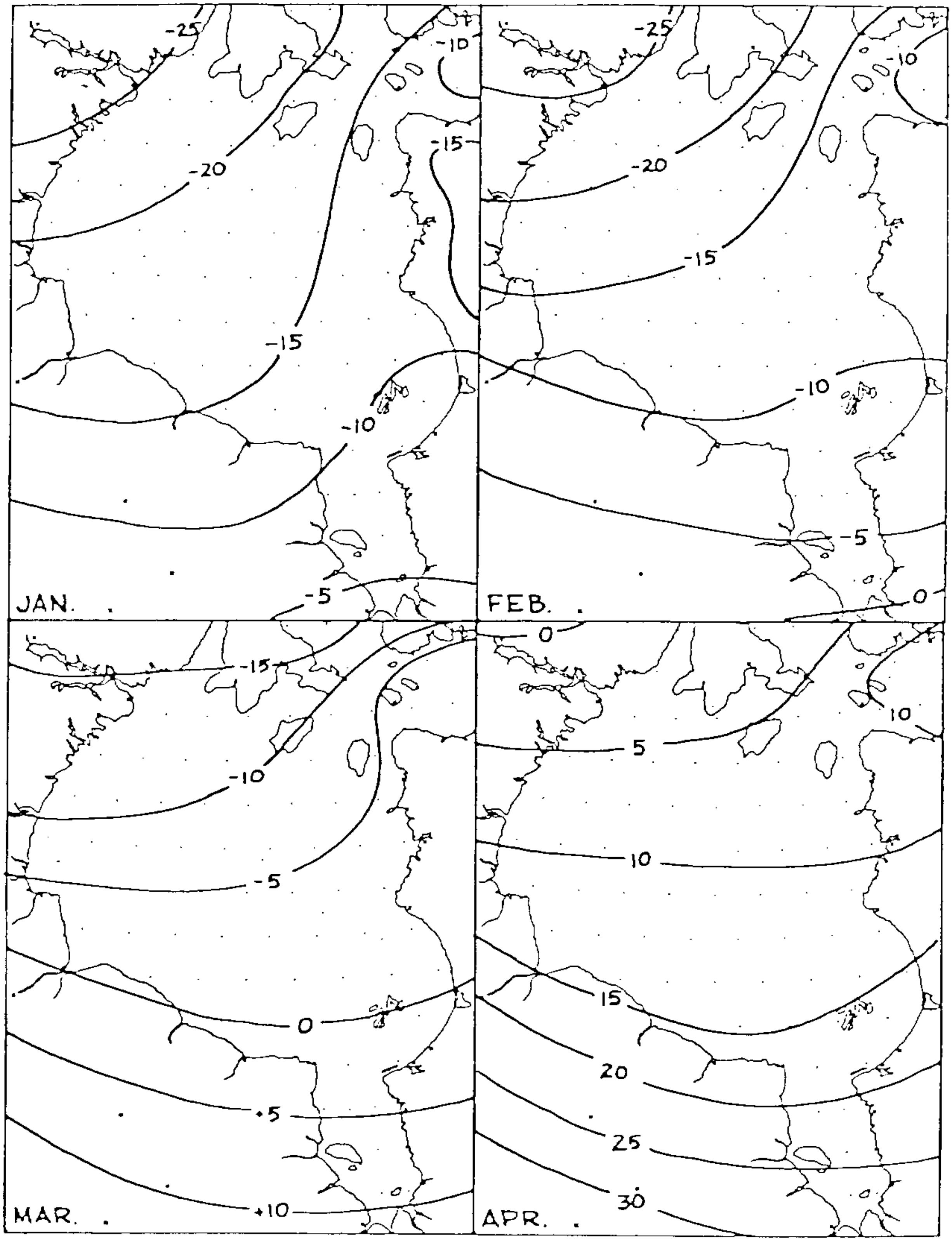


Fig. 2-7 Mean air temperature (deg F) (from Danielson, 1969).

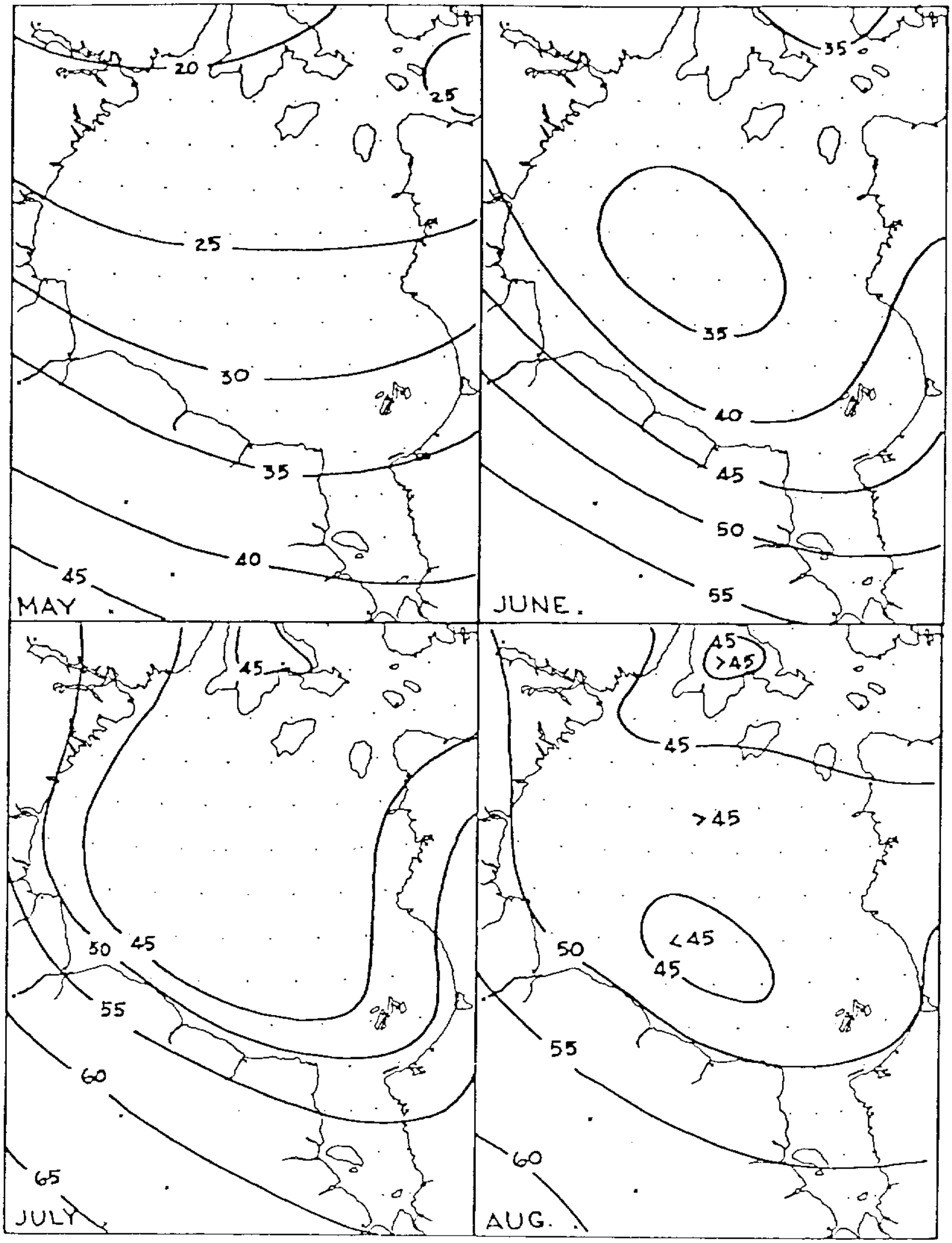


Fig. 2-7 (continued)

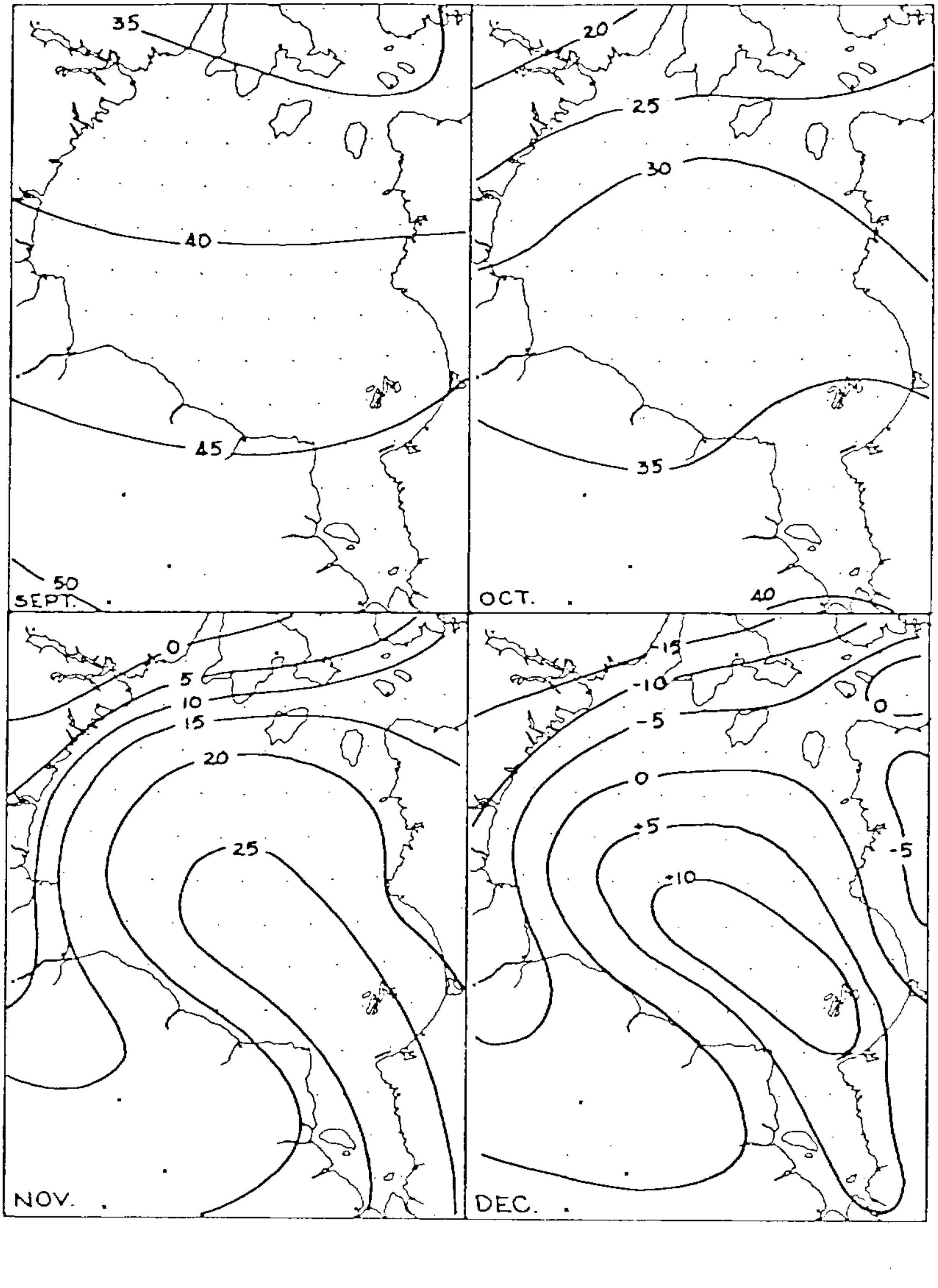


Fig. 2-7 (continued)

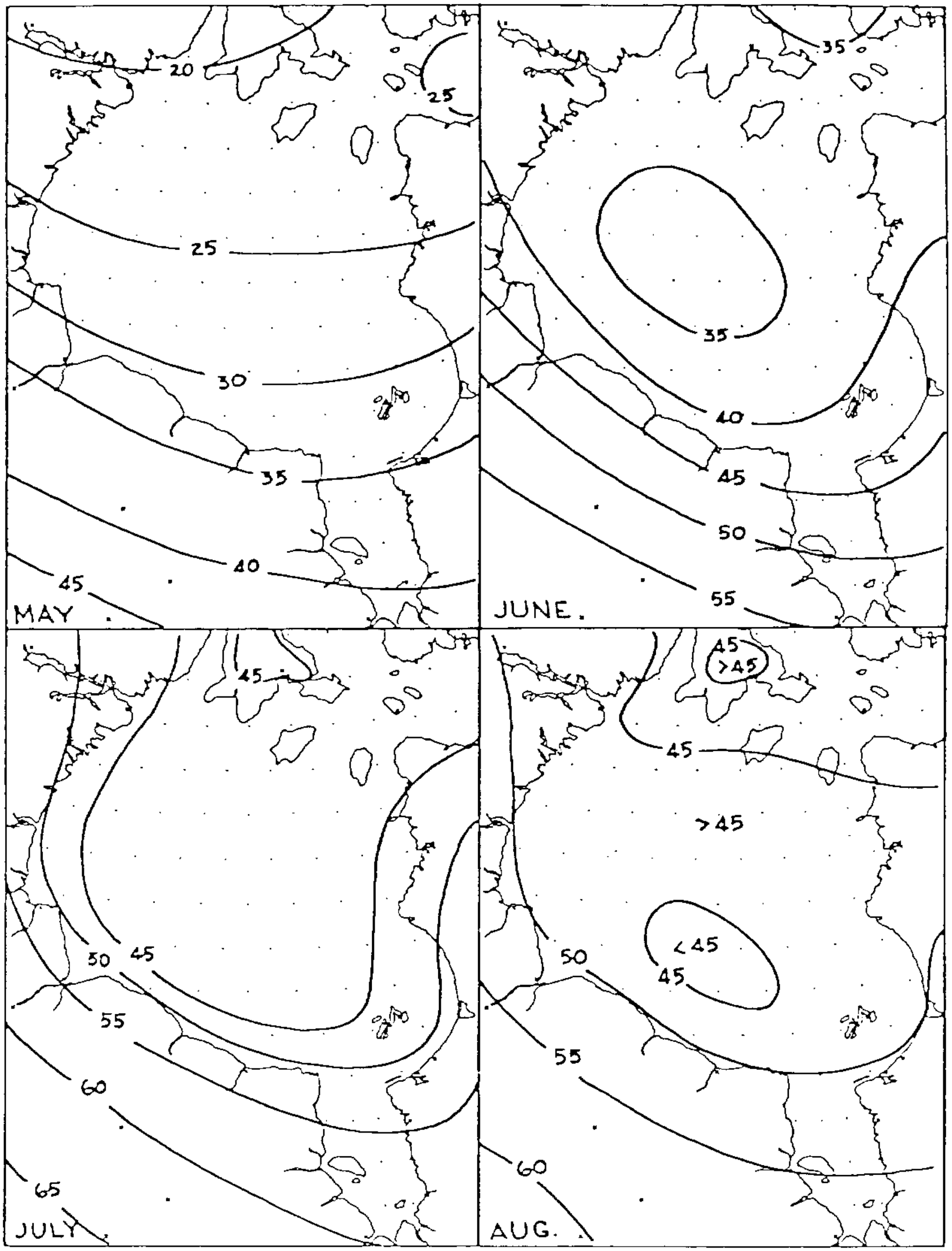


Fig. 2-7 (continued)

TABLE 2-2

MONTHLY MEAN AIR TEMPERATURES FOR CHURCHILL AND INUKJUAK

degrees centrigrade

Month	Churchill			Inukjuak		
	Extreme Minimum	Mean	Extreme Maximum	Extreme Minimum	Mean	Extreme Maximum
Jan	-45.0	-27.5	0.0	-46.1	-24.5	0.6
Feb	-45.4	-25.9	1.1	-43.9	-25.0	5.0
Mar	-43.9	-20.4	5.6	-45.0	-20.6	3.9
Apr	-33.3	-10.1	28.2	-34.4	-10.9	7.2
May	-21.7	-1.5	27.2	-25.6	-1.6	23.3
Jun	-9.4	6.2	31.1	-9.4	4.4	30.0
Jul	-2.2	11.8	33.9	-6.7	9.3	27.8
Aug	-2.2	11.3	32.8	-2.2	8.9	25.6
Sep	-11.7	5.4	27.8	-11.1	5.0	22.8
Oct	-22.4	-1.5	20.6	-22.8	-0.4	16.7
Nov	-36.1	-12.1	7.2	-33.9	-7.2	8.3
Dec	-40.0	-22.2	2.2	-43.3	-17.9	7.2
YEAR	-45.4	-7.2	33.9	-46.1	-6.7	30.0

Source: Atmospheric Environment Service, 1983

During July and August the temperatures are lower on the east coast than the west coast mainly due to cooling of westerly winds over the partially ice covered Bay. In October the trend reverses with the east coast temperatures being higher than the west coast as westerly winds traverse the relatively warm open water of Hudson Bay.

2.5.2 Precipitation

There are no known precipitation records in Hudson Bay. Shore stations give some indication of the seasonal variability and some knowledge of the precipitation regime over the Bay. Table 2-3 gives precipitation data for Inukjuak and Churchill. The heaviest precipitation occurs between June and October. All west shore stations receive less precipitation than those on the east shore. Perhaps most critical from operations viewpoint is the accumulation of freezing precipitation on horizontal and vertical surfaces. Extreme values for ice accretion for Churchill and Poste de la Baleine are given in Table 2-4.

TABLE 2-3

MONTHLY PRECPITATION

AT CHURCHILL AND INUKJUAK (INOUCDJOUAC)

CHURCHILL A
58° 45'N 94° 4'W 29 m

	JAN JAN	FEB FÉV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEP SEPT	OCT OCT	NOV NOV	DEC DÉC	YEAR ANNÉE	CODE CODE
Rainfall	T	0.1	0.6	2.0	13.5	39.9	45.6	58.3	44.5	15.4	1.0	0.2	221.1	1
Snowfall	16.9	14.6	18.6	22.3	19.5	3.5	0.0	0.0	6.4	29.3	41.6	22.8	195.5	1
Total Precipitation	**15.3**	**13.1**	**18.1**	**22.9**	**31.9**	**43.5**	**45.6**	**58.3**	**50.9**	**43.0**	**38.8**	**20.9**	**402.3**	1
Standard Deviation, Total Precipitation	9.5	7.9	13.5	19.6	24.4	29.8	21.9	28.0	22.4	21.4	19.2	13.0	87.4	1
Greatest Rainfall in 24 hours	0.3	1.3	15.2	8.4	22.4	32.5	52.3	51.1	42.2	26.2	4.0	1.8	52.3	
Years of Record	37	37	38	37	38	38	38	37	37	38	38	38		
Greatest Snowfall in 24 hours	16.0	12.7	22.6	25.4	47.6	15.7	T	T	17.5	36.1	35.1	21.8	47.6	
Years of Record	37	37	38	37	38	37	38	37	38	38	38	38		
Greatest Precipitation in 24 hours	12.9	12.7	21.9	25.4	55.6	32.5	52.3	51.1	42.2	35.8	35.1	21.8	55.6	
Years of Record	37	37	38	37	38	38	38	37	37	38	38	38		
Days with Rain	•	0	•	1	5	9	11	13	12	6	1	•	58	1
Days with Snow	11	10	10	10	7	2	0	0	4	14	18	14	100	1
Days with Precipitation	11	10	10	10	11	10	11	13	14	17	18	13	148	1

INOUCDJOUAC A
58° 27'N 78° 7'W 5 m

	JAN JAN	FEB FÉV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEP SEPT	OCT OCT	NOV NOV	DEC DÉC	YEAR ANNÉE	CODE CODE
Rainfall	T	0.0	0.2	1.9	12.5	31.1	53.9	64.9	54.2	24.4	3.1	0.1	246.3	1
Snowfall	10.0	8.7	9.0	13.3	11.1	3.7	0.4	T	4.9	22.0	37.9	23.2	144.2	1
Total Precipitation	**9.8**	**8.6**	**9.0**	**14.6**	**23.4**	**34.7**	**54.2**	**65.0**	**59.2**	**45.9**	**39.6**	**22.5**	**386.5**	1
Standard Deviation, Total Precipitation	8.6	8.3	7.2	14.9	16.1	19.0	31.1	25.0	26.8	17.2	20.0	17.7	96.3	1
Greatest Rainfall in 24 hours	T	0.8	1.3	9.7	25.9	38.6	40.1	48.5	32.3	36.8	9.7	1.0	48.5	
Years of Record	42	43	43	44	47	50	52	47	53	52	47	47		
Greatest Snowfall in 24 hours	13.5	10.4	22.9	34.1	17.0	8.9	6.4	0.8	19.4	28.2	43.2	34.3	43.2	
Years of Record	43	44	43	44	47	50	49	45	51	48	47	47		
Greatest Precipitation in 24 hours	13.5	10.4	22.9	34.1	25.9	38.6	40.1	48.5	30.2	34.5	43.2	34.3	48.5	
Years of Record	43	44	43	44	47	50	49	44	50	48	47	47		
Days with Rain	0	0	•	1	4	8	11	14	14	8	1	•	61	1
Days with Snow	8	7	7	8	8	3	•	•	3	11	18	13	86	1
Days with Precipitation	8	7	7	8	11	9	11	14	16	17	18	13	139	1

Source: Atmospheric Environment Service, 1983

TABLE 2-4

ICE ACCRETION AT CHURCHILL AND POST DE LA BALEINE

	ACCUMULATION ON HORIZONTAL SURFACE (in)		ACCUMULATION ON VERTICAL SURFACE (in)	
	Churchill	Poste de la Baleine	Churchill	Poste de la Baleine
Average	0.15	0.07	0.29	0.14
RETURN PERIOD				
2 years	0.10	0.05	0.20	0.11
5 years	0.40	0.14	0.66	0.28
10 years	0.60	0.20	0.97	0.39
20 years	0.78	0.26	1.25	0.49
30 years	0.89	0.29	1.42	0.56

Source: Chaine and Skeates (1974)

The lower values of ice accretion on the east coast compared with the west coast correspond to the precipitation pattern noted before. The potential problem of sea spray freezing on structures is discussed in Section 3.7 Sea Spray Icing.

2.5.3 Fog and Visibility

Long term records for fog and visibility are available only for land stations. The fog frequency for Churchill and Poste de la Baleine for the months of July through December are given in Table 2-5. Fog formation is most frequent in late summer, when relatively warm water provides adequate moisture to increasingly cold air.

TABLE 2-5

PERCENTAGE FREQUENCY OF FOG

Station	Jul	Aug	Sep	Oct	Nov	Dec
Poste de la Baleine	21.2	22.6	11.1	7.1	2.6	3.3
Churchill	10.8	9.2	11.8	7.2	4.4	4.5

Source: Atmospheric Environment Service Hourly Data Summaries

During open water months (i.e. August through November), the incidence of fog formation will be greater over the Bay than at the land stations, due to additional moisture over the water surface.

Another constraint on visibility is the amount and level of cloud. Danielson (1969) has prepared monthly maps of cloud cover over Hudson Bay which are presented in Figure 2-8. After August the air is generally cooler than the water and the input of heat and water vapour becomes a major source of low clouds over the Bay. Percentage of cloudiness over the Bay reaches a maximum of 85% in October.

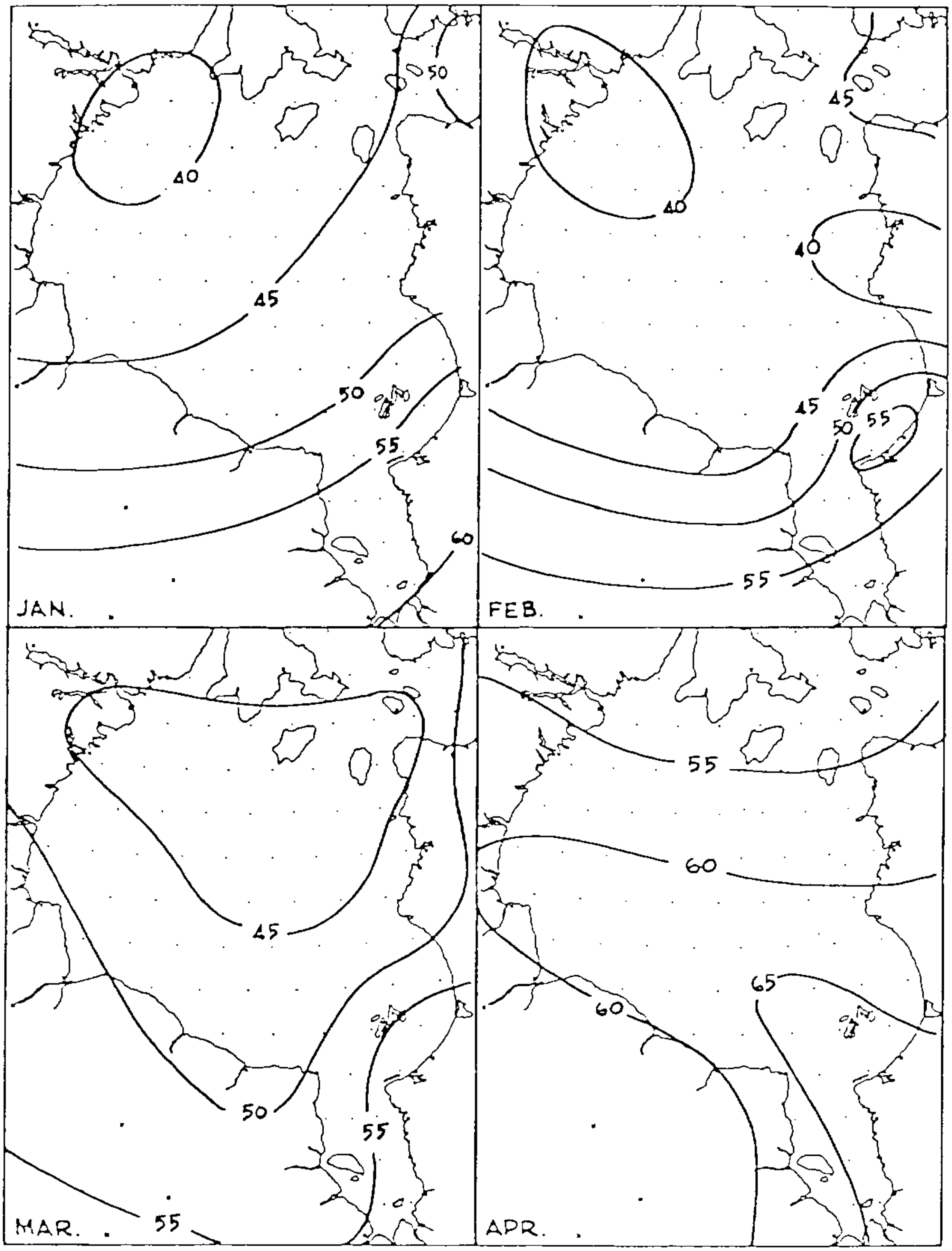


Fig. 2-8 Mean total cloud cover (per cent) (from Danielson, 1969).

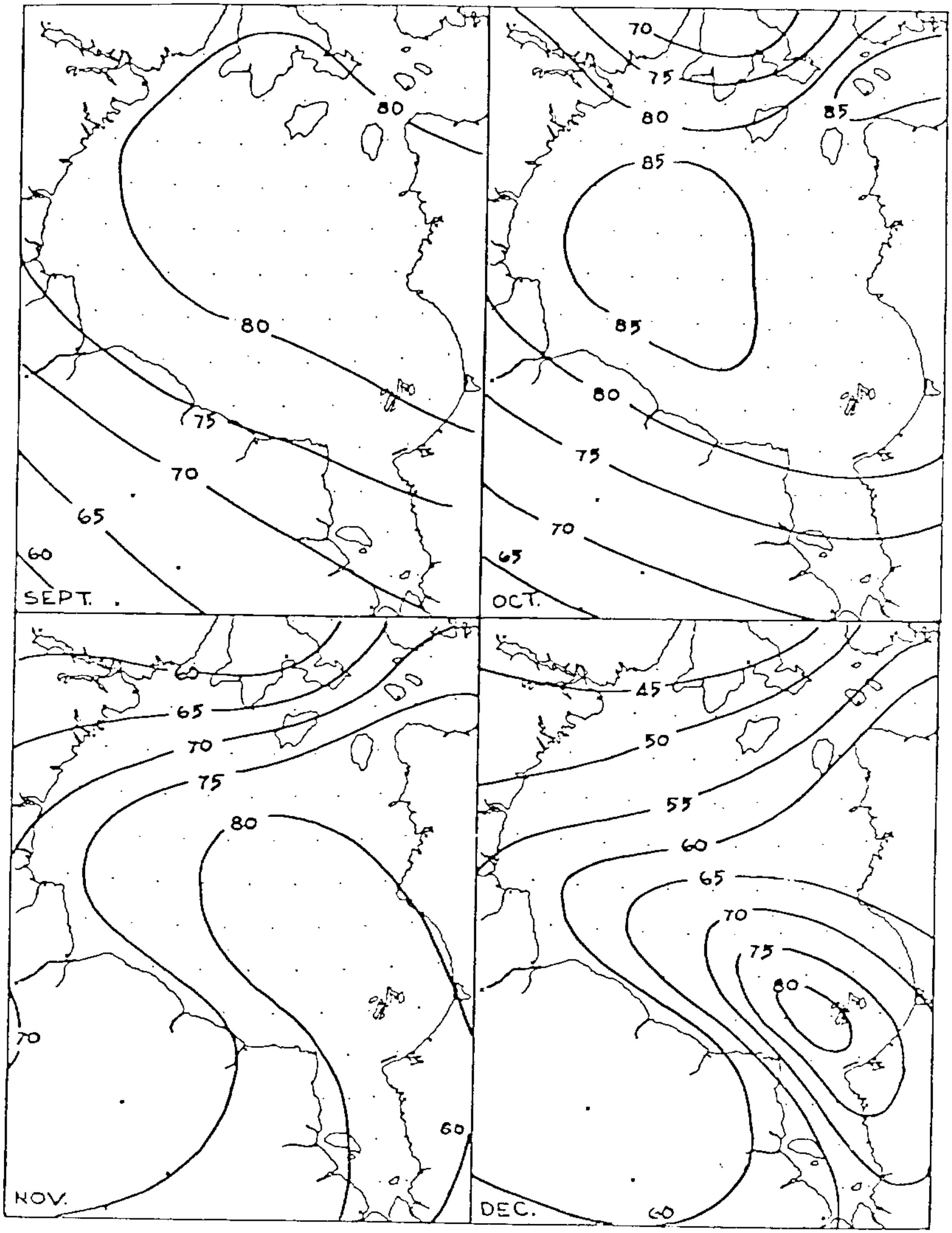


Fig. 2-8 (continued)

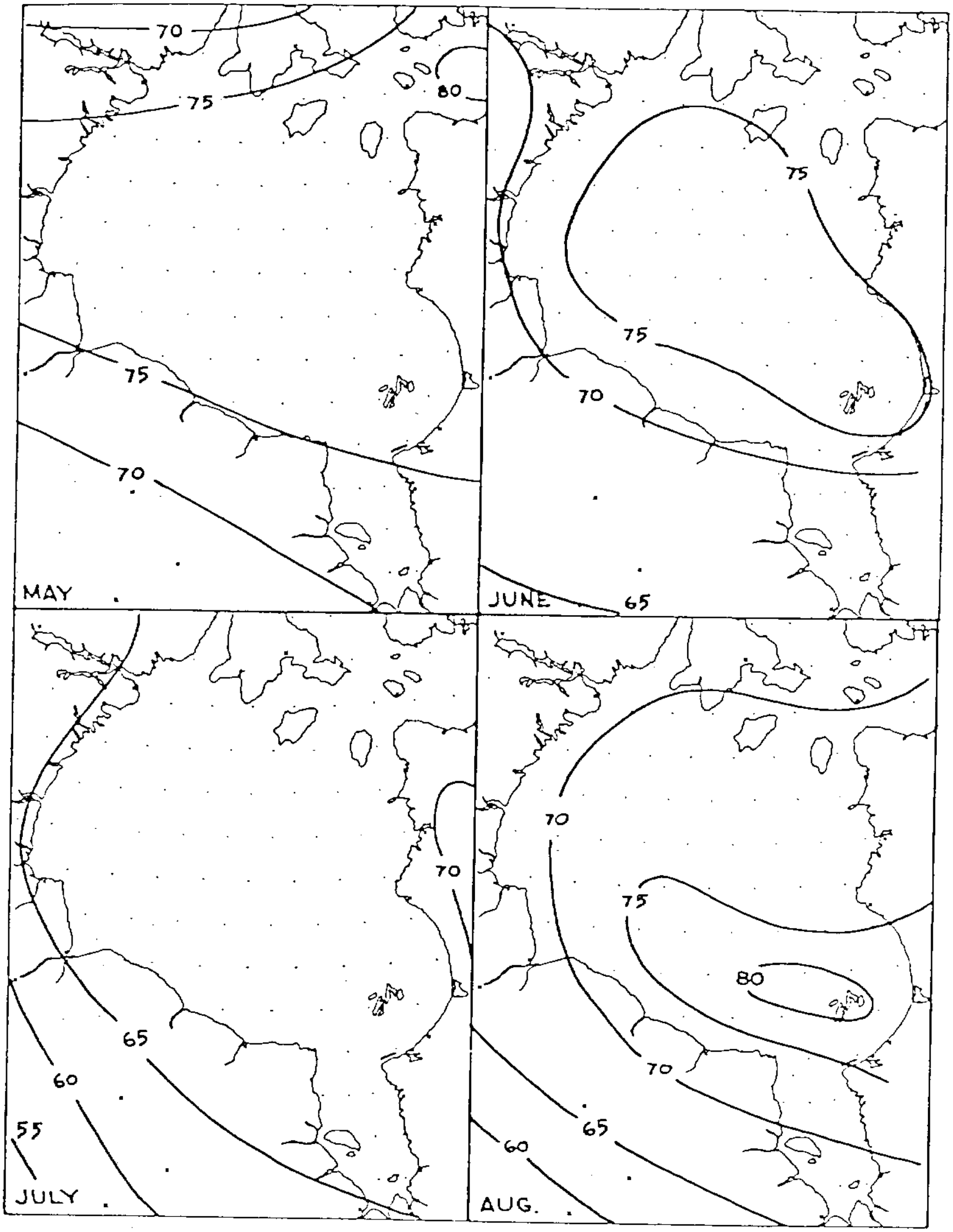


Fig. 2-8 (continued)

3. PHYSICAL OCEANOGRAPHY

3.1 INTRODUCTION

Hudson Bay is a relatively shallow water body within a gently sloping basin having a shoreline of low relief. The bay occupies an area of approximately 766,000 km² and has an average depth of about 125 m, with no known depths in excess of 235 m. Figure 3-1 illustrates the bathymetry of Hudson Bay, and Figure 3-2 contains three cross-sectional profiles of the bay along transects indicated on Figure 3-1.

The bottom sediments are mainly from glacial drift, which is a mixture of silts, sands, gravels, pebbles in variable proportions. Glacial boulders on or in the sediments are also possible. A more detailed discussion of bottom charcteristics is provided in Section 4.

The physical oceanographic parameters of greatest relevance to exploratory drilling in Hudson Bay include coastal physiography, ice conditions, currents and tides, and sea state. A comprehensive summary of relevant data for these parameters is provided below.

3.2 COASTAL PHYSIOGRAPHY

The physiography of the Hudson-James Bay coastal region, for the most part, is a reflection of regional geological structure. There are in effect three basic coastal types (1) low lying coasts associated with unmetamorphosed Palaeozoic sedimentary formations, (2) coastal cliff and headland areas, and (3) intervening areas of complex coastline exhibiting numerous small bays, inlets and headlands (Figure 3-3).

Low coastal sections occur more or less continuously from southern James Bay northwards along the west coast of James Bay and the southwest coast of Hudson Bay to the McConnel River some 100-150 km north of the Manitoba-N.W.T. border. Representation of this coastal type is also strongly expressed along southern and western

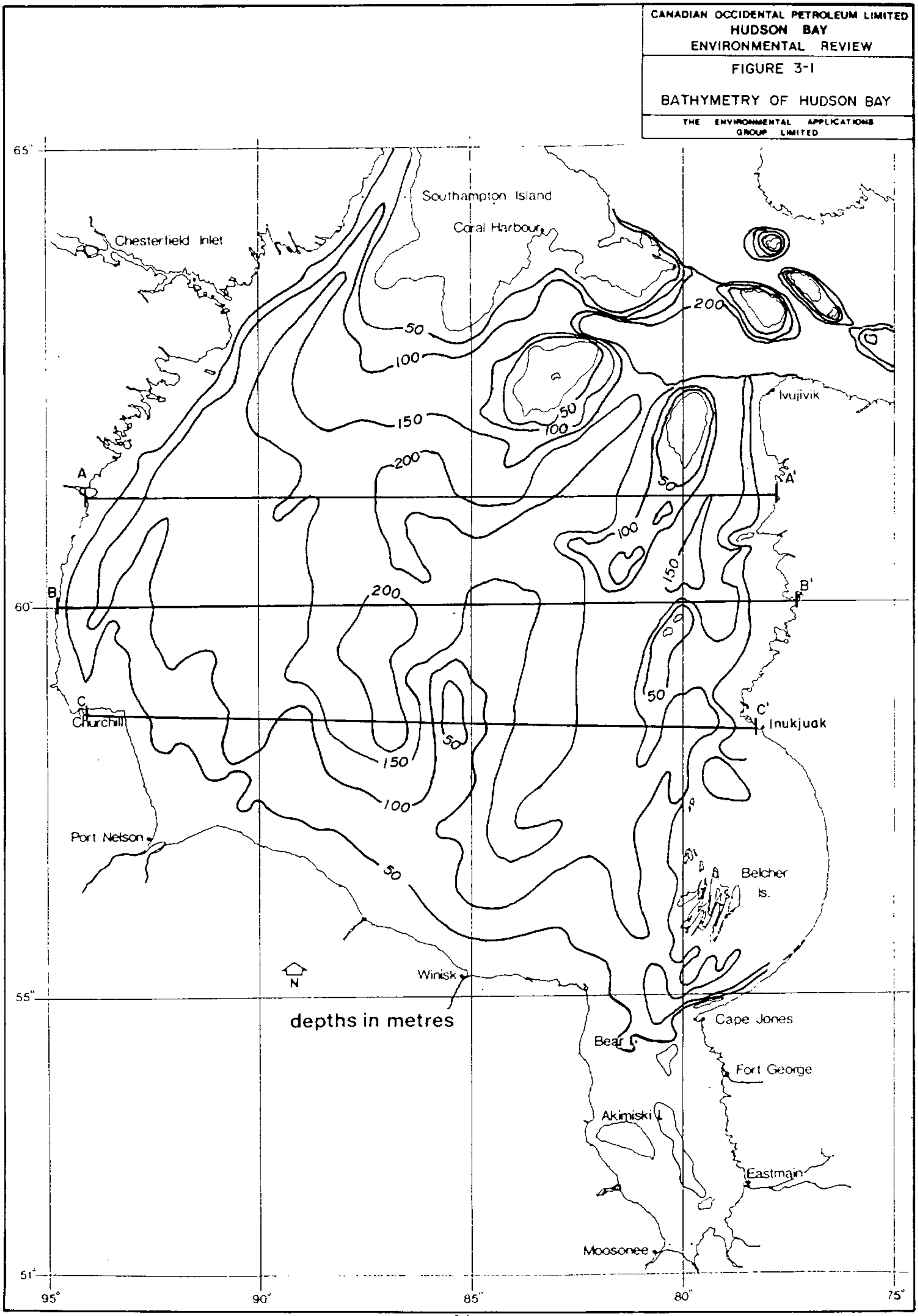
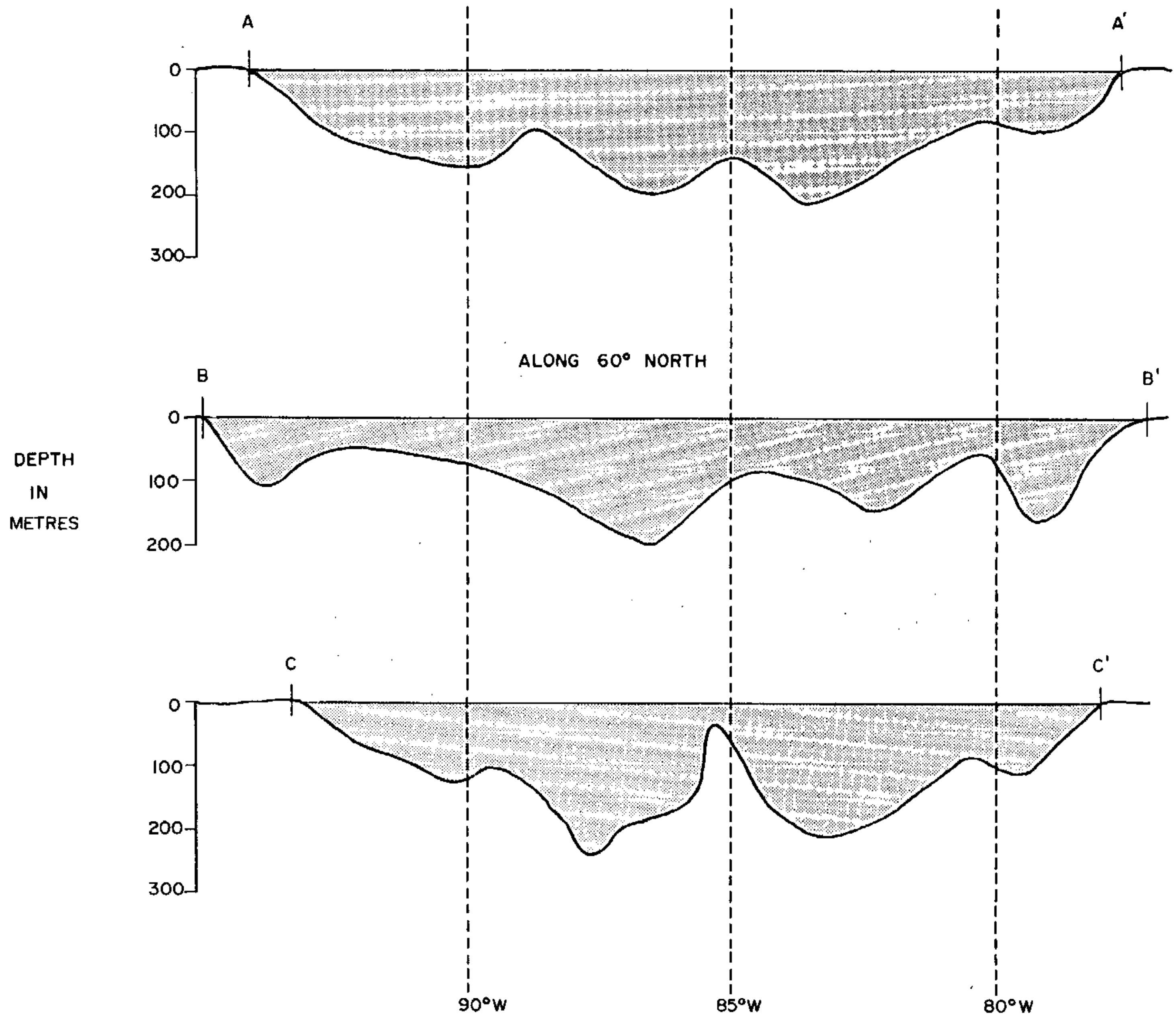


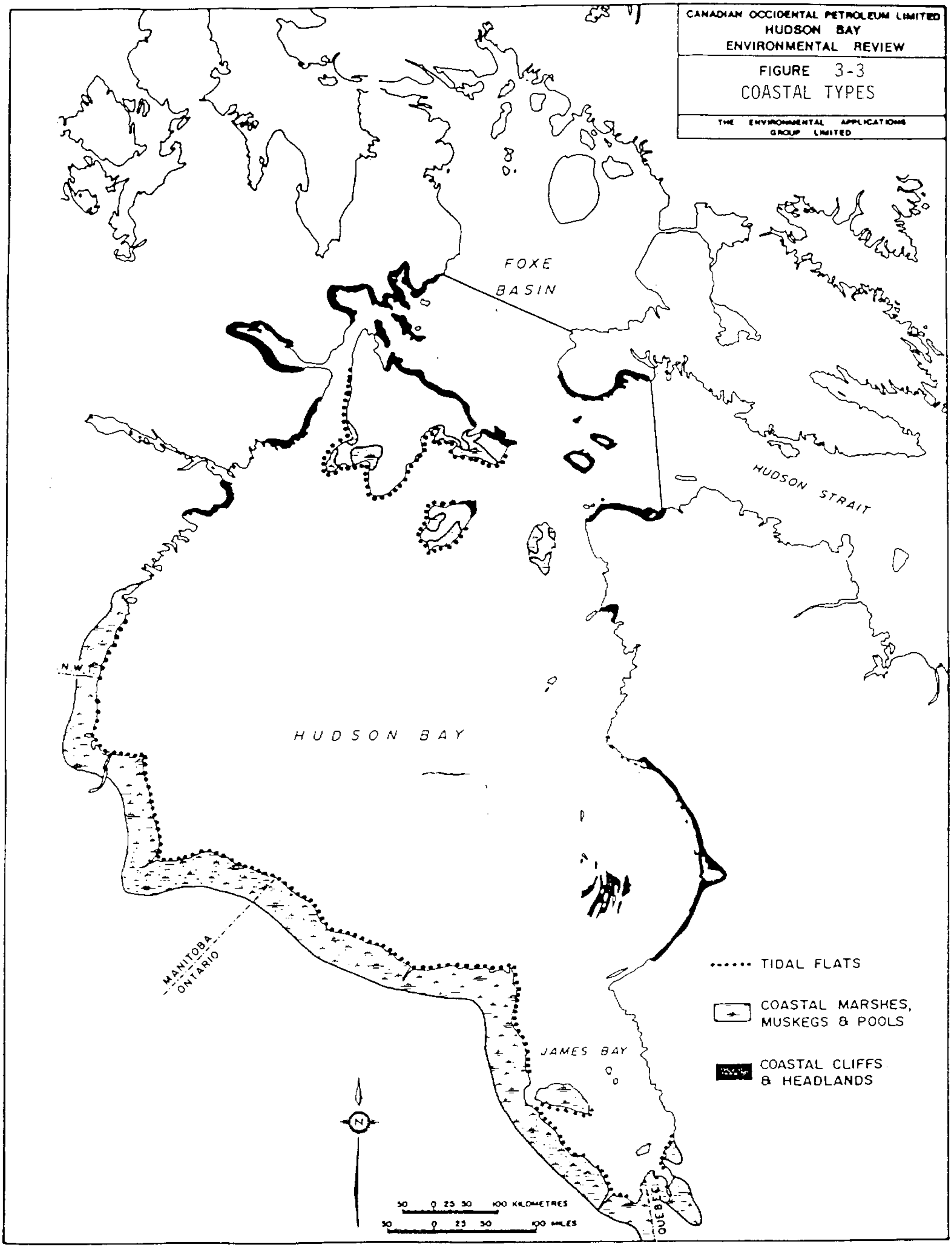
FIGURE 3-1

BATHYMETRY OF HUDSON BAY

FIGURE 3-2

CROSS-SECTIONAL PROFILES OF HUDSON BAY
(See Figure 3-1 for transect locations)




CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 3-3
COASTAL TYPES
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
N.W.T.
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
TIDAL FLATS
COASTAL MARSHES, MUSKEGS & POOLS
COASTAL CLIFFS & HEADLANDS
N
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

portions of Southampton Island, and on Coats and Mansel Islands at the north end of Hudson Bay. Associated onshore areas are characterized by extensive coastal marshes, muskegs and pools (Figure 3-3). Well developed raised beaches and abandoned shorelines are also characteristic features of onshore areas, their development having resulted from the combined isostatic rebound and low energy conditions. Offshore areas are characterized by expansive tidal mud flats, which in some locations are up to 10 km in width.

Well developed cliff coasts and headlands occur primarily in two distinct portions of the Region. The first area is located at the north end of Hudson Bay and includes the west end of Hudson Strait, northeast Southampton Island, and portions of the northwest coast of Hudson Bay. Most of these areas are associated with broadly developed fault systems and fold blocks (Bolton et al. 1977), and show a distribution similar to that of offshore submerged canyons and cliffs.

The remaining prominant cliff-headland area is that of the Richmond Gulf-Belcher Islands area, otherwise known as the Nastapoka Arc. Debate over the structural development of this area is continuing, but there is considerable evidence to suggest that cliffs of the Nastapoka Arc represent the exposed portion of an extremely large astroidal impact crater (Beals 1968). The crater is 457 km in diameter, and dips westward such that only 155 degrees of the arc is exposed.

Intervening complex coastal areas, mainly the east coast of James Bay, the east coast of Hudson Bay north from Inoucdjouac, and the west coast of Hudson Bay between Eskimo Point and Daly Bay owe their present form primarily to extensive folding and in some instances to volcanism. Associated differential erosion of exposed rock types has resulted in the development of an intricate coastline of small headlands and bays. These areas are among the more interesting of the Region from a physical and biological viewpoint, because of the complexity of land form types and associated habitats present.

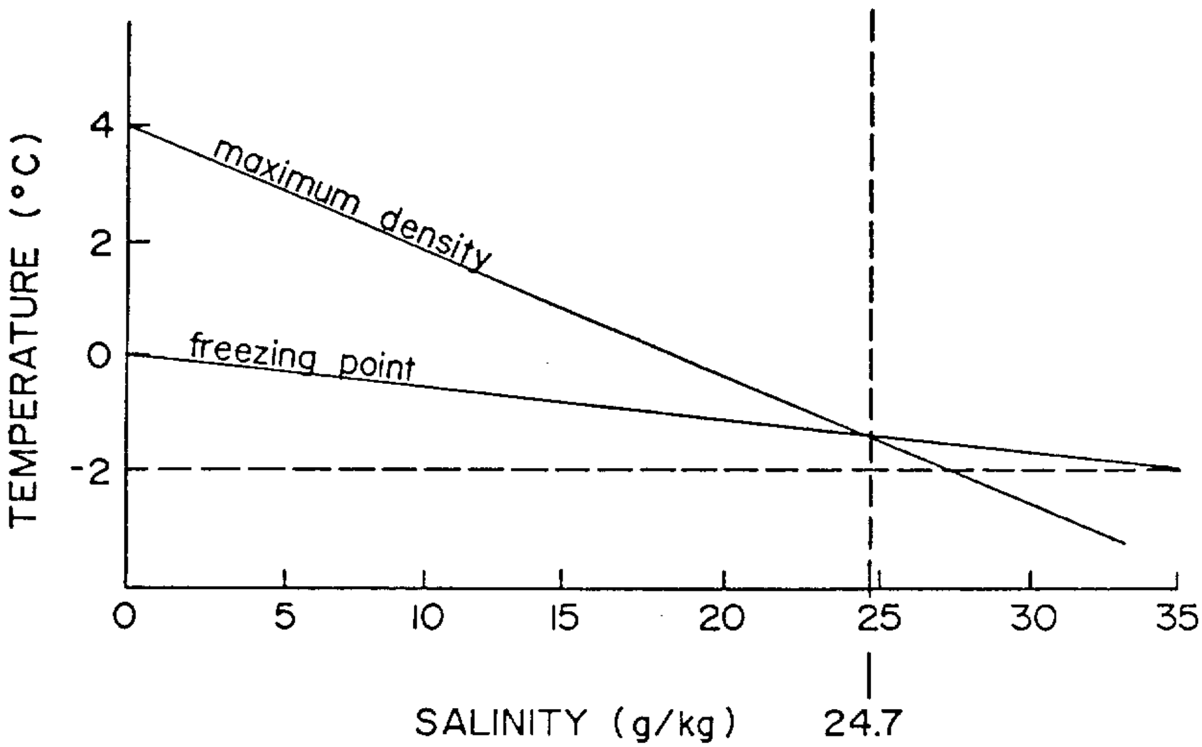
3.3 THERMAL AND SALINITY REGIME

An understanding of the thermal regime of Hudson Bay is important for planning and operations in that it determines the timing and rate of ice formation and disintegration and to an extent the seasonal variation of pycnocline depths.

There are a number of sources for data that can be used to infer a thermal regime. Danard et al. (1981) describe the growth of ice as being due to the difference between the heat flux into the atmosphere and the heat flux from the water to the ice. This is complicated by the relationship between salinity, temperature and density which results in a convective mixing of the surface layers in the fall and winter, referred to as the Arctic vertical winter circulation. As the temperature of the surface layer decreases, the density increases, resulting in an unstable vertical stratification and consequent vertical mixing between the surface and lower layers. As illustrated in Figure 3-4, when the surface layer achieves a maximum density, a further decrease in water temperature produces a thin stable layer that is much more prone to freezing.

Density gradients near the surface are due to salinity changes as well as to temperature differences. Doronin and Kheisin (1977) give an average salinity for Hudson Bay of between 32‰ and 33‰, which corresponds to the value 30‰ given by Prinsenberg (1982) for an area east-northeast of Churchill. According to the density, temperature and salinity relationship illustrated in Figure 3-4, this range of salinity will result in a freezing point between -1 and -2°C, at less than maximum density. Figures 3-5 and 3-6 contain water temperatures provided by AES drifter buoys in 1979 (Stark and Campbell, 1979) and in 1981 and 1982 (Markham 1983). These data indicate that along the buoy trajectory, ice formation may be expected near the end of November to early December, in spite of the fact that water temperatures may be below 0°C from early to mid November. Doronin (1970) has a nomogram for calculating the growth of ice from degree days, and Cox and Weeks (1974) use a linear regression for ice growth based on salinity values (Danard et al. 1981). Either method may be useful for future operations as an indicator of the timing of ice formation.

FIGURE 3-4 DENSITY, TEMPERATURE AND SALINITY RELATIONSHIPS OF SEA WATER



Source: Pounder (1965)

FIGURE 3-5

1981 HUDSON BAY WATER TEMPERATURES FROM AES BUOYS

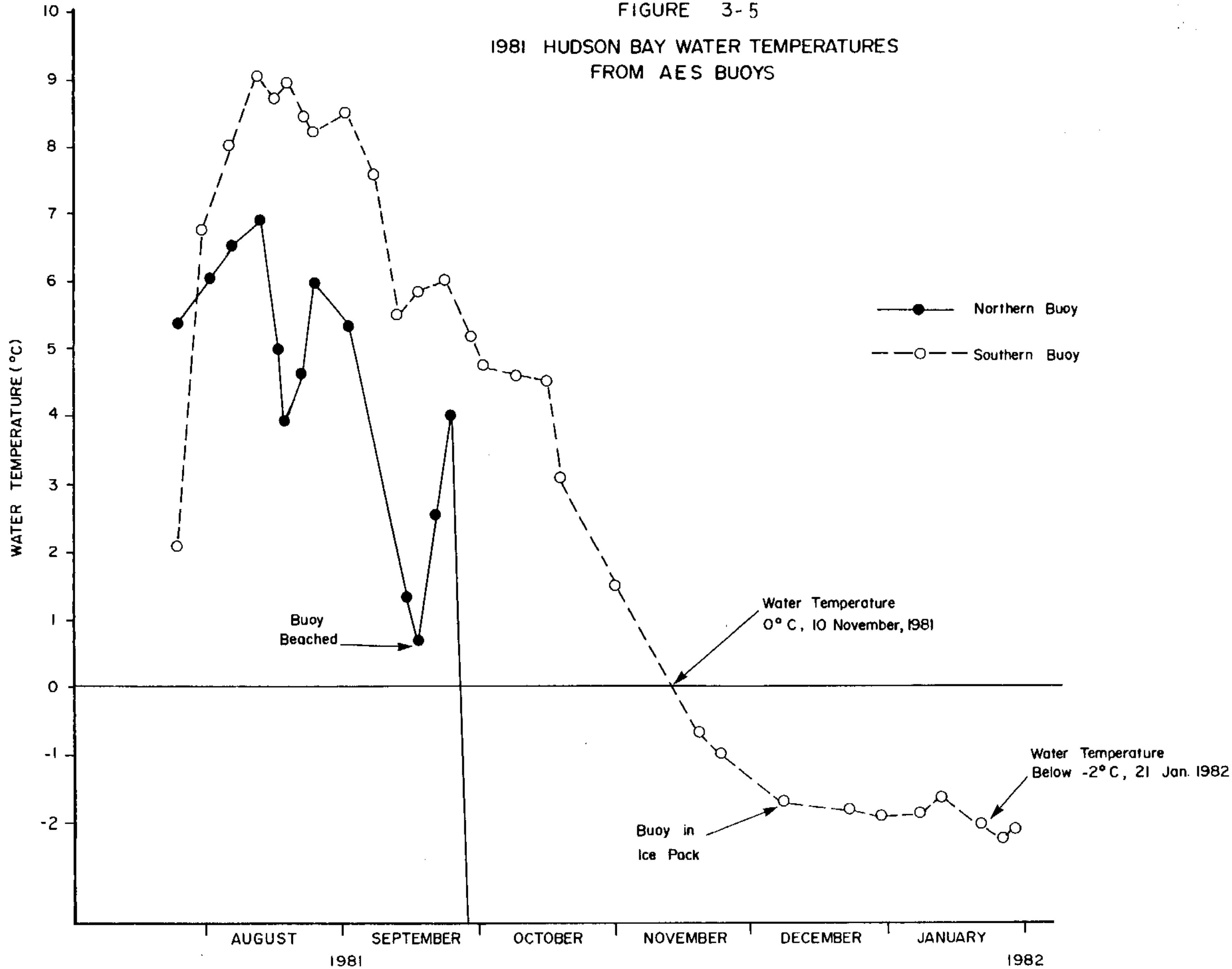
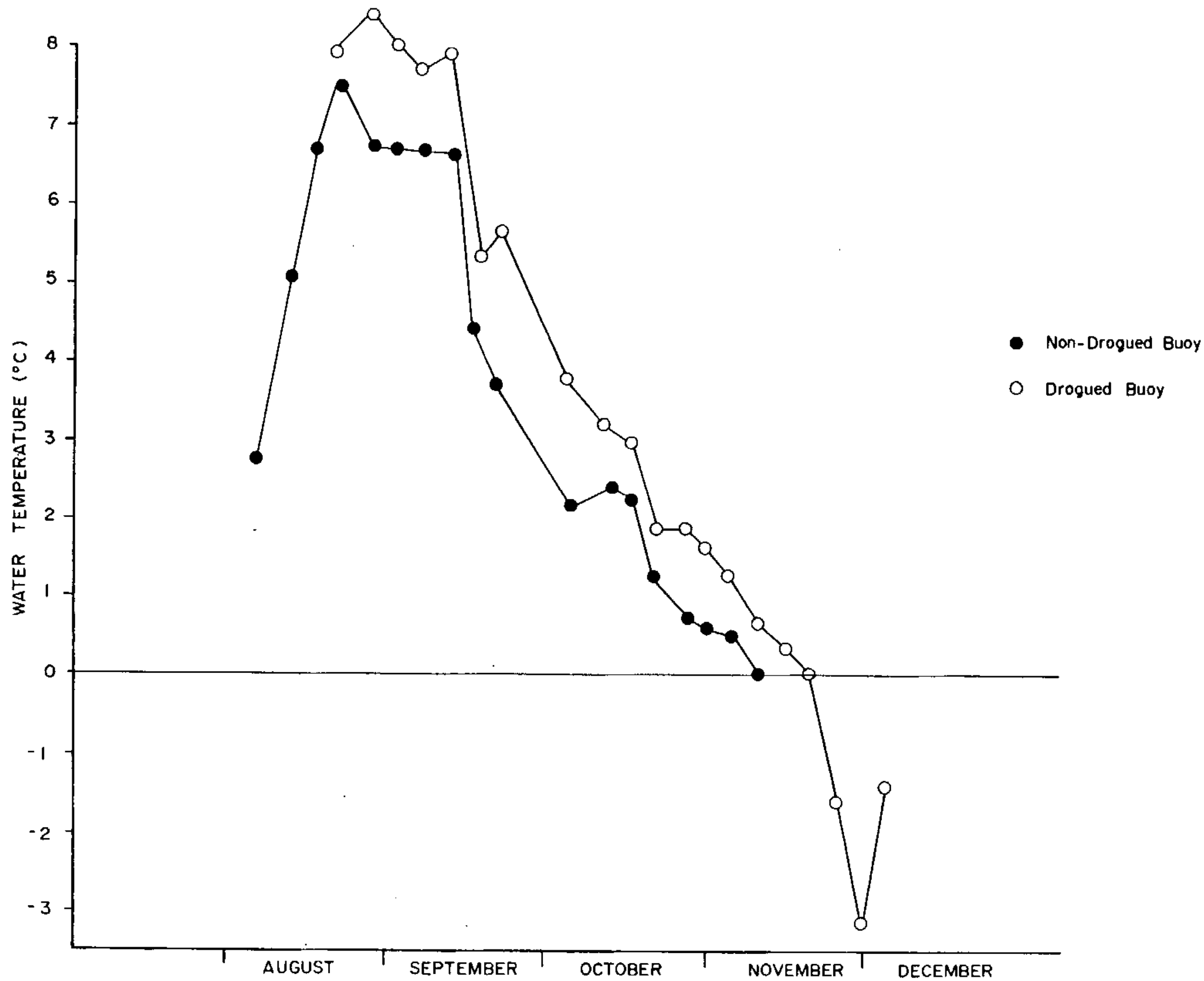


FIGURE 3- 6

1982 HUDSON BAY WATER TEMPERATURES
FROM AES BUOYS



Prinsenberg (1982) modelled the seasonal variation of pycnocline depths in Hudson Bay. Figure 3-7 shows that during the early summer pycnocline depth is at its minimum. As summer progresses, the surface water will reach its minimum salinity and temperature values before the pycnocline depth starts to increase. In fall, large storms and maximum cooling deepen the pycnocline. On the diagram, observed data ranges (denoted by range bars) are from the centre of Hudson Bay in 1975. A typical vertical profile of temperature and salinity for Hudson Bay in early September is shown in Figure 3-8.

3.4 ICE CONDITIONS

Hudson Bay is the largest body of water in the world that freezes completely over each winter and becomes ice-free in the summer (late August to late October). The absence of a stable ice cover during winter (January to April) prevents stationary ice-based drilling and requires a floating platform that is limited to operations during the ice-free period. This operational mode necessitates information concerning the extent of ice cover and the timing of freeze-up and break-up over the Bay and the entrance from the Atlantic, for both planning and operational purposes.

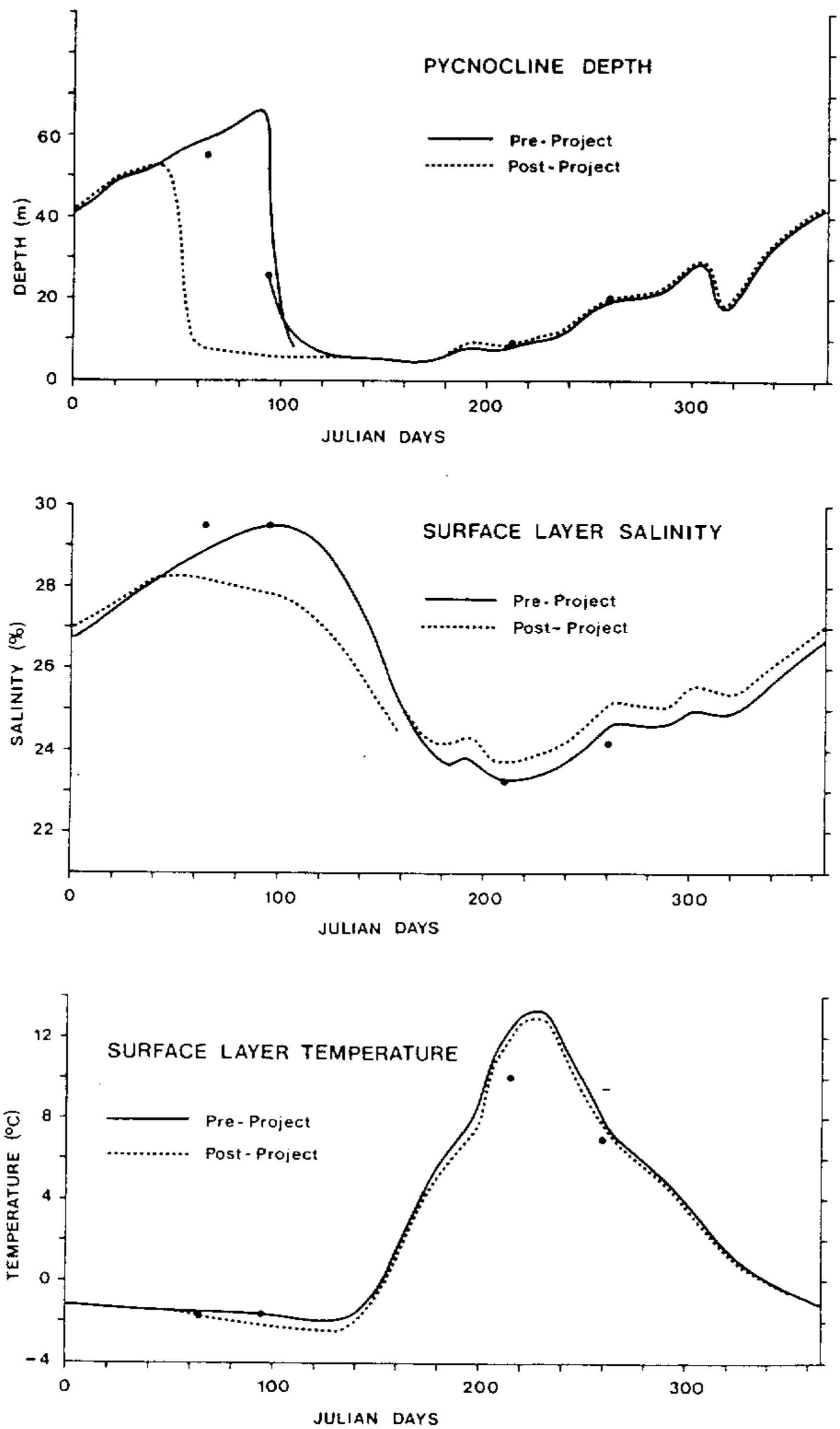
Ice reconnaissance flights over Hudson Bay have been made nearly every year since 1950 by the Atmospheric Environment Service (formerly the Meteorological Branch of the Department of Transport). These observations have been published yearly or bi-yearly as a series of circulars (i.e. Ice Summary and Analysis, 1968-70: Hudson Bay and Approaches). Since 1958 aerial surveys of ice break-up and formation in Hudson Bay have been conducted primarily in support of shipping.

Danielson (1969) presented monthly mean ice cover distributions for Hudson Bay based mainly on 9 years of aerial reconnaissance data from 1958 through 1966. Although 9 years of data were insufficient to draw conclusions on small scale features he made the following statements regarding the region:

1. Hudson Bay ice coverage varies annually from 0 percent to nearly 100 percent, with mean annual maximum ice thickness of about 1.5 metres (5 feet) occurring in April. In winter only a pronounced shore lead and isolated other leads interrupt a continuous ice pack.

FIGURE 3-7

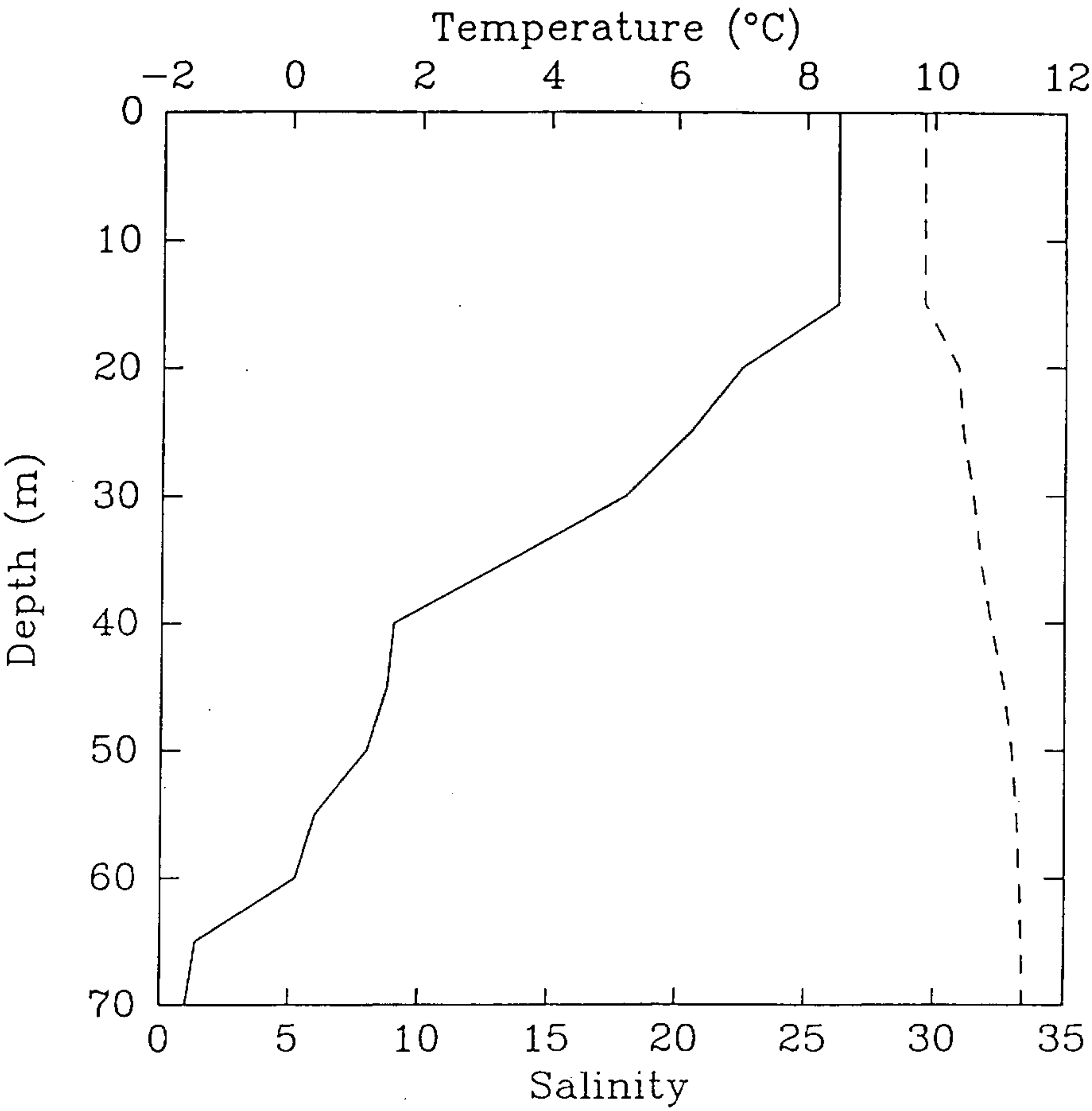
PYCNOCLINE DEPTHS, AND SURFACE SALINITY AND TEMPERATURE



Source: Prinsenberg (1982)

FIGURE 3-8

TEMPERATURE AND SALINITY PROFILE - EARLY SEPTEMBER



Source: Danard _et al_. (1982)

2. Ice break-up begins in May, appearing first in James Bay and along the western, northern, and eastern shores of Hudson Bay. The local appearance of open water is controlled by wind direction and current movement as well as thawing.

3. The islands in eastern Hudson Bay may hasten break-up in that area.

4. Most years, Hudson Bay sees its last ice in August.

5. Freeze-up begins along the northern shore in September and gradually extends southwards and eastwards. In the southeast, freeze-up occurs last, typically around the first of January.

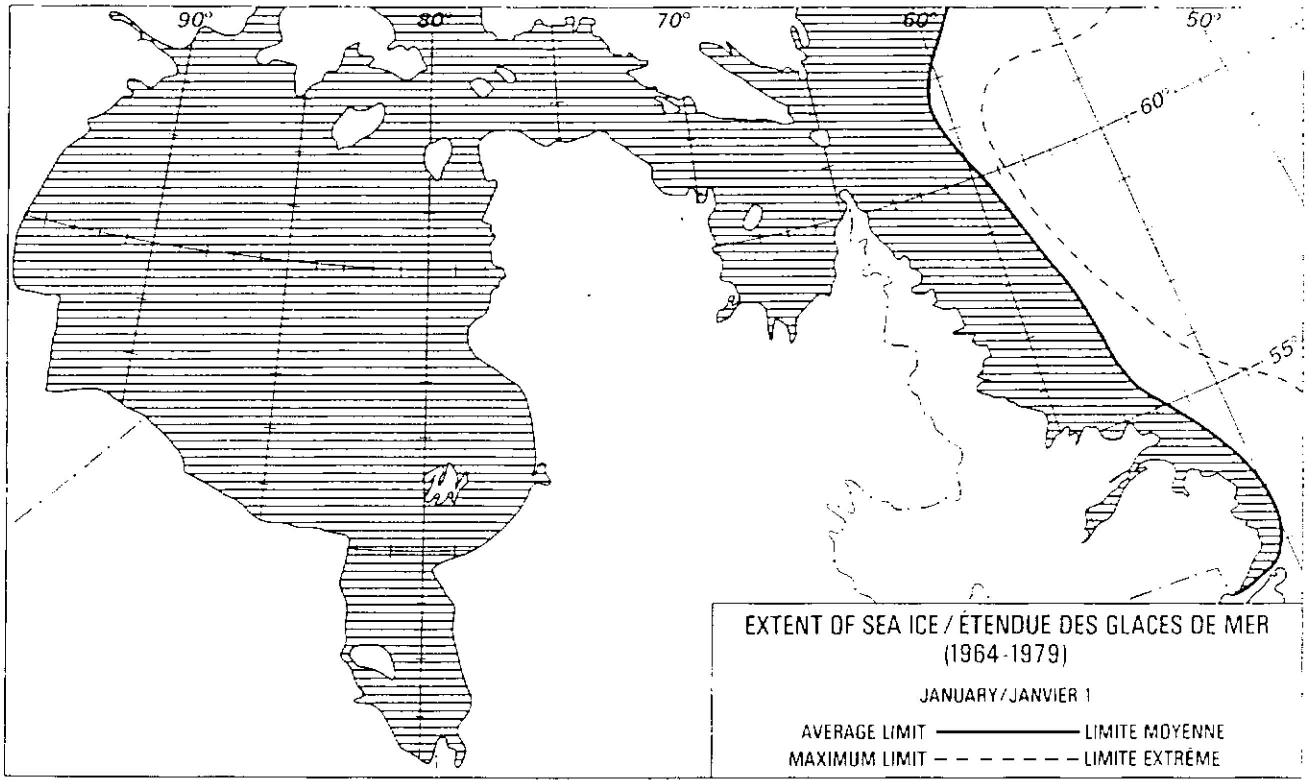
A more recent compilation of ice reconnaissance data appears in Sailing Directions — Labrador and Hudson Bay (Fisheries and Oceans Canada, 1983).

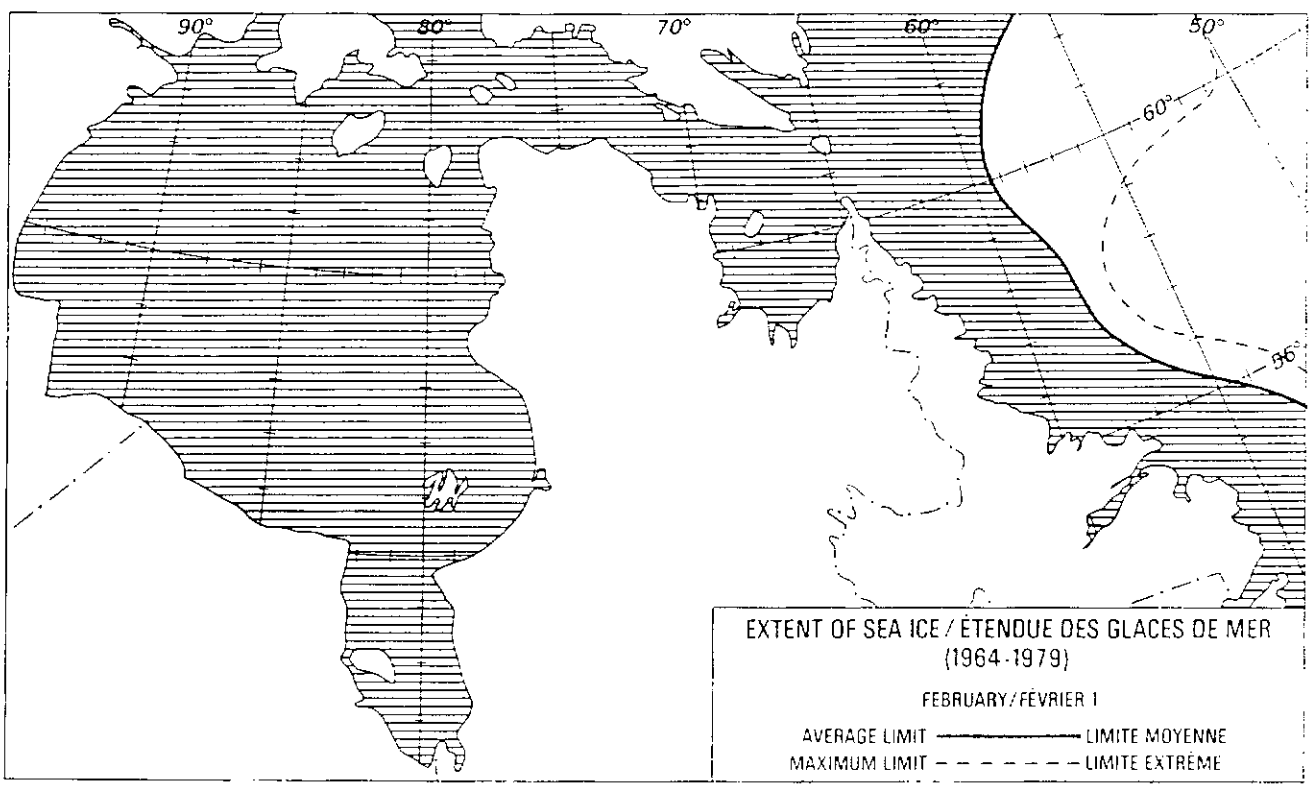
Figure 3-9 shows monthly average and maximum conditions with respect to sea ice in Hudson Bay, based on data from 1964 to 1979. The first ice formation usually occurs in small coves in late October, although intrusions of ice from the Foxe Basin can occur from late August on. By mid-December all of Hudson Bay is iced over. Throughout January to May leads develop in the lee of Coats and Mansel Islands and along the west coast from Cape Kendall to Churchill, as pack ice is moved by the wind. These leads refreeze quickly when the winds change direction or drop in intensity. In late May and June the leads no longer refreeze, and by August approximately half of the Bay is ice-free. Hudson Bay is generally ice-free during September and October, and during the latter part of August and the first part of November.

This summary of ice conditions was based primarily on data compiled by Ice Forecasting Central-Environment Canada in Ottawa. A compendium of approximately 25 years of ice observations will be available from Atmospheric Environment Service in 1984 (W. Markham, personal communications). This ice atlas will illustrate minimum, maximum and median ice conditions in Hudson Bay and its approaches. It is anticipated that the atlas will be a valuable source of ice information for planning purposes.

Another pertinent source of data are the studies undertaken by the Aquitaine Company of Canada Ltd. in support of its drilling programme in Hudson Bay in 1969 and

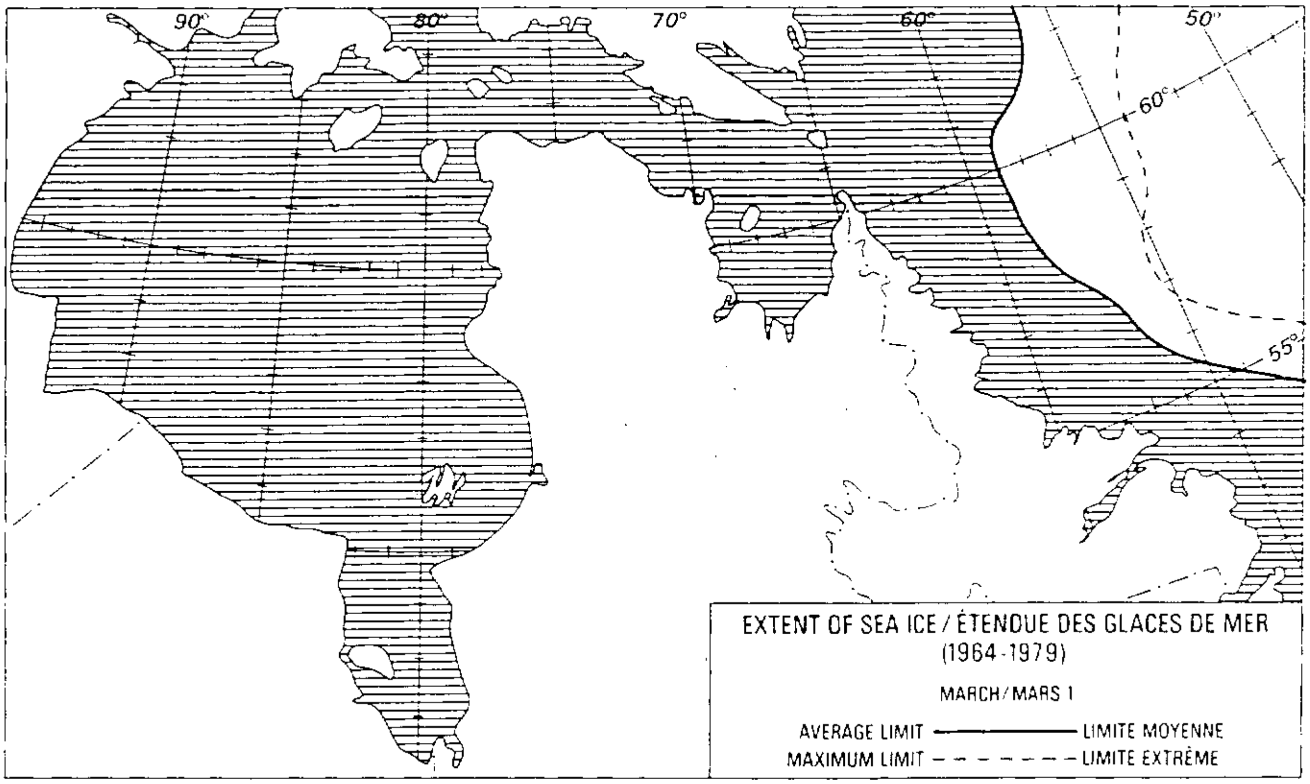
FIGURE 3-9

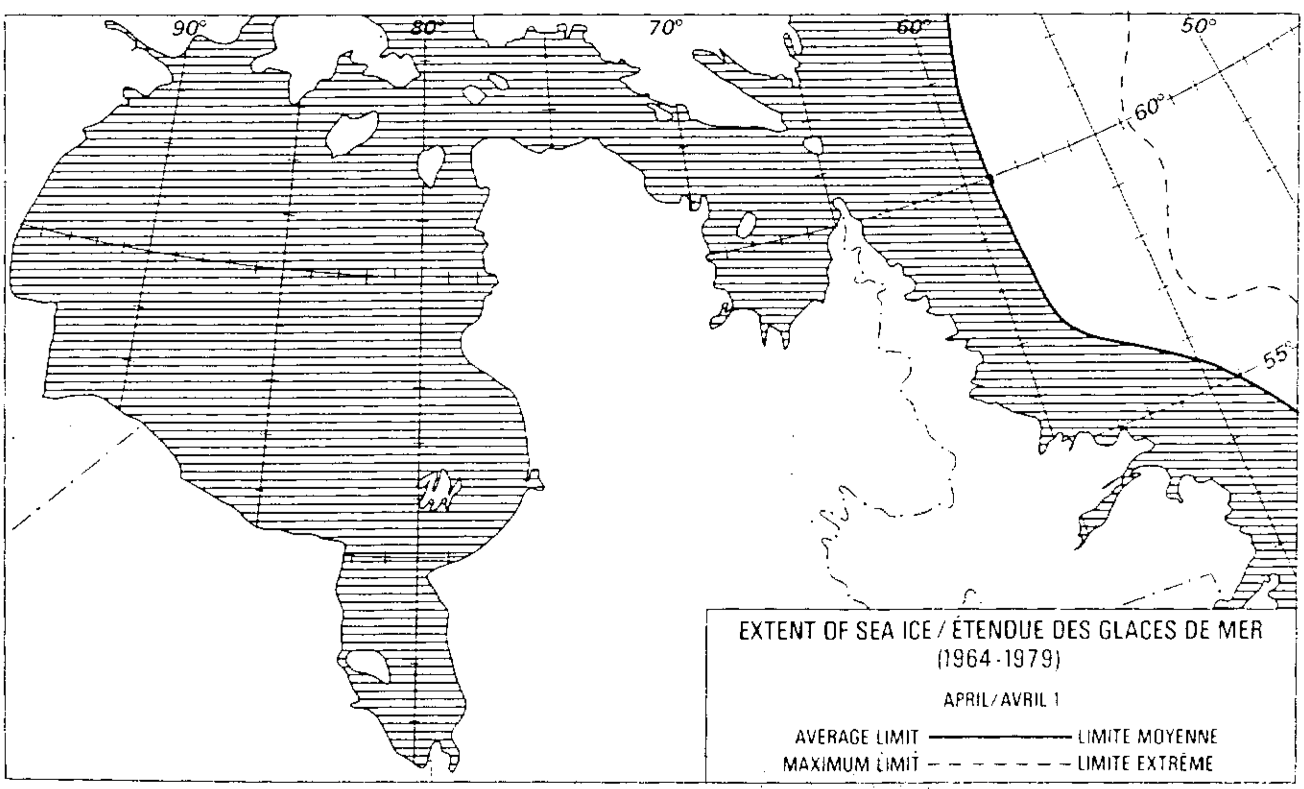




SOURCE: FISHERIES AND OCEANS CANADA 1983

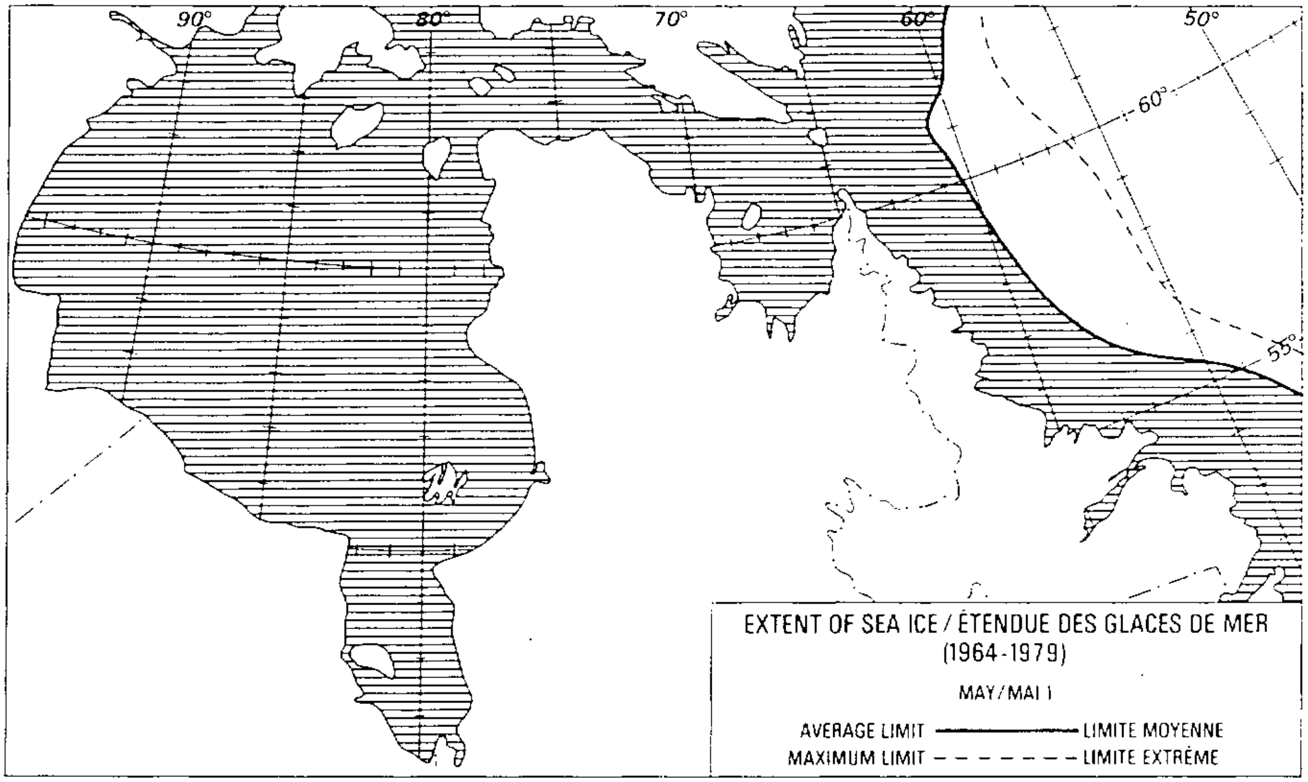
FIGURE 3-9

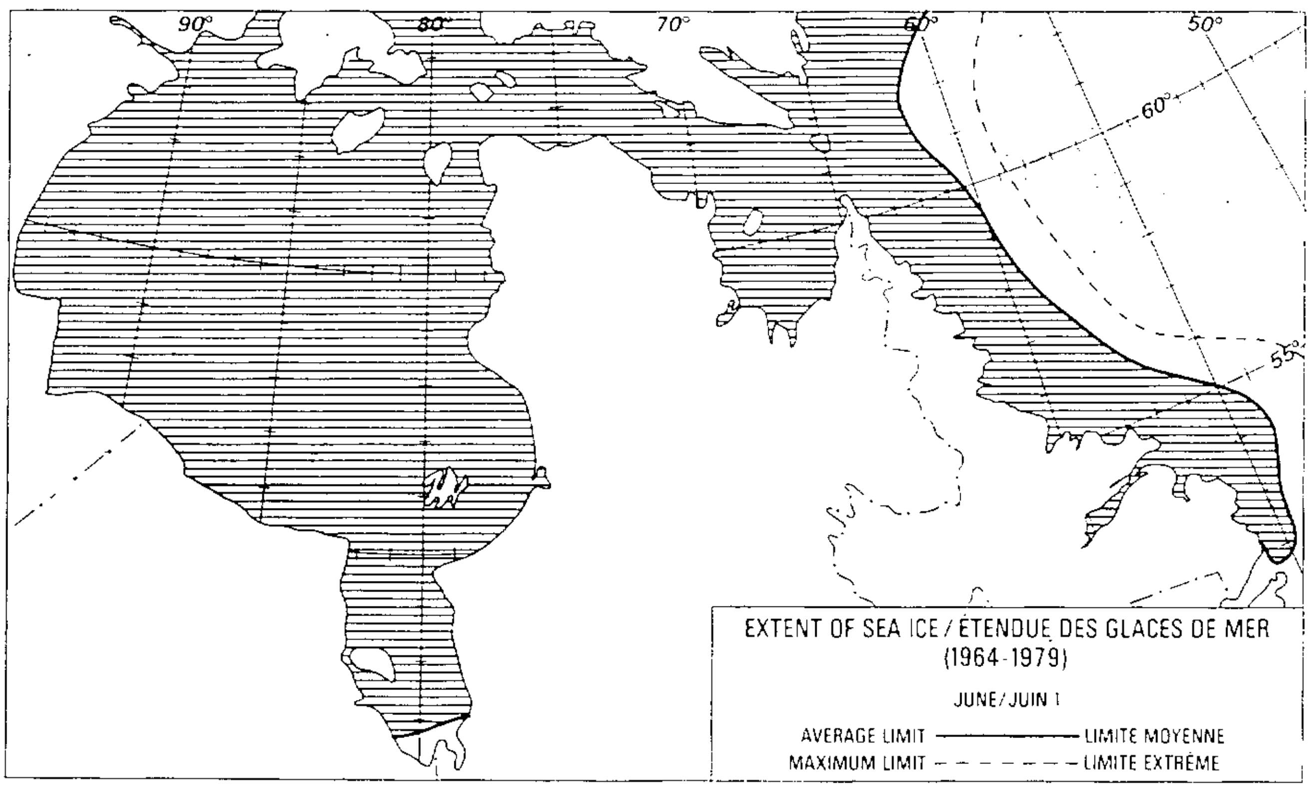




SOURCE : FISHERIES AND OCEANS CANADA 1983

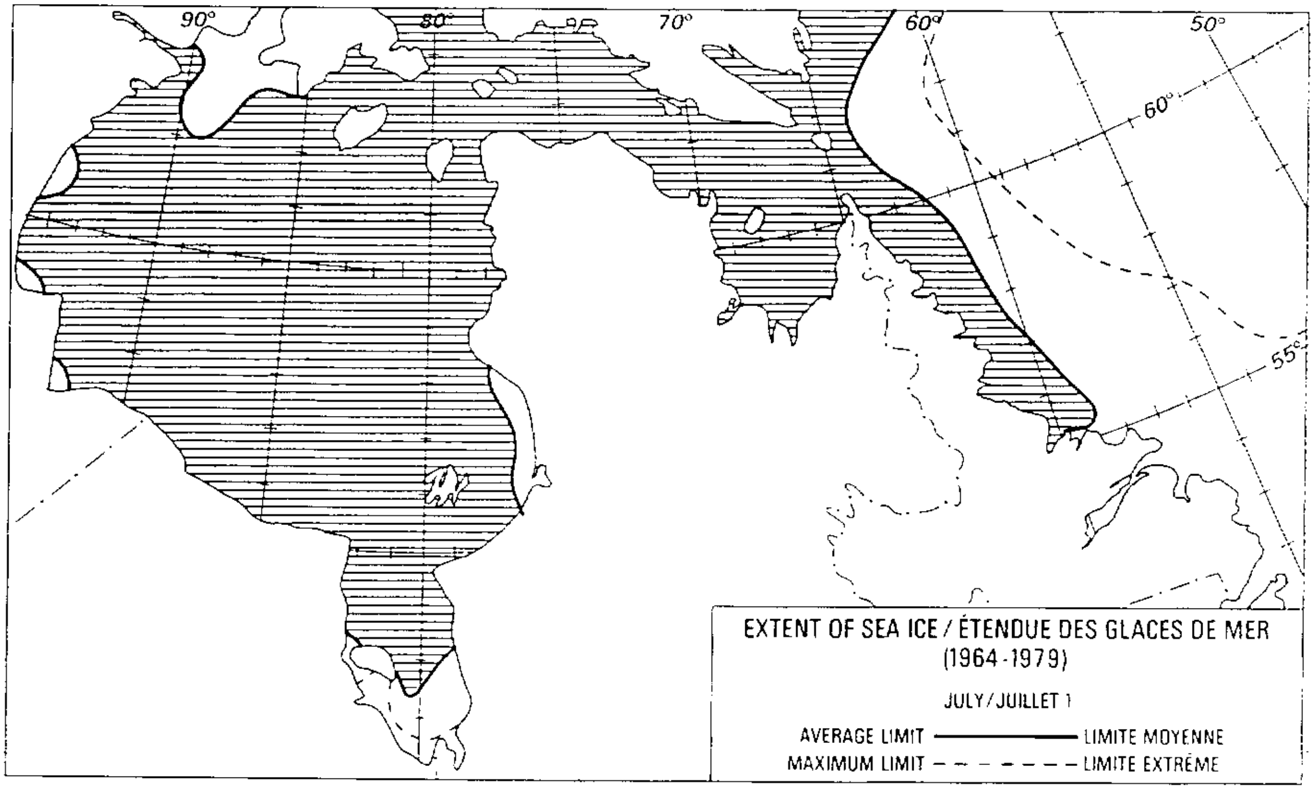
FIGURE 3- 9

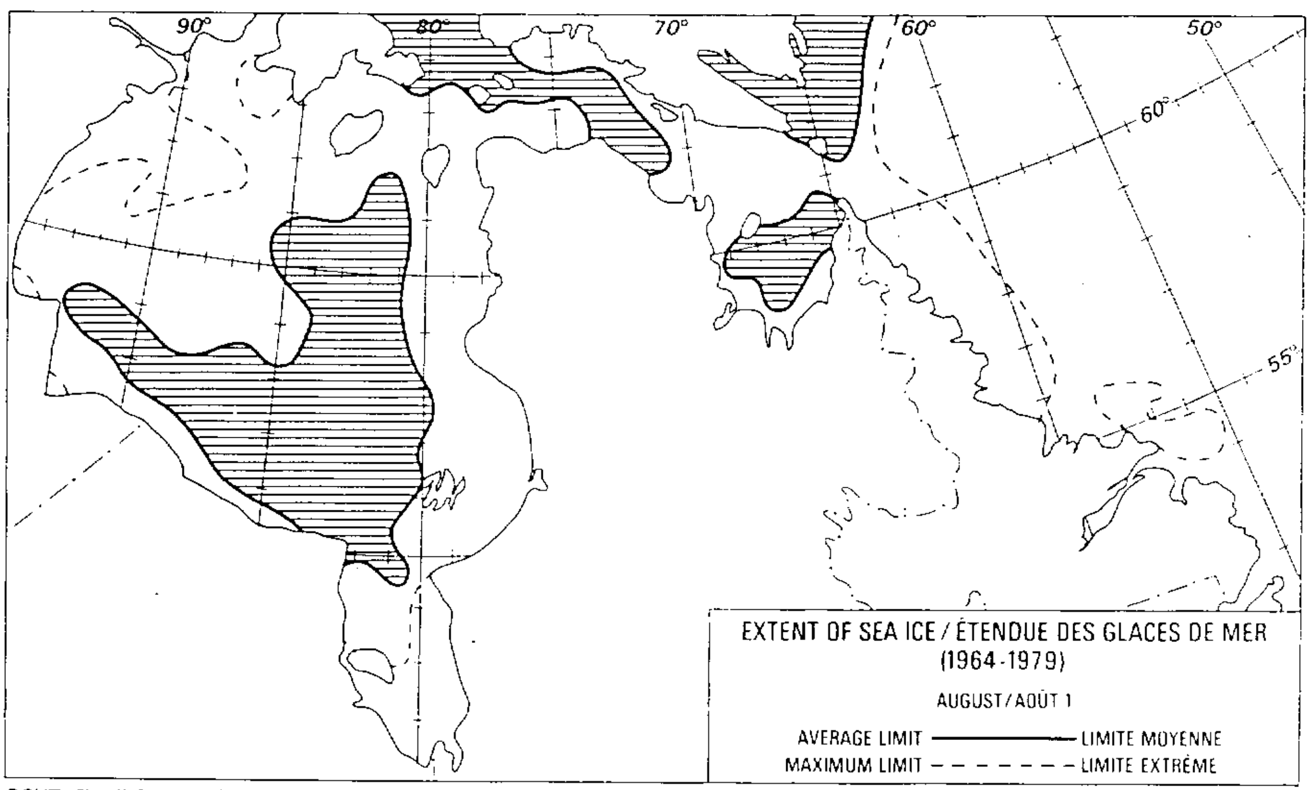




SOURCE: FISHERIES AND OCEANS CANADA 1983

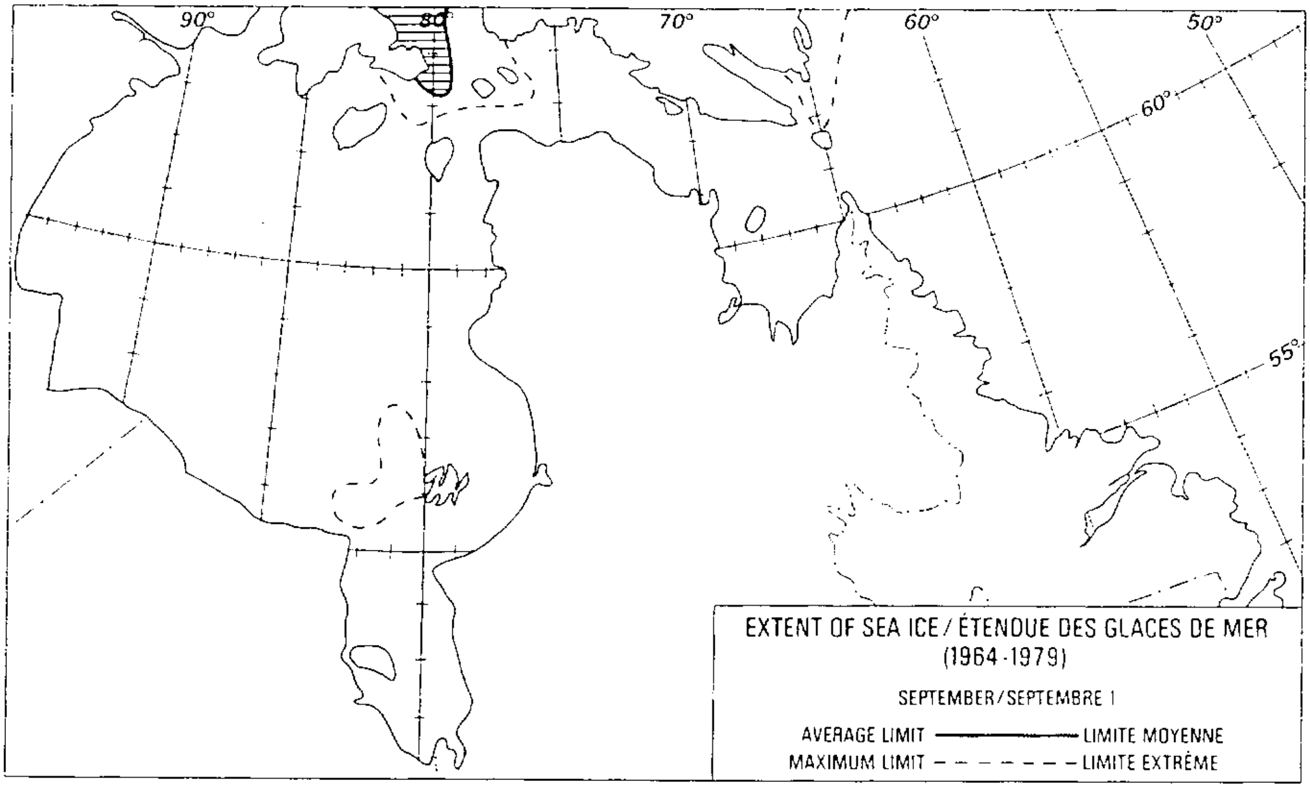
FIGURE 3- 9

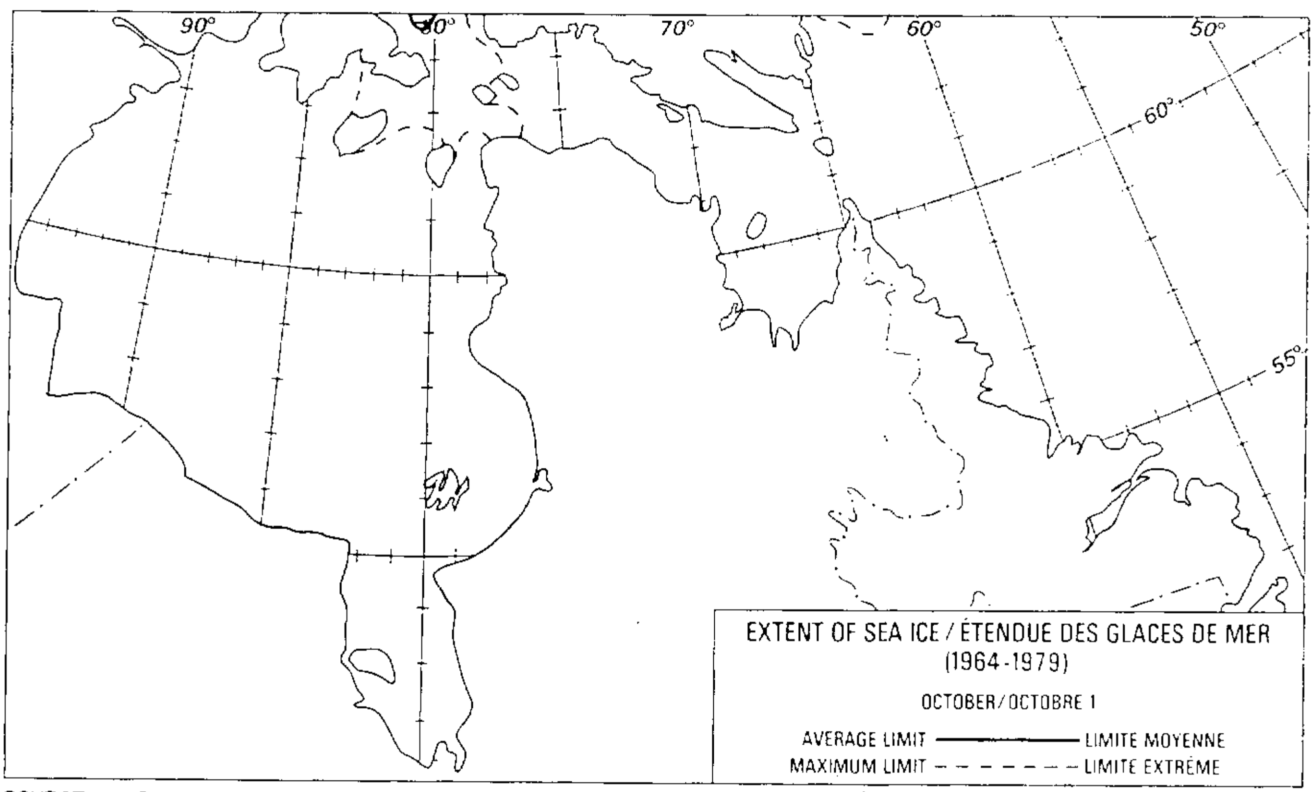




SOURCE: FISHERIES AND OCEANS CANADA 1983

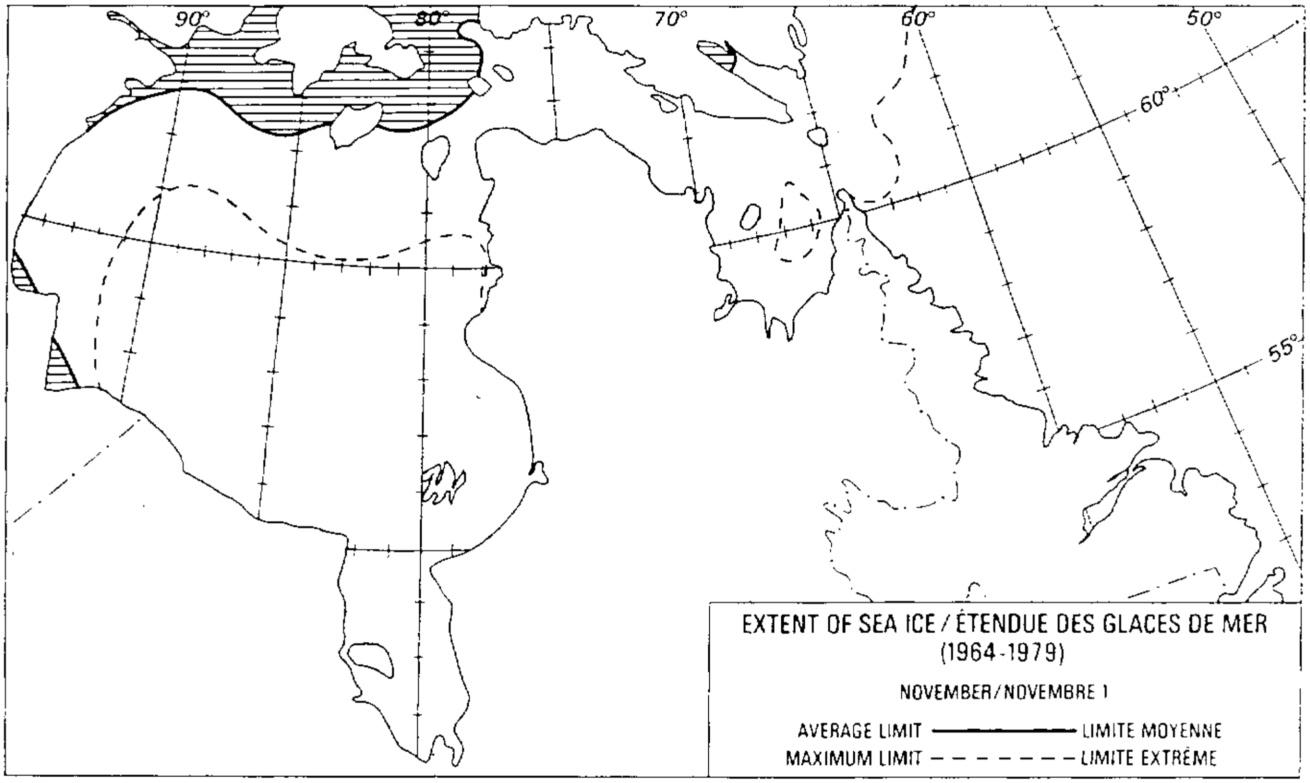
FIGURE 3- 9

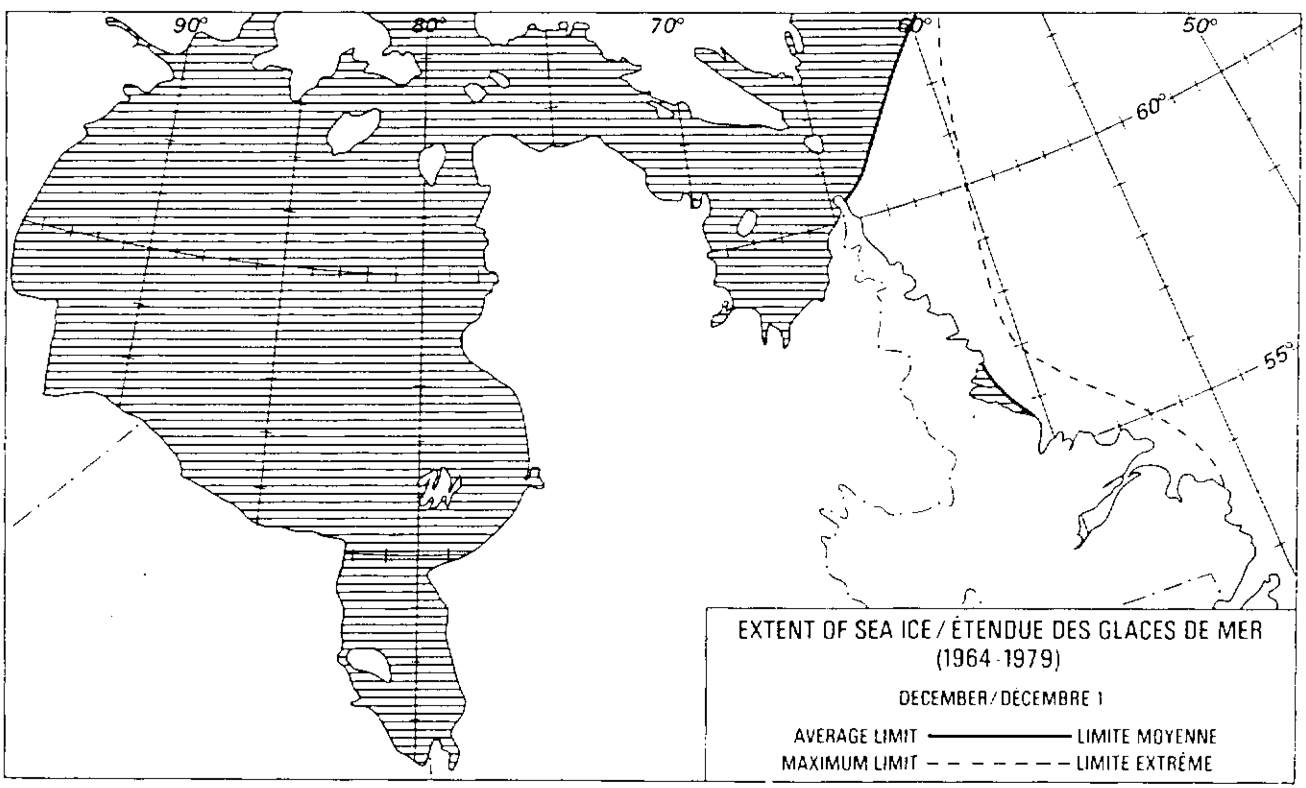




SOURCE : FISHERIES AND OCEANS CANADA 1983

FIGURE 3-9





SOURCE: FISHERIES AND OCEANS CANADA 1983

1974 (Aquitaine Co. Ltd. 1970 and 1975). The Aquitaine reports summarize ice data relevant to their area of operations and to the Atlantic approach to the Bay. The reports also concluded that the data from Ice Forecasting Central of the Atmospheric Environment Service were useful and accurate in relation to the area of operations, and invaluable in relation to moving the drilling rig into and out of Hudson Bay. Ice Forecasting Central provides seasonal forecasts, 30-day forecasts, and weekly 2-week forecasts during open water, based on satellite imagery, aerial reconnaissance flights, ship observations and shore station data.

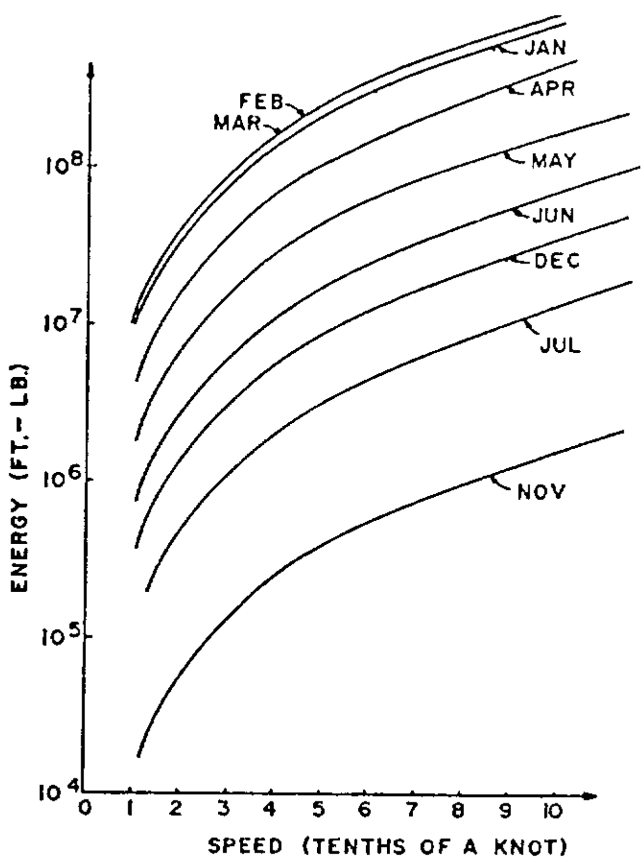
Archibald (1969) determined the energy of moving ice in Hudson Bay assuming that the ice floes were circular in order to determine the volume and mass of the ice. An energy diagram (Figure 3-10) shows the energy of moving ice as a function of speed in tenths of a knot. The greatest energy occurs during the months from January to June. Archibald (ibid.) points out that 8 foot-pounds would be approximately equivalent to a 60,000 ton ship moving at 7 knots. Even during the shoulder months of July and November, there is potentially sufficient energy in ice floes to be of concern to a drilling rig.

The movement of pack ice results from the interaction of three primary forces: wind stress, water drag, and coriolis force. Results of numerical calculation of these forces indicate (Ice Central, unpublished notes):

1. the drift angle relative to the wind direction of the wind induced ice drift is a function of geographic latitude being greatest at the poles;
2. the drift angle shows little variation with wind speed except at very low wind speeds;
3. the drift speed is a near linear relationship of wind speed;
4. the smaller and thinner the floes, the greater the drift speed;
5. the rougher the surface of the ice floe, the greater the sail factor, and the greater the drift speed;
6. the greater the ice concentration, the slower the drift speed.

FIGURE 3-10

ENERGY OF MOVING ICE



Source: Archibald (1969)

Current work by Dr. Sykes on prediction of ice floe movements is being conducted at the University of Waterloo, Ontario under funding by the National Research Council.

Dynamics of ice growth and formation in Hudson Bay have been addressed by a number of researchers (Donovan 1957, Lardner 1968, Danielson 1971, Peck 1976, Catchpole et al. 1976, Markham 1976, Freeman 1982, Danard et al. 1982) often in association with chemical oceanography and/or meteorological investigations. For the most part these data describe site specific ice conditions at a discrete point in time and thus have limited exploration application. Other researchers, most notably Danielson (1969), Danard (1980) and Danard et al. (1981) have examined the theoretical dynamics of ice formation and disintegration.

The data base concerning ice conditions in Hudson Bay and its approaches indicates that on average, there are three months of open water (August, September and October); the duration of open water and the timing of freeze-up and break-up is variable—dependent on meteorological factors. Information shortly to be available from Atmospheric Environment Service is sufficient for planning purposes, and ice forecasts will form the core of ice information required for operational purposes.

3.5 TIDES AND CURRENTS

The Fisheries and Marine Service of Fisheries and Environment Canada publishes annual tidal data for Canadian waters. Daily tides as heights above a datum are available for Churchill in Hudson Bay and for Sand Head in James Bay. There are also data for secondary ports in the form of differences in water levels at high, mean and low water between the secondary ports and the primary reference stations. Secondary port tidal data from Hudson Bay are available for Kopack Island, Inukjuak (Inoucdjouac—formerly Port Harrison), Tukarak Island, Innetalling Island, Flaherty Island, Winisk, Port Nelson, Eskimo Point, Marble Island, Rankin Inlet, Chesterfield Inlet and Coral Harbour. There are also 15 secondary ports with tidal data referenced to Sand Head in James Bay. Tidal data, for the most part descriptive and specific to shore effects, are available in Godin (1974) Langford

(1963) and Barnett (1966). Computer models have been used to interpret tidal effects over the entire Bay, by Freeman et al. (1976 and 1974). A description of the tides in Hudson Bay is provided in Sailing Directions—Labrador and Hudson Bay and is summarized as follows.

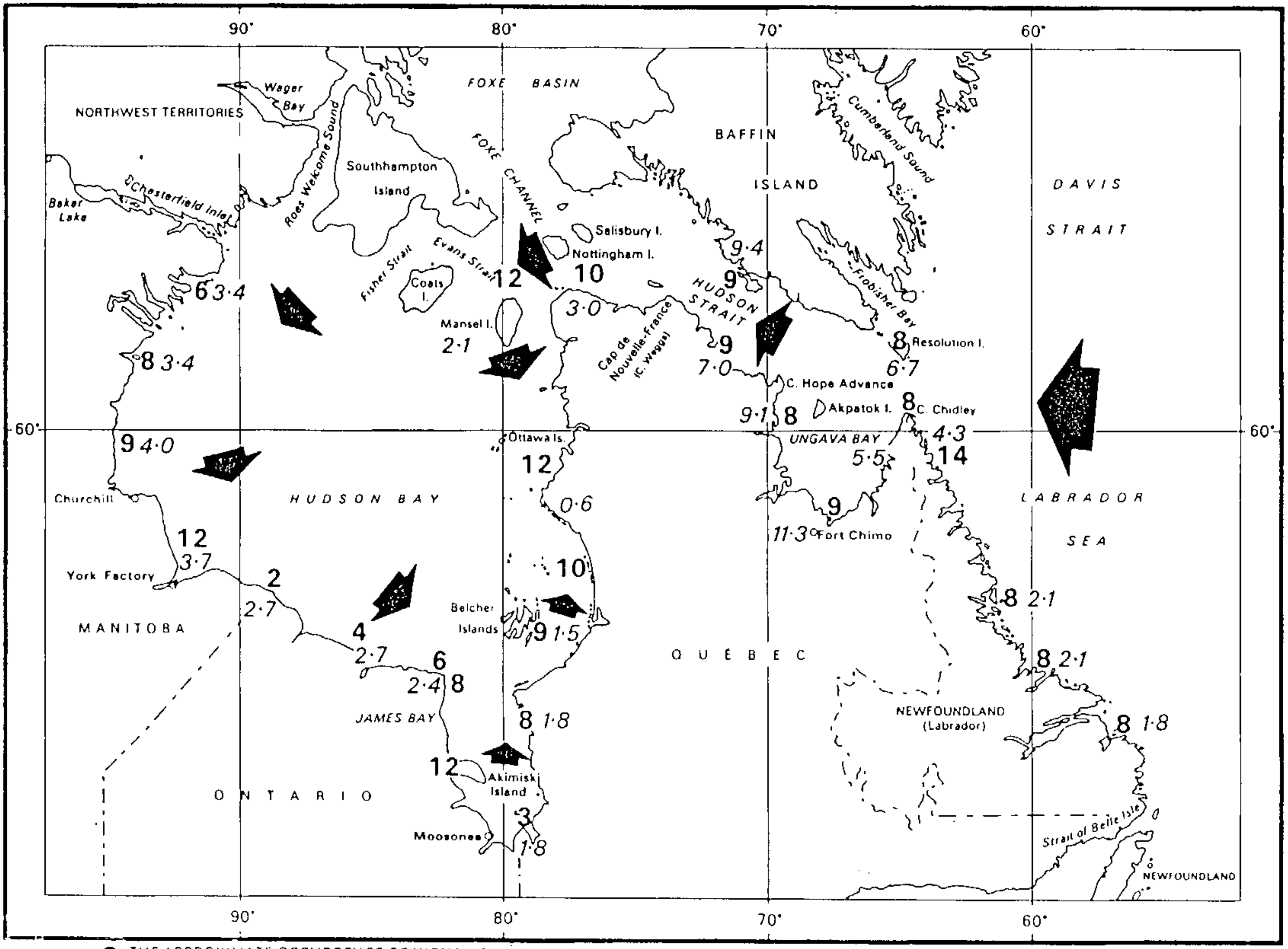
Powerful tides surge twice daily into Hudson Bay through Hudson Strait, entering the Bay via Evans and Fisher straits. The tide progresses in a counter-clockwise, roughly circular movement, following the contour of the shoreline (Figure 3-11). The tidal height increases along the west side of the Bay to about Churchill, probably as a result of water piling up on the extensive shallows along the coast (refer to Figure 3-1), to an average height of 4.0 m at Churchill. Eastward from Churchill the tide decreases in height as it travels along the southwestern coastline, enters James Bay at the western side of the mouth and exits along the eastern side, and then travels up the eastern coast of Hudson Bay. The difference in tidal heights along the west and east coasts is illustrated in Figure 3-12. The range in height between high and low water may be as great as 5.2 m at Churchill and as little as 0.5 m at Inukjuak.

There is a ridge-like area within the centre of Hudson Bay, from about 60° 30' N, 87°W, extending southwestward toward Inukjuak, where the change in water level during the semi-diurnal tide cycle is close to zero. The shape, size and depth of water in Hudson Bay, and the gyroscopic and gravitational forces acting upon this water body are assumed to have produced this effect. Although this ridge does traverse some relatively shallow areas which could deflect tidal currents to some extent, the bottom configuration as illustrated in Figure 3-1 and 3-2 does not appear to correspond to the alignment of this ridge. The length and width of this zone of apparently tideless water are not yet clearly defined.

Information concerning currents within Hudson Bay is limited. Site-specific short-term current data have been collected by numerous investigators (Budgell 1982, Baird 1976, Brooks 1980, Freeman et al. 1982, Peck 1976, Prinsenberg 1977, 1978, 1980, 1982) generally in support of chemical oceanographic research. Current meter data was also collected by Aquitaine during its 1969 drilling campaign. Limited longer term current data is available from Prinsenberg and Deys (1979), Prinsenberg (1982) and Prinsenberf (1983). Figure 3-13 shows the location of current

FIGURE 3-11

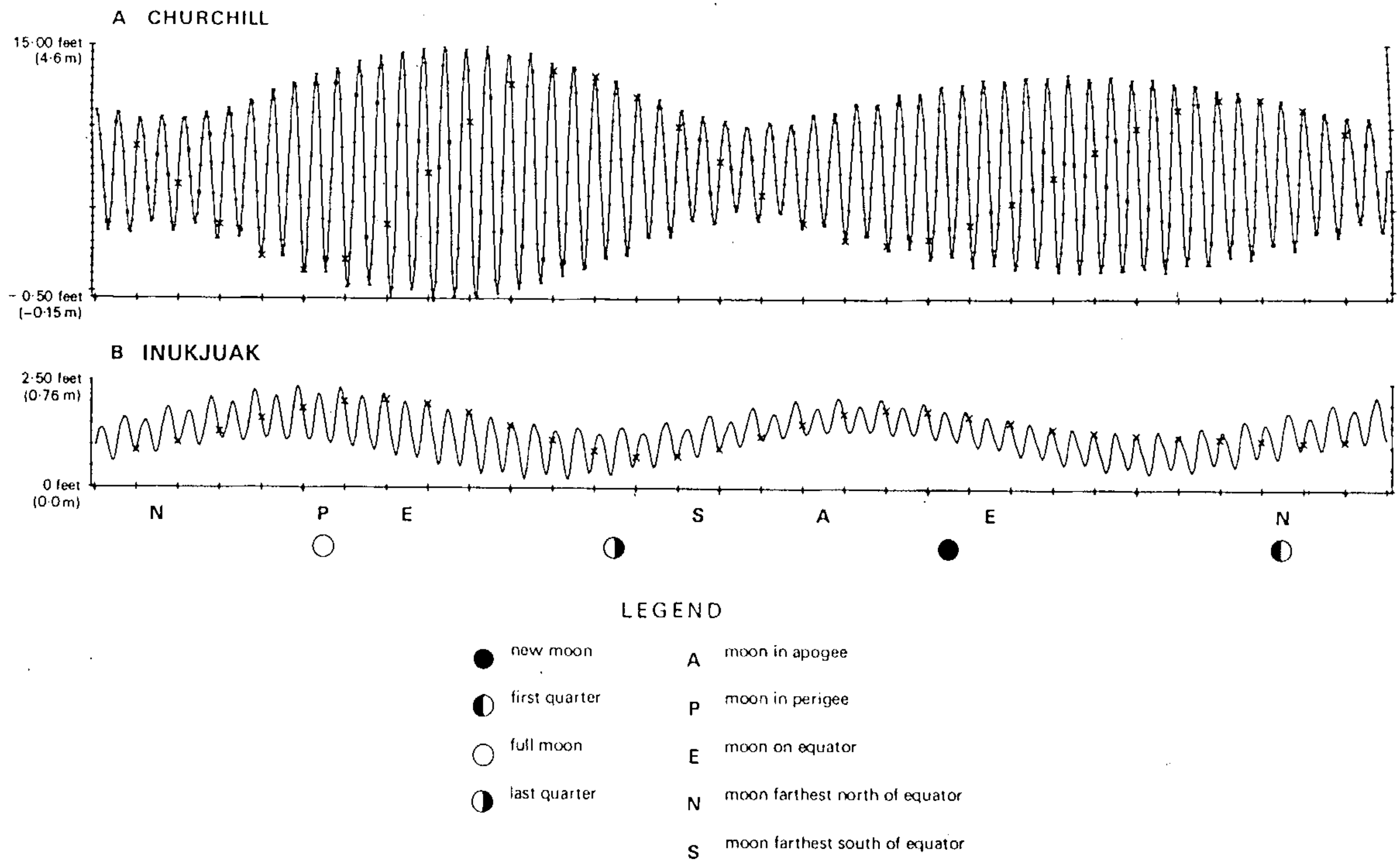
TIDAL MOVEMENT IN THE HUDSON BAY



8 THE APPROXIMATE OCCURRENCE OF HIGH WATER IN HOURS AFTER THE MOON'S MERIDIAN PASSAGE AT 60° WEST.

1·8 MEAN HIGH WATER. HEIGHT IN METRES ABOVE CHART DATUM

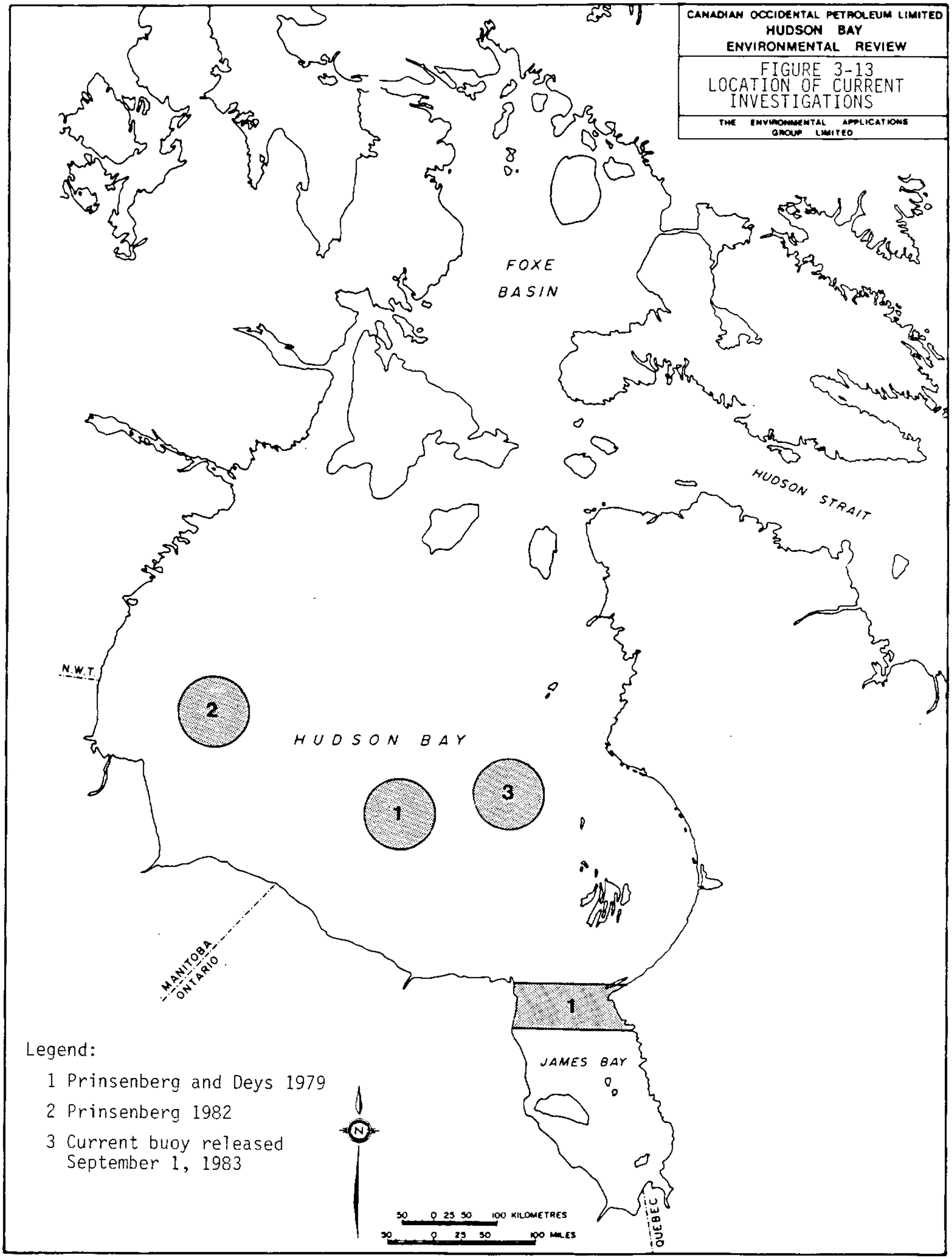
FIGURE 3-12



Typical tidal curves for Churchill and Inukjuak

Hudson Bay and Hudson Strait showing height of mean high water above chart datum and times of occurrence of high water.

Source: Fisheries and Oceans Canada 1983



CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 3-13
LOCATION OF CURRENT INVESTIGATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
1
2
3
1
Legend:
1 Prinsenberg and Deys 1979
2 Prinsenberg 1982
3 Current buoy released September 1, 1983
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES
N

monitoring sites described in these sources, including the deployment point of a buoy placed to the northwest of the Belcher Islands in September 1983. The findings of these studies are essentially in agreement. Surface and near-surface currents are dominated by the tidal component at all depths, resulting in an overall counter-clockwise rotation. During the summer, low pressure systems cause inertial currents that change and even reverse the tidal current for a number of days, depending on the strength of the attendant winds. Average current speeds recorded at 20 m, 50 m and 100 m depths in September/October 1981, were approximately 30, 12 and 15 cm/sec, respectively.

Prinsenberg (1982) indicates that, based on data and model results, the oceanographic parameters are highly dependent on the wind stress and resulting currents. Wind stress varies on a daily time scale, due to passing weather systems, and on a monthly basis due to seasonal weather changes. Passage of weather systems cause 4-6 day cycle variations in wind stress and currents, and daily Bay excursions of 20 km. Figure 3-14 illustrates the daily mean current (in cm/s) and wind vectors (in m/s) for the summer of 1979, sampled at two different sites on Hudson Bay. When the wind stress changes direction or intensity, inertial currents are generated. These currents rotate with a time period (called inertia period) valued at near 14 hours for Hudson Bay.

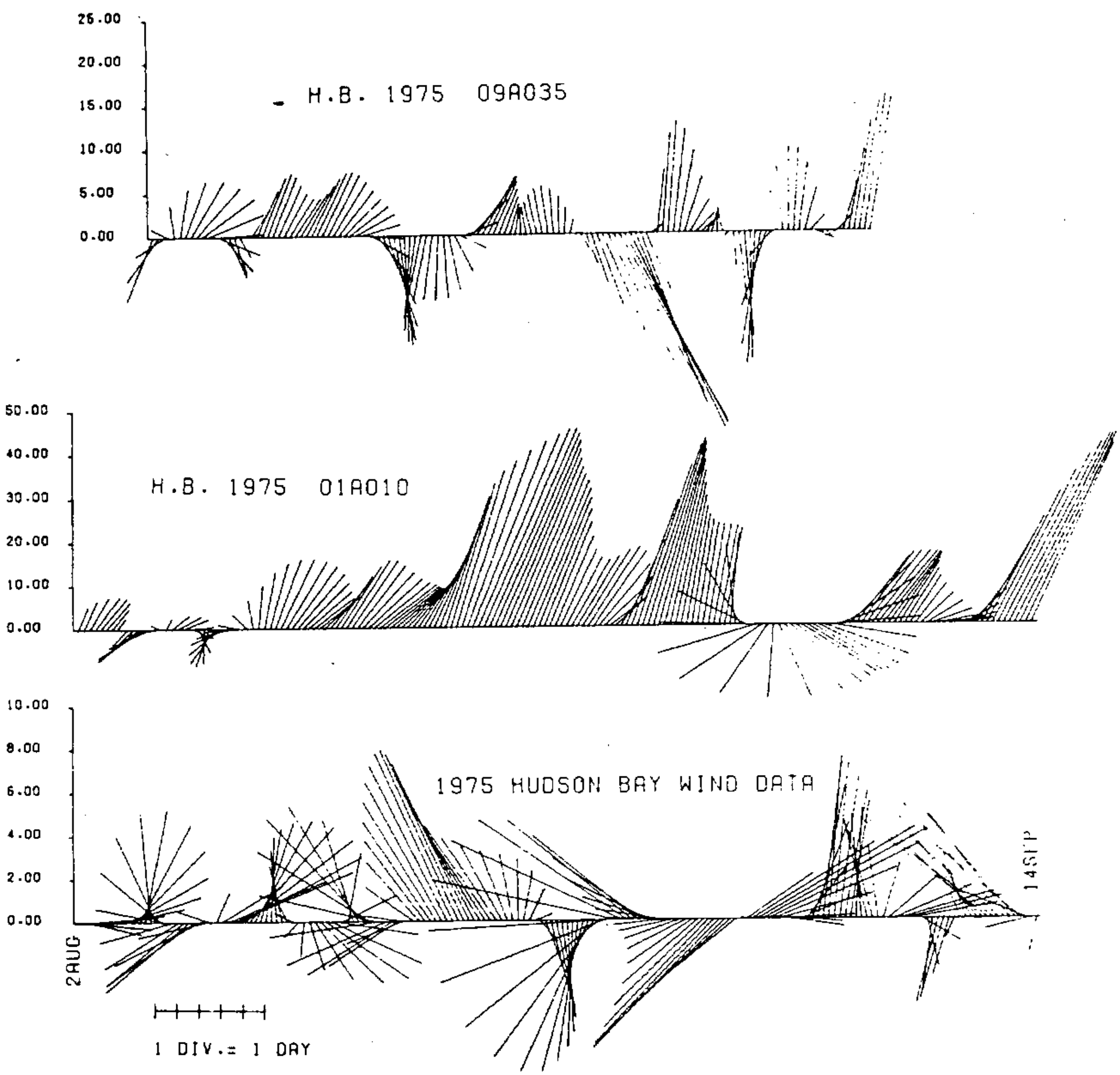
Other data on surface currents were generated by buoy drift studies in 1979 (Stark and Campbell 1979) and in 1981, 1982 (Markham 1983). These studies concur that surface currents are influenced greatly by strong winds, and that the general surface current pattern corresponds to the tidal movement—counter-clockwise. Figures 3-15 and 3-16 illustrate the surface currents of Hudson Bay as determined by 1981 and 1982 buoy trajectories.

3.6 WAVES

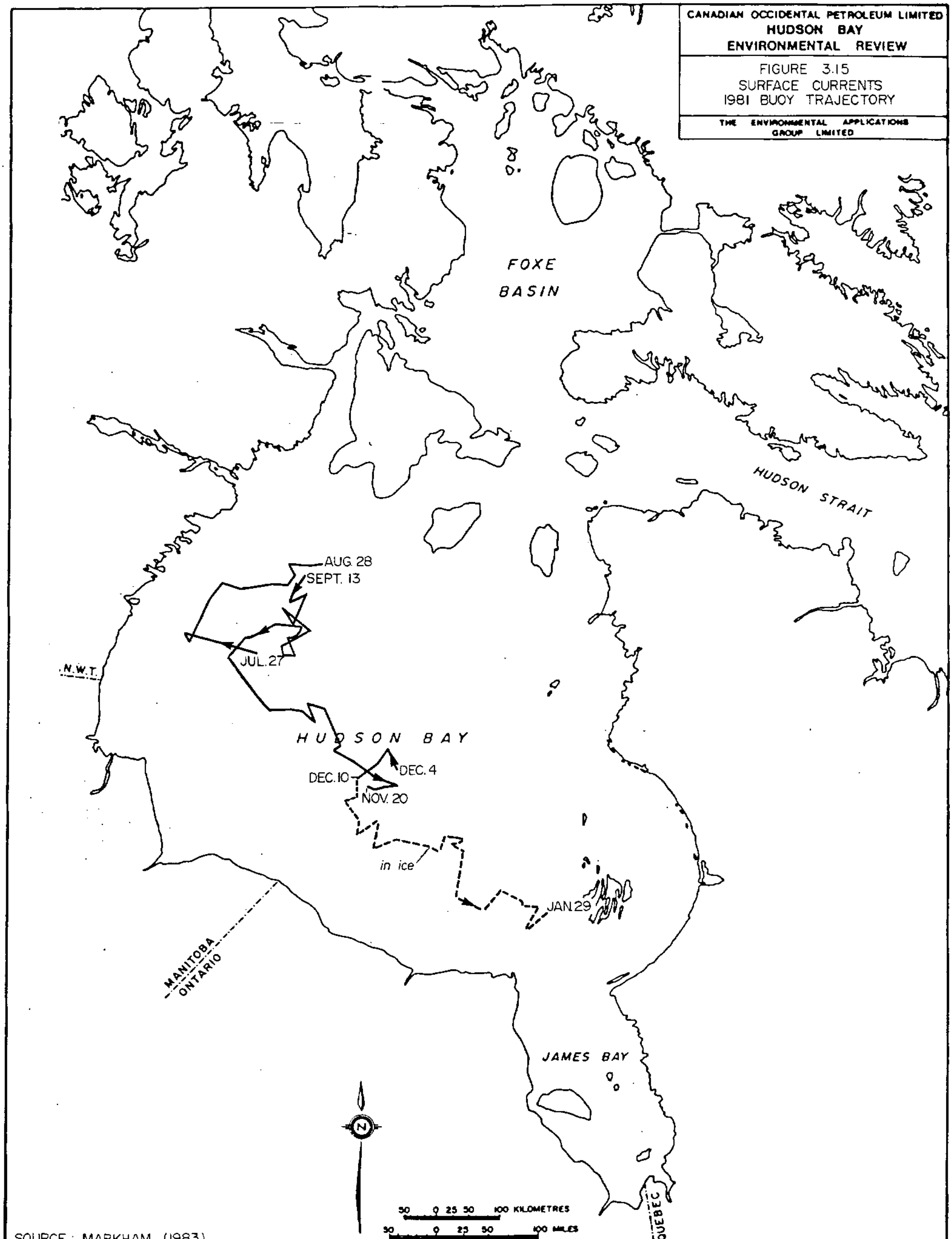
There are no extensive wave or swell measurements available for Hudson Bay, apart from those made at ports (MEDS, personal communications). Ship observations within Hudson Bay (for the period 1895-1977) indicate a maximum wave height of 8.2 m and a maximum swell height of 23.5 m (AES, 1983). Tables 3-1 and 3-2 summarize the ship observations on file recorded over a period of 82 years.

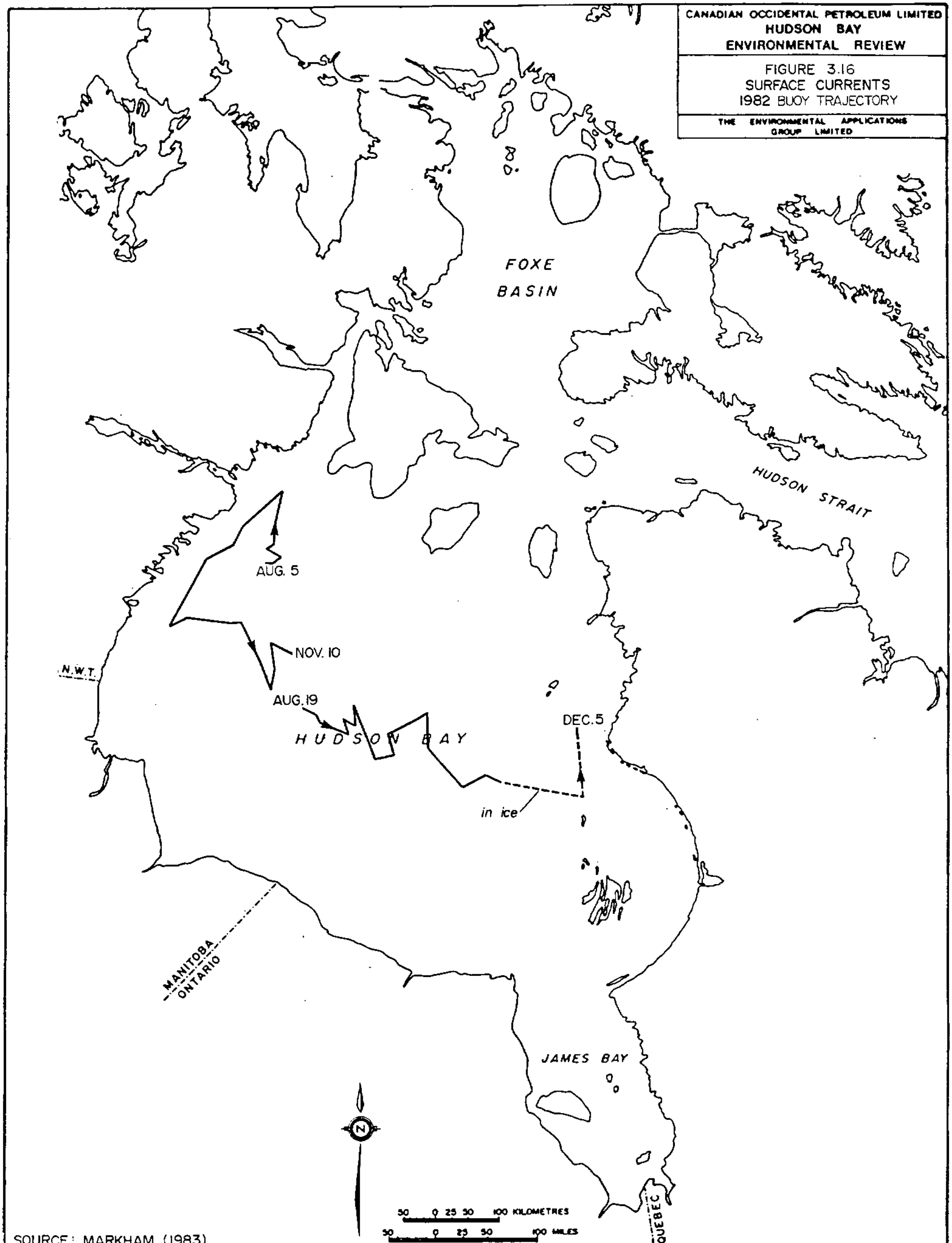
FIGURE 3-14

DAILY MEAN SUMMER CURRENT



Source: Prinsenberg (1982)


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 3.15
SURFACE CURRENTS
1981 BUOY TRAJECTORY
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
AUG. 28
SEPT. 13
JUL. 27
N.W.T.
HUDSON BAY
DEC. 4
DEC. 10
NOV. 20
in ice
JAN. 29
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
N
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES
SOURCE: MARKHAM (1983)



SOURCE: MARKHAM (1983)

TABLE 3-1

SUMMARY OF HUDSON BAY : WAVE DATA — MARINE OBSERVATIONS 1895-1979

ENVIRONMENT CANADA / ENVIRONNEMENT CANADA
ATMOSPHERIC ENVIRONMENT SERVICE / SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE
CANADIAN CLIMATE CENTRE / CENTRE CLIMATOLOGIQUE CANADIENNE

MARINE CLIMATOLOGICAL SUMMARIES / RESUMES CLIMATOLOGIQUES MARITIMES

LOCATION: HUDSON BAY
LIEU:

PERIOD: 1895 - 1979
PERIODE: 1895 A 1979

	WAVE HEIGHT (M) / HAUTEUR DES VAGUES (M)						WAVE PERIOD (SEC) / PERIODE DES VAGUES (S)						
	MED / MED	MAX / MAX	MIN / MIN	95%UL / 95%LS	95%LL / 95%LI	NO. OF READINGS / NBRE DE LECTURES	MED / MED	MAX / MAX	MIN / MIN	95%UL / 95%LS	95%LL / 95%LI	NO. OF READINGS / NBRE DE LECTURES	MOST FREQUENT DIRECTIONS / DIRECTIONS LES PLUS FREQUENTES
JANUARY/JANVIER	****	****	****	****	****	0	**	**	**	**	**	0	**
FEBRUARY/FEVRIER	****	****	****	****	****	0	**	**	**	**	**	0	NW
MARCH/MARS	0.5	4.0	0.1	****	****	3	5	6	5	**	**	3	NE
APRIL/AVRIL	1.0	2.0	1.0	****	****	2	5	5	5	**	**	2	S SW
MAY/MAI	1.0	1.5	1.0	****	****	2	5	5	5	**	**	2	NW
JUNE/JUIN	2.0	****	****	****	****	1	5	**	**	**	**	1	NW
JULY/JUILLET	0.6	7.6	0.0	1.9	0.1	124	5	10	5	8	5	113	NW
AUGUST/AOUT	0.9	6.0	0.0	3.3	0.1	668	5	10	5	6	5	585	NW
SEPTEMBER/SEPTEMBRE	1.1	8.2	0.0	5.1	0.1	666	5	16	5	8	5	589	NW
OCTOBER/OCTOBRE	1.1	7.5	0.0	4.1	0.1	352	5	12	5	8	5	307	NW
NOVEMBER/NOVEMBRE	1.5	2.2	0.1	****	****	9	5	6	5	**	**	9	W
DECEMBER/DECEMBRE	****	****	****	****	****	0	**	**	**	**	**	0	**

SOURCE: Marine observations on file with Environment Canada

TABLE 3-2

SUMMARY OF HUDSON BAY SWELL DATA -- MARINE OBSERVATIONS 1895-1979

ENVIRONMENT CANADA / ENVIRONNEMENT CANADA
ATMOSPHERIC ENVIRONMENT SERVICE / SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE
CANADIAN CLIMATE CENTRE / CENTRE CLIMATOLOGIQUE CANADIENNE

MARINE CLIMATOLOGICAL SUMMARIES / RESUMES CLIMATOLOGIQUES MARITIMES

LOCATION: HUDSON BAY
LIEU:

PERIOD: 1895 - 1979
PERIODE: 1895 A 1979

	SWELL HEIGHT (M) / HAUTEUR DE LA HOULE (M)						SWELL PERIOD (SEC) / PERIODE DE LA HOULE (S)						
	MED / MED	MAX / MAX	MIN / MIN	95%UL / 95%LS	95%LL / 95%LI	NO. OF READINGS / NBRE DE LECTURES	MED / MED	MAX / MAX	MIN / MIN	95%UL / 95%LS	95%LL / 95%LI	NO. OF READINGS / NBRE DE LECTURES	MOST FREQUENT DIRECTIONS / DIRECTIONS LES PLUS FREQUENTES
JANUARY/JANVIER	****	****	****	****	****	0	**	**	**	**	**	0	**
FEBRUARY/FEVRIER	****	****	****	****	****	0	**	**	**	**	**	0	**
MARCH/MARS	1.0	****	****	****	****	1	12	**	**	**	**	1	W
APRIL/AVRIL	0.1	****	****	****	****	1	**	**	**	**	**	0	**
MAY/MAI	****	****	****	****	****	0	**	**	**	**	**	0	**
JUNE/JUIN	2.0	****	****	****	****	1	5	**	**	**	**	1	W
JULY/JUILLET	0.9	3.5	0.0	2.1	0.1	47	5	16	5	14	5	40	NE
AUGUST/AOUT	1.1	9.0	0.0	3.0	0.1	353	5	16	5	12	5	320	NE
SEPTEMBER/SEPTEMBRE	1.5	10.5	0.0	4.7	0.1	389	6	16	5	11	5	338	N
OCTOBER/OCTOBRE	1.4	23.5	0.0	3.9	0.1	209	6	20	5	12	5	187	N
NOVEMBER/NOVEMBRE	2.1	23.5	1.4	****	****	9	5	13	5	**	**	8	W
DECEMBER/DECEMBRE	2.5	****	****	****	****	1	10	**	**	**	**	1	E

SOURCE: Marine observations on file with Environment Canada

There are sea state data available for the southwestern quadrant of Hudson Bay arising from earlier exploration of this area by Aquitaine. Sea state observations were undertaken on board the Andromede, during the period late July to late October in 1968 and 1970, using a "Tucker" ship-borne wave meter. Figure 3-17 illustrates the location of the 1970 sea state monitoring programme. The mean wave recorded had a height of 0.7 to 2.0 m and a period of 5 to 6 seconds. The maximum swell observed had a height of 4.0 m and a period of 8 seconds.

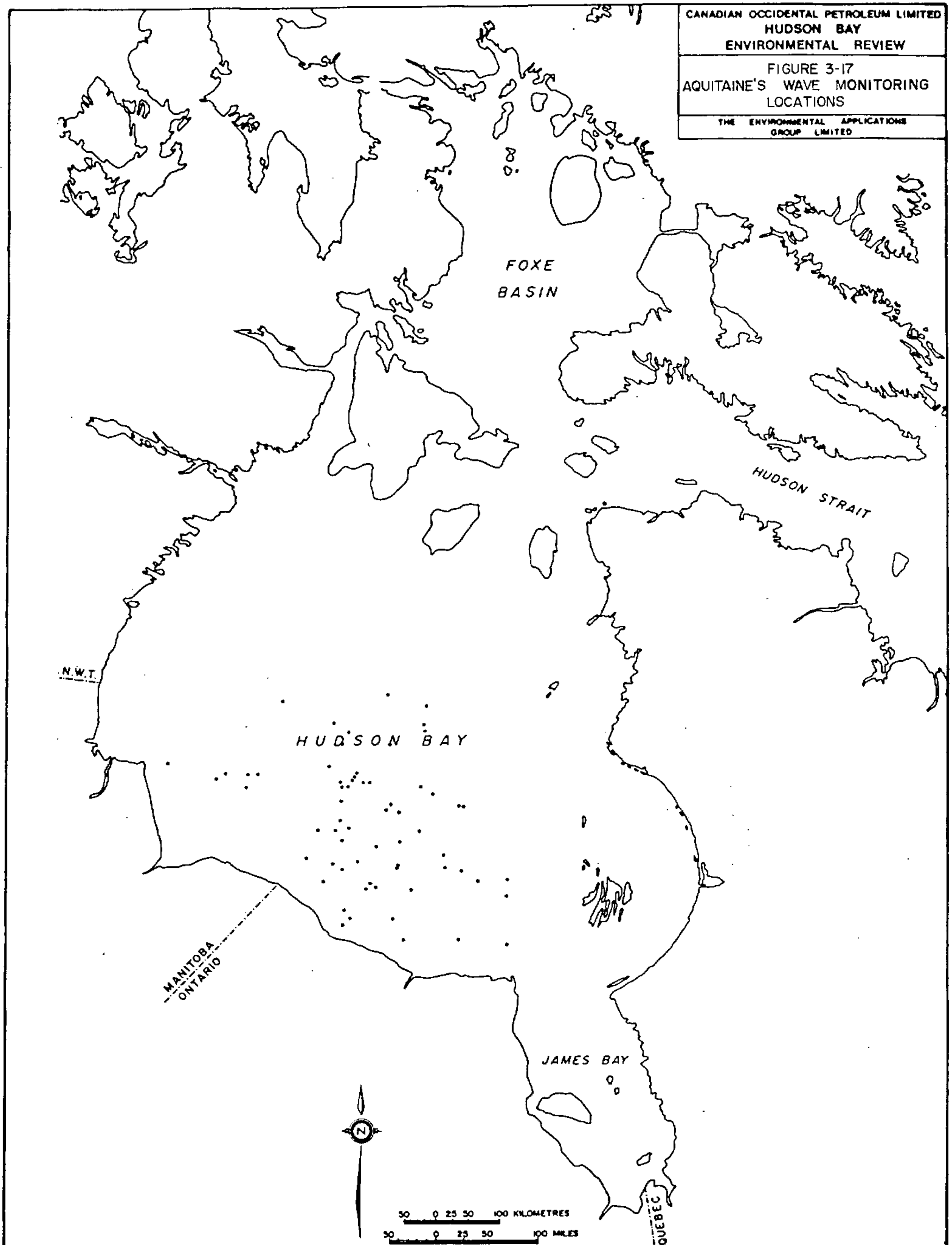
Extreme wave statistics are used in the design of exploratory and production structures to determine the following (Readshaw and Baird 1981):

1. the extreme loading including drag, inertial and impact forces on offshore structures;
2. the minimum deck or freeboard clearances for moored or gravity structures;
3. the response of floating structures in survival conditions.

Estimates of extreme wave values are determined by extrapolating a wave height which is characteristic of the peak of a storm. Extrapolation is conducted by assuming a suitable probability distribution. This approach has been used in the Beaufort Sea, North Sea, and in the Great Lakes. These techniques provide the probability that a wave height will not exceed a certain value over a specified period.

Two recent reports published by the Marine Environmental Data Service describe available techniques for estimating extreme wave heights (Readshaw and Baird, 1981; LeBlond, 1981). These reports provide technical descriptions of statistical methods and various wave hindcasting models.

Of the many methods relating observed or predicted meteorological data to wave conditions, one of the most commonly used is due to Bretschneider (1951, 1957, 1970) based on the work of Sverdrup and Munk (1947). This approach uses wind speed, the duration of the storm, and the length of water fetch over which the wind acts, to derive the height and period of the significant wave (the average of the one-third highest waves). A description of this method as applied to the


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 3-17
AQUITAINE'S WAVE MONITORING LOCATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
N.W.T.
HUDSON BAY
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
N
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

Beaufort Sea is given in a report submitted to AES by Dames & Moore (1975) and summarized in Beaufort Sea Project Report No. 21 (1975) "Weather, Waves, and Icing in the Beaufort Sea". A FORTRAN program to solve the Bretschneider wind-wave relationships for deep water is available from the Atmospheric Environment Service (Lalande, 1975). This technique is adequate in providing a large area extreme wave climatology for Hudson Bay with currently available Fleet Numerical Oceanic Centre (U.S. Navy) geostrophic level pressure analysis and Atmospheric Environment Service ice cover data.

Spectral methods describe the evolution of the sea state in terms of discrete frequency and direction bands, representing the evolution of wave spectra in time. These models are more computer intensive than the parametric models such as the Bretschneider technique.

Aquitaine commissioned an extreme wave hindcast study designed to predict maximum conditions on the basis of available information. Tables 3-3 and 3-4 contain extreme sea state conditions estimated for the 1 in 10 year, and the 1 in 100 year storms, respectively, for various locations in southwest Hudson Bay. The greatest significant wave height predicted for the 1 in 10 and the 1 in 100 year storms is 10.4 and 14.0 m, respectively.

3.7 SEA SPRAY ICING

Ice accumulation on marine structures, especially on sea going vessels, represents a substantial danger to the maritime community. Ship icing occurs with the crystalization and accretion of atmospheric water or ocean spray onto the vessel's sides, the walls of the superstructure and the deck houses, deck gear and cargo, and the open deck itself, as well as the ship's masts, spars, rigging, and aerials. This accumulation of ice leads to an increase in the vessel's weight and a lowering of the freeboard. As the ice builds up above the centre of gravity, the stability of the ship is greatly reduced. Its rolling movement is increased with the wind load and a dangerous listing of the vessel can occur. While the most frequent

TABLE 3-3

PREDICTED SEA STATE DURING THE 1 IN 10 YEAR STORM

LOCATION	$H_s(H_{1/3})$ M	$H_{1/10}$ M	$H_{1/100}$ M	T_s secs
Walrus	9.7	12.5	16.5	14
61°N 90°45'W	10.4	13.3	17.4	14
60°N 90°45'W	10.4	13.3	17.4	14
59°N 90°45'W	8.9	11.3	14.9	14
58°N 91°W	8.4	10.7	14.0	13
57°N 88°45'W	>5.2	>6.7	8.5	--
57°N 82°30'W	7.9	10.1	13.4	13
58°N 83°15'W	8.8	11.3	14.9	14
59°N 83°45'W	9.1	11.6	15.4	14
60°N 83°15'W (Aquitaine only)	10.1	12.8	16.9	14½

LEGEND:

H_s — the significant wave height

$H_{1/3}$ — the average height of the highest third of all waves

$H_{1/10}$ — the average height of the highest tenth of all waves

$H_{1/100}$ — the average height of the highest 1% of all waves reaching the structure

T_s — the significant period (average 'period' of the highest third of waves)

Source: Aquitaine studies in support of exploration

TABLE 3-4

PREDICTED SEA STATE DURING THE 1 IN 100 YEAR STORM

LOCATION	$H_s(H_{1/3})$ M	$H_{1/10}$ M	H_{max} M	T_s secs
Walrus	12.8	16.5	23.8	15½
61°N 90°45'W	13.7	17.5	25.7	16
60°N 90°45'W	14.0	17.9	26.2	15
59°N 90°45'W	12.3	15.8	23.2	15
58°N 91°W	10.7	13.6	19.8	15
57°N 88°45'W	> 6.1	8.5	8.5	--
57°N 82°30'W	10.9	14.0	20.4	15
58°N 83°15'W	11.9	15.2	22.1	15½
59°N 83°45'W	12.2	15.5	22.9	15½
60°N 83°15'W	13.7	17.5	25.8	16

LEGEND:

H_s — the significant wave height

$H_{1/3}$ — the average height of the highest third of all waves

$H_{1/10}$ — the average height of the highest tenth of all waves

H_{max} — the height reached by one wave in a thousand, during the 1 in 100 year storm

T_s — the significant period (average 'period' of the highest third of waves)

Source: Aquitaine studies in support of exploration

Shellard (1974) summarized the conditions for icing due to sea water. Icing rarely occurs at air temperatures above 6°C and has been recorded at temperatures below -25°C. The freezing point of saline spray varies from a little below 0°C for slightly saline water to -1.9°C for ocean water; the freezing point is dependent on the salinity. At a wind speed of 17-21 knots (Beaufort Force 5) a small vessel is likely to begin generating spray. At 22-27 knots (Force 6 with waves of 3 m or higher), most small vessels moving against the waves will be showered in spray. However, spray resulting from wind action against the wave tops is not likely to be a serious source of icing until higher wind speeds are reached. It takes a Force 9 wind of 41-47 knots to carry significant amounts of the spray as high as deck level to the point where visibility would be affected. Measurements of sea spray with height indicate that sea spray seldom reach as high as 16 m above the peak water level (Minsk 1977). In general, the lower the air temperature and the higher the wind speed, the more likely icing is to occur and the greater the severity.

While the most frequent reports of tragic losses due to icing involve ships, the phenomenon of marine icing can occur on any structure surrounded by or in the proximity of ocean waters. These structures could include stationary or submersible drill rigs as well as ships and boats of all sizes. However the larger structures have sufficient buoyancy and stability to be less susceptible to the effects of icing.

4. CHEMICAL OCEANOGRAPHY

4.1 INTRODUCTION

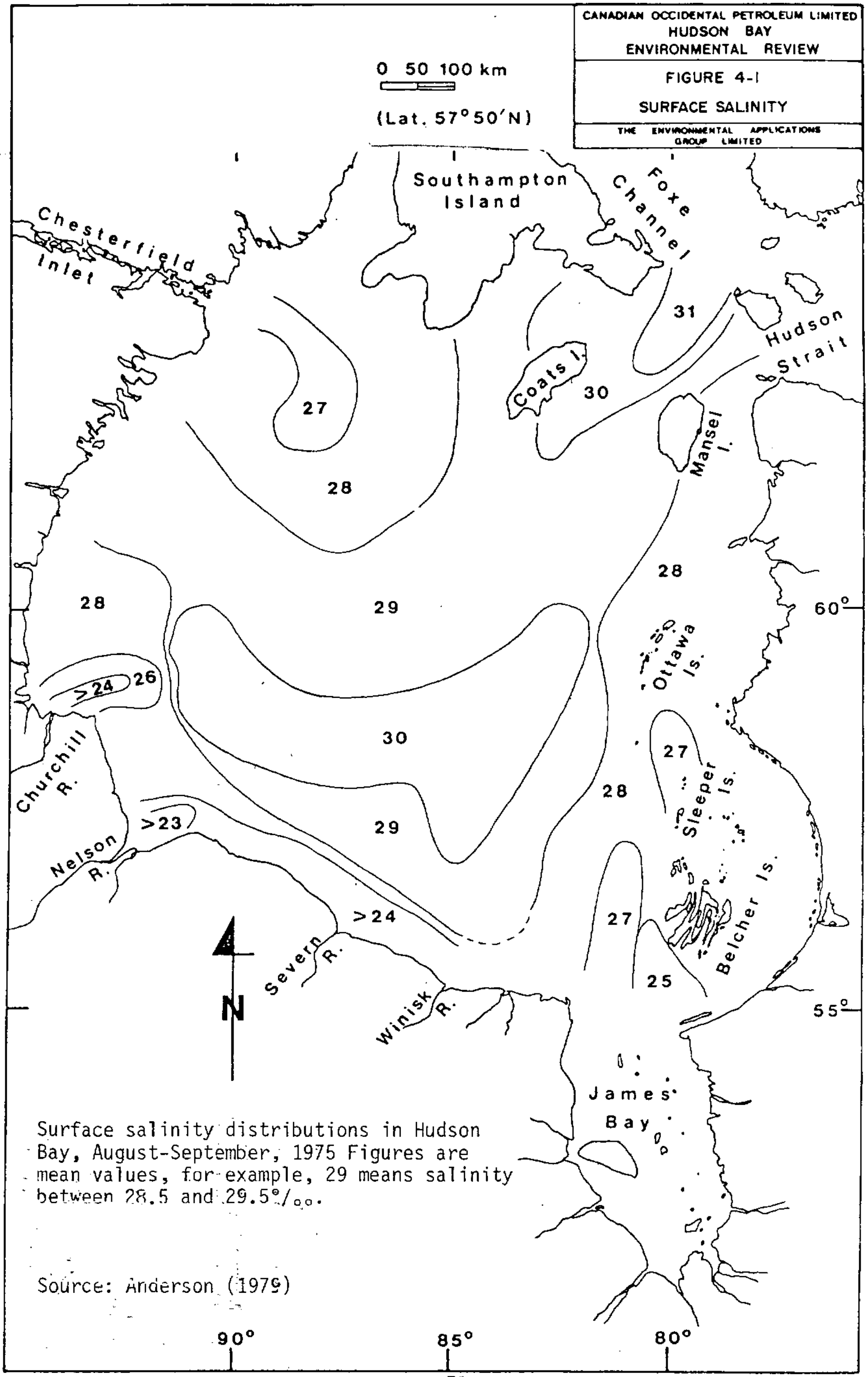
In recent years, the existing data base related to the chemical composition of Hudson Bay waters has become much improved, particularly with respect to the summer and fall seasons, when exploration activity would take place. Major information sources include the results of oceanographic cruises sponsored by Fisheries and Oceans Canada in the 1970's. At present, there are no specific COGLA requirements relating to chemical oceanography, and this discipline does not play a significant role in operational safety. Other than direct petroleum inputs in the event of an oil spill, the only potential area for interaction between the marine waters and exploration activities might relate to the release of drilling muds and their components.

4.2 SALINITY

Numerous oceanographic cruises took place in the 1970's, particularly concentrating on the southeast portion of Hudson Bay and on James Bay. These have provided important data on the salinity distributions during the open water (drilling) season. Winter measurements, however, are somewhat sparse.

Salinity patterns have been described for the northern portion of Hudson Bay by Dunbar (1958) and for the whole of Hudson Bay by Anderson and Roff (1980a) based upon data reported by Anderson (1979), Prinsenberg and Collins (1979), Prinsenberg and Flemming (1982) and Prinsenberg (1977). Figure 4-1 outlines surface salinity (3 m) distribution in summer, 1975. Values ranged from 22.0 to 31.8‰ with highest salinities being found inshore around Coats and Southampton Islands, and offshore near the middle of the Bay.

Anderson and Roff (1980a) reported that the lower salinities were found in all inshore areas except the west coast where values 29 $^{o}/oo$ were similar to those in



Surface salinity distributions in Hudson Bay, August-September, 1975 Figures are mean values, for example, 29 means salinity between 28.5 and 29.5°/₀₀.

Source: Anderson (1979)

the adjacent offshore region. Lowest concentrations ($<23\ ^o/oo$) were recorded very close to shore, adjacent to the Nelson River. The authors reported a relatively large body of water of 25 $^o/oo$ salinity south of the Belcher Islands (Figure 4-1).

Pett and Roff (1982) reviewed salinity and other data and concluded that recent (1975-1978) oceanographic cruises by the "Narwhal" and "Petrel" have yielded the same deep water temperature - salinity relationships reported in earlier studies (Hachey 1931, Bailey and Hachey 1951, Bailey 1957, Dunbar 1951, Coachman and Aagard 1974, Dunbar 1958, Barber 1967, 1968, 1972, Sadler et al. 1979). Waters below 50 m are characterized by temperatures between 0 and -1.86 °C and salinities of 30 to 33.7 $^o/oo$. Although warmer, fresher bottom waters are prevalent near the James Bay - Belcher Islands area, Pett and Roff (1982) concluded all bottom water points fall within the Arctic polar waters temperature - salinity polygon described by Dunbar (1951).

Observed patterns of salinity and other parameters may be explained in terms of the water budget of Hudson Bay, including both marine and freshwater sources. Barber (1968) proposed the following:

In ($10^6\ m^3\ sec^{-1}$)		Out ($10^6\ m^3\ sec^{-1}$)	
From Hudson Strait	: 0.5	Through Hudson Strait	: 0.6
Through Fundy and Helca Strait	: 0.05		
Fresh Water	: 0.05		

Prinsenberg (1977) examined the freshwater inputs to the Hudson/James Bay system in light of the proposed James Bay hydroelectric development. Over a yearly period, the equivalent of a 64 cm layer of freshwater is added over the surface area of Hudson/James Bays by rivers in the southern portion of the system, with ten times as much entering from May to October as in the winter. The author concluded that following hydroelectric development, the runoff rate of the La Grande River itself will increase by 470% of its present winter rate resulting in a 20% runoff increase in winter for the Hudson/James Bay system.

In the summer, there appears to be little vertical mixing among surface and sub-pycnocline waters, particularly in the offshore areas (Pett and Roff 1982). Pett and Roff (1982) proposed a turnover time for deep Hudson Bay waters in the range of 4 to 14 years, and noted that this range agreed well with Barber's (1967) 5 to 7 year estimate. Stability of the water column in the central portion of Hudson Bay appear to be quite strong during the open water season. In nearshore waters, greater instability is found (Legendre et al. 1982) related to the combined effects of both winds and fortnightly tides.

With regard to winter conditions and vertical water exchange, Dunbar (1982) noted the differing opinions on the strength and extent of such mixing. While Hachey (1954) and Dunbar (1958) postulated (having the benefit of very meagre data) that the water column would be uniform by freeze-up time, Barber (1967) came to a different conclusion on the basis of salinity values between 50 and 75 m depth and Prinsenberg (personal communication reported in Dunbar 1982) considered about 60 m to be the depth to which winter vertical mixing reaches.

Recent studies by Prinsenberg (1982 b) examined data near a river mouth entering Hudson Bay where large horizontal gradients in temperature and salinity are found. Variations of 0.5 C and 0.3 °/₀₀, which are equal to 30% of their total range with depth, occur at the 10 m level. The 0.3 °/₀₀ variation in salinity was reported to be caused by tidal motion of surface water, which has a horizontal gradient of 1°/₀₀ in ten kilometers. This magnitude of salinity gradient is found in the inshore areas of Hudson Bay.

A more detailed discussion of vertical temperature and salinity characteristics of Hudson Bay is provided in Section 3 (Physical Oceanography).

4.3 NUTRIENTS AND MEASURES OF PRODUCTIVITY

The primary nutrients - phosphorus, nitrogen, and for some organisms, silicon - are present in inorganic form in seawater mostly as phosphate, nitrate and silicate ions, respectively (Dugdale 1976). The major exogenous source of phosphorus and silicon is from land drainage but this is very small compared with the supply contained in the vast volume of seawater. Nitrogen compounds also enter by land runoff but the larger proportion comes from the atmosphere as a result of evaporation of ammonia from the land surface and fixation by marine plant life.

Dugdale (1976) noted that nutrients are removed from seawater by photoplankton in the euphotic zone, resulting in a nutrient-depleted layer. This surface nutrient deficit is replenished in most seas by mixing from the nutrient-bearing deeper waters and by local regeneration processes.

Legendre and Simard (1979) suggested nitrogen limitation in Hudson Bay, and demonstrated low nitrate levels (maximum of 6.6 mg m^{-3} as $N\text{-}NO_3$) even in deep Hudson Bay water, with similar levels noted by Pett and Roff in the Chesterfield Inlet area (unpublished data cited by Anderson and Roff 1980a). Legendre and Simard (1979) suggest that the low concentrations of nitrate observed in deep waters might be a result of a low rate of nutrient regeneration and also the uncoupling of Hudson Bay from Atlantic waters due to intense mixing in Hudson Strait. Nutrient levels reported by Pett and Roff (1982) support the theory of a non-Atlantic source for deep waters in Hudson Bay. Reactive nitrate plus nitrite, soluble reactive phosphorus, and reactive silicate are very similar to levels in other Arctic areas, but are distinctly different from Atlantic Ocean waters.

Using nutrient and oxygen measurements from the 1976 and 1978 "Petrel" cruises, Pett and Roff (1982) provided further evidence that low concentrations of nitrate and other nutrients are a consequence of slow or incomplete nutrient regeneration alone. The authors used a model based upon apparent oxygen utilization (AOU) to separate expected nutrients of oxidative origin (i.e.

TABLE 4-1

Mean Observed and Expected Nutrient Concentrations ($\mu g\ L^{-1}$) in Sub-Pycnocline Hudson Bay Waters

Depth Interval (m)	Reactive Nitrate Plus Nitrite		Soluble Reactive Phosphorus		Reactive Silicate	
	Observed	Expected	Observed	Expected	Observed	Expected
25 - 50	0.9	3.2	0.8	0.3	5.2	4.8
50 - 100	3.7	12.6	1.1	0.8	11.2	17.6
100 - 125	4.5	17.2	1.1	1.1	14.1	24.9
> 125	5.1	18.2	1.3	1.1	16.5	25.3

Data from Pett (1981) and Legendre and Simard (unpublished).

Source: Pett and Roff (1982)

regenerated from organic matter) from those performed (originally present in surface waters of source regions). The quantity of nutrients actually measured is then the sum of oxidative and preformed nutrients. Table 4-1 summarizes mean observed and expected (calculated from AOU) nutrient concentrations in sub-pycnocline waters.

The authors noted that at almost all stations considered, the measured nitrate was less than expected, while observed levels of soluble reactive phosphorus were greater than or equal to those expected throughout the water column. Observed levels of reactive silicate only exceeded expected levels in the upper 50 m.

Pett and Roff (1982) concluded that nitrogen regeneration in deep offshore waters of Hudson Bay is clearly slow and characterized by incomplete nitrification. With respect to phosphorus and silica, their much smaller deficits in deep water suggested that additional factors may be significant in their regeneration. The authors noted that in both cases the expected concentration never attains values comparable to deep Atlantic waters.

The low productivity of Hudson Bay reported by Anderson and Roff (1980 a) (see Section 5) was attributed by Pett and Roff (1982) to incomplete mixing and resultant low regeneration rates of nitrogen. Their preliminary calculations indicated that nitrate and total nitrogen contributions from deep water mixing and freshwater runoff are of the same order of magnitude, but direct atmospheric contributions are about 10% of the total. The authors felt that freshwater runoff to Hudson Bay affects primary production negatively by increasing vertical stability, but positively by its relatively significant nutrient additions.

To summarize, it appears that, during the summer months, Hudson Bay is an oligotrophic body of water of low productivity, heavily influenced by freshwater runoff.

There are still many unknowns regarding nutrient distributions (spatial and temporal) in Hudson Bay, particularly for winter, and a complete understanding of nutrient cycling is not currently possible.

4.4 OTHER PARAMETERS

4.4.1 Metals

Baseline concentrations of metals and organic parameters are poorly known, since oceanographic cruises to date have concentrated on physical and biological characteristics of Hudson Bay. Barber (1968) included no data of this nature in his major review of Hudson Bay waters. Information relating to sources and sinks of such materials is not available. Atmospheric deposition and geological sources of metals, hydrocarbons or other parameters of water quality interest have not been evaluated.

4.4.2 Oxygen

Hudson Bay waters are generally well oxygenated with observed values ranging generally from 4 to 9 mg/L although lower values are occasionally noted in deep waters due to respiration of animals and other oxidative processes. Dissolved oxygen data for deep waters suggest water exchange in late summer as high values occur throughout the depths after August (Barber 1968). The condition of coldest water with least oxygen appeared to have taken place in August suggesting a greater influence at the sampling location of water predominantly from within Hudson Bay. Conversely, the author felt that the relatively warm water of high oxygen content of October suggests a greater influence of water from Hudson Strait.

4.4.3 Bottom Sediments and Turbidity

Although bottom sediment data are sparse, Leslie (1965) collected 73 grab samples and 6 cores and analyzed them for selected ecological and sedimentary characteristics. He found that in shallow coastal regions and offshore shoals, sediment particles generally have a median diameter in the fine sand-silt range, whereas deeper basin areas, which are less influenced by wave and tide energy, are characterized by sediments with relatively high organic carbon content and have a median diameter in the clay range. As a general rule, clay-sized particles tend to contain higher concentrations of adsorbed metals and organic materials than larger grain sizes. As well, the fine materials are more easily re-suspended by disturbance and remain in the water column for longer periods of time.

Sea bottom conditions are important with respect to anchor holding power. As well, the nature of the substratum influences the types of benthic communities that can utilize this habitat. The earlier Environmental Impact Assessment for Aquitaine Company of Canada Ltd. (Carruthers et al. 1974) noted that available data indicates that the bottom sediments are mainly glacial drift — a mixture of consolidated silt, sand, gravel and pebbles — providing a stable surface which should provide good holding power.

In a study of dredged samples in Hudson Bay by the Bedford Institute of Oceanography (1968) it was found that there was a predominance of a rather Upper Ordovician affinity. X-ray diffractometry was used to determine the proportions of quartz, calcite, dolomite, potash feldspars and plagioclase feldspars. Twenty-two types of microfacies and one intermediate type were recognized.

Extensive survey data on the nature and distribution of sub-tidal substrates appear to have been gathered in a preliminary sense for Hudson and James Bays but these apply only to materials less than 2 mm in diameter (Leslie 1963). Any assessment of bottom types is therefore speculative (EAG 1979). It is assumed that within the shallow water zone, bottom types will be similar to those of inter-tidal zones except that finer sediments will occur in greater abundance. Hence, rocky inter-tidal zones will tend to accumulate sands and silts further offshore (Bird 1977), and muddy shore communities will grade into silty clays. Superimposed on this process are general circulation patterns which are known to be important in Hudson Bay. For example, along the west coast of Hudson Bay, counter clockwise currents tend to remove finer materials and deposit them in southern and eastern portions of the bay, leaving sands and gravels as the major sediment type along the west coast (Leslie 1963). Pelletier (1969) provided additional information on sediment physiography, bottom sediments and models of sediment transport in Hudson Bay.

Sandy bottom communities are undoubtedly better developed with sub-tidal ecosystems than they are in inter-tidal zones, with modest to good representation occurring in parts of western and southwestern Hudson Bay. Local occurrences are also likely to be found along the east James Bay coast. With the possible exception of southwestern Hudson Bay, it is anticipated that most sand deposits will occur in conjunction with silts, gravel and rock substrates.

The predominant sediment type of Hudson and James Bays and undoubtedly Foxe Basin, in deep waters is silt (Leslie 1963). Therefore, given that silt communities are widespread and abundant in the vicinity of most of the region's coastlines both at depths and in the inter-tidal zones, it is reasonable to assume that muddy bottom communities are well represented at intermediate depths as well (EAG 1979). Common life forms present include sea anemones, polychaete tube worms, sea stars, sea urchins and sea cucumbers.

Kranck and Ruffman (1982) summarized data for the northern part of James Bay provided by Meagher et al. (1976) and Duncan (1981). All sediment samples reported from the north end of James Bay and the portion of Hudson Bay south of the Belcher Islands comprised fine mud.

Few background turbidity data have been recorded in Hudson Bay but levels would likely be low in the offshore zone (EAG 1979). Except for periods of excessive fluvial discharge during melt-off, Hudson Bay waters are clear owing largely to oligotrophic conditions which prevail throughout the region. Seasonal variations are limited to brief algal blooms during the open water season, and spatial variation typically involves local differences caused by estuarine effects or nearshore turbulence.

Kranck and Ruffman (1982) and Barber (1972) have brought together miscellaneous measurements of Secchi disk transparency and report that the Secchi depth exceeds 15 m in the open water of Hudson Bay. This can be contrasted with the much more turbid waters of James Bay which range from a Secchi depth of only about 2 m in the south to about 10 m at the junction with Hudson Bay. The low transparency in James Bay results from high sediment loads entering from tributary rivers in James Bay and southwestern Hudson Bay. Higher turbidity in shallow waters was attributed to re-suspension of bottom sediments by wave action.

5. MARINE ECOLOGY

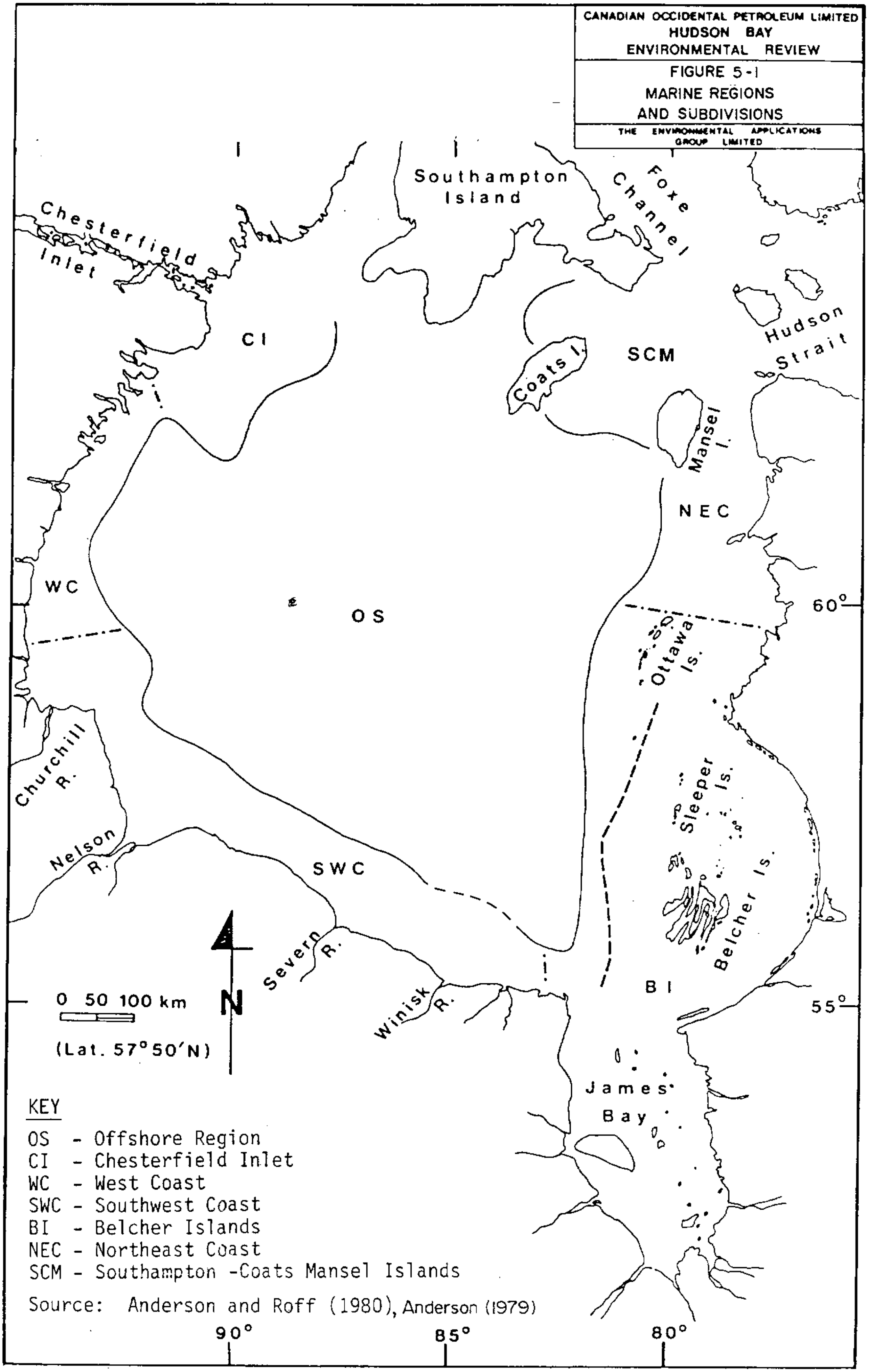
5.1 INTRODUCTION

This section of the review focuses on phytoplankton (including general primary productivity questions), zooplankton, benthic invertebrate communities and marine plants. These components of the ecosystem are closely interrelated with the physical, biological and social aspects of the Hudson Bay environment. Both community structure information and energy nutrient mechanism data are required to undertake a detailed analysis of marine community structure. As has been noted in section 4, the nutrient budget for Hudson Bay is quite poorly understood. Data relating to plankton and primary productivity have recently become much improved, although a detailed understanding of interrelationships among plankton, fish, mammals, birds etc. is not yet feasible.

In general terms Anderson and Roff (1980 a) found that clear inshore-offshore gradients in physico-chemical and biological variables existed in Hudson Bay. Within the inshore region, they delineated 6 areas based upon biomass values, biomass ratios, salinity-temperature distributions, phytoplankton data, corresponding watershed areas and known duration of winter ice cover. Figure 5-1 outlines these areas which are:

1. Chesterfield Inlet area
2. The west coast area, north of the Churchill River
3. The southwest coast, from the Churchill River to James Bay
4. The Belcher Islands area, north of James Bay-Hudson Bay boundary and west of the Belcher and Sleeper Islands
5. The Southampton-Coats-Mansel Islands area, around these islands and contiguous with Hudson Strait
6. The northeast coast area, between Marcel Island and the Ottawa Islands.

The authors notes that the inshore areas which are subject to higher freshwater runoff had significantly lower salinities and temperatures, and signi-


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 5-1
MARINE REGIONS
AND SUBDIVISIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
Southampton Island
Foxe Channel
Chesterfield Inlet
CI
SCM
Coats I.
Hudson Strait
Mansel I.
NEC
WC
OS
60°
Ottawa Is.
Churchill R.
Sleeper Is.
Belcher Is.
Nelson R.
SWC
Severn R.
Winisk R.
BI
N
0 50 100 km
(Lat. 57°50'N)
55°
James Bay
KEY
OS - Offshore Region
CI - Chesterfield Inlet
WC - West Coast
SWC - Southwest Coast
BI - Belcher Islands
NEC - Northeast Coast
SCM - Southampton -Coats Mansel Islands
Source: Anderson and Roff (1980), Anderson (1979)
90°
85°
80°

ficantly higher chlorophyll a. Land runoff and associated coastal circulation appear to be the predominant factors influencing standing crop and probably productivity in the surface waters of Hudson Bay (Anderson and Roff 1980 a).

Offshore waters in summer were comparatively oligotrophic with significantly lower values for such measures of productivity as chlorophyll a, adenosine triphosphate, particulate organic carbon, particulate organic nitrogen and ash-free dry weight (Anderson and Roff 1980 a, Table 2). Their transect analyses indicated that in all cases biomass decreases away from shore in the summer.

5.2 MICROBIOTA

The microbial part of the biological cycle in Arctic waters has been little studied except for some work on the microphytoplankton (Dunbar 1975). In response to Beaufort Sea oil exploration, the metabolic requirements of oil degrading bacteria are now under investigation. Bunch et al. (1980) examined the abundance and activity of heterotrophic marine bacteria in marine bays at Cape Hatt, N.W.T., while Mulkins-Phillips and Stewart (1973, 1974) undertook surveys of distributions of hydrocarbon-utilizing bacteria such as Nocardia sp. in northwestern Atlantic waters and coastal sediments and subsequently (1975) examined the effect of environmental parameters on bacterial degradation of Bunker C oil, crude oils and hydrocarbons.

Atlas et al. (1978) examined Prudhoe crude oil degradation and interactions with microbial and benthic communities in an Arctic setting, and found that in non-oil-contaminated ecosystems, the oil-degrading microbial population constituted only a small percentage (0.01 to 0.1%) of the viable heterotrophic microorganisms. Following exposure to oil for 30 days, the estimated percentage of oil-utilizing organisms rose greatly (~50%) in over-water experiments but only minimally in over- and under-ice experiments (0.03 to 0.5%).

It appears that no specific microbiological studies have yet taken place in Hudson Bay which examined the baseline characteristics of marine bacterial populations. Similarities to other northern waters would be expected, although the oligotrophic nature of Hudson Bay may result in some adaptations in heterotrophic communities.

5.3 PHYTOPLANKTON AND PRIMARY PRODUCTIVITY

Dunbar (1982) has provided a historical review of phytoplankton research in Hudson Bay, based upon the work of Davidson (1931) to date. Bursa (1968) noted that the number of phytoplankton species recorded in the Arctic Ocean (63 species) is less than the number found in Foxe Basin (121) which in turn is much less than the number found in Hudson Bay (235). Dunbar (1982) found that the number of known species in Hudson Bay has been increased by the recent work of Gerrath et al. (1980) who added 37 freshwater species new to the flora and recorded 42 freshwater species in all, reflecting the large freshwater runoff into the Bay.

Results from the "Narwhal" cruises in the 1970's (Anderson 1979, Anderson and Roff 1980 a,b, Anderson et al. 1981) have greatly augmented the data base with respect to biomass (total seston), phytoplankton and general productivity. A total of 82 genera and 158 species of phytoplankton were identified in 130 samples, many of these being reported for the first time. Diatoms formed the largest group with 23 genera and 57 species. Dinoflagellates were represented by 10 genera and 46 species.

Figures 5-2 to 5-4 depict surface abundances of diatoms, dinoflagellates and other flagellate forms of plankton. Anderson (1979) provides complete listings of genera and species from Hudson Bay along with qualitative and quantitative descriptions of the taxa from 130 stations. Phytoplankton abundances and species composition both reflected freshwater and marine influences at the surface in Hudson Bay. Cell abundances ranged from 5,000 to 200,000 cells per litre for diatoms and 2,000 to 125,000 cells/L for dinoflagellates. In general, Anderson reported that high numbers of diatoms were associated with lower numbers of both dinoflagellates and "flagellates", the latter group including Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, and unidentified flagellate forms.

Subsequent work by Anderson et al. (1981) noted that certain areas of Hudson

Bay have much higher phytoplankton standing crops than previously believed, often greatly exceeding counts from Foxe Channel and Hudson Strait. The lowest diversity indices of diatoms, dinoflagellates, and the two groups combined were observed at lower salinities along the southwest coast. The diversity index of diatoms and dinoflagellates combined was found by the authors to be otherwise high throughout the Bay (>3) and was highest in the Coats and Mansel islands area.

Anderson and Roff (1980b) also reported the presence of a subsurface chlorophyll maximum layer in the offshore waters of Hudson Bay, one of the most northerly and most highly developed maxima yet discovered. This layer occurred at depths from just below to 20 m below the pycnocline, usually between 0.1 to 1.0% of surface light levels, and may contribute significantly to annual production in Hudson Bay.

Legendre et al. (1982) concluded that summer phytoplankton blooms in upper Manitounuk Sound, north of Great Whale River in southeastern Hudson Bay (Figure 1-1), were caused by cycles of relative stability and instability of the water column, driven by local winds and tides. These authors also suggested that other coastal embayments of Hudson Bay may also exhibit similar summer phytoplankton blooms. No subsurface chlorophyll maximum was observed in nearshore waters, in contrast to the results reported by Anderson and Roff (1980 b) for offshore areas.

Figures 5-5 to 5-7 report surface chlorophyll a, particulate organic cabon and ash free dry weight values for surface waters of Hudson Bay, these being parameters which reflect plankton biomass and nutrient status. These findings contributed to the delineation of areas by Anderson and Roff (1980 a) shown in Section 5.1 (Figure 5-1). Offshore values of chlorophyll a were always low, averaging 0.09 mg m^{-3} while inshore values averaged 0.28 mg m^{-3}. Sampling stations are shown on Figure 5-8.

The higher inshore concentrations of phytoplankton in Hudson Bay (along with nutrients, standing crop and plankton production) are characteristic of most large bodies of water (Anderson and Roff 1980 a). The authors noted that the Belcher Islands area was characterized by low salinities of 25 to 27‰ and the highest biomass of all inshore areas. It receives 44.6% of the annual runoff to

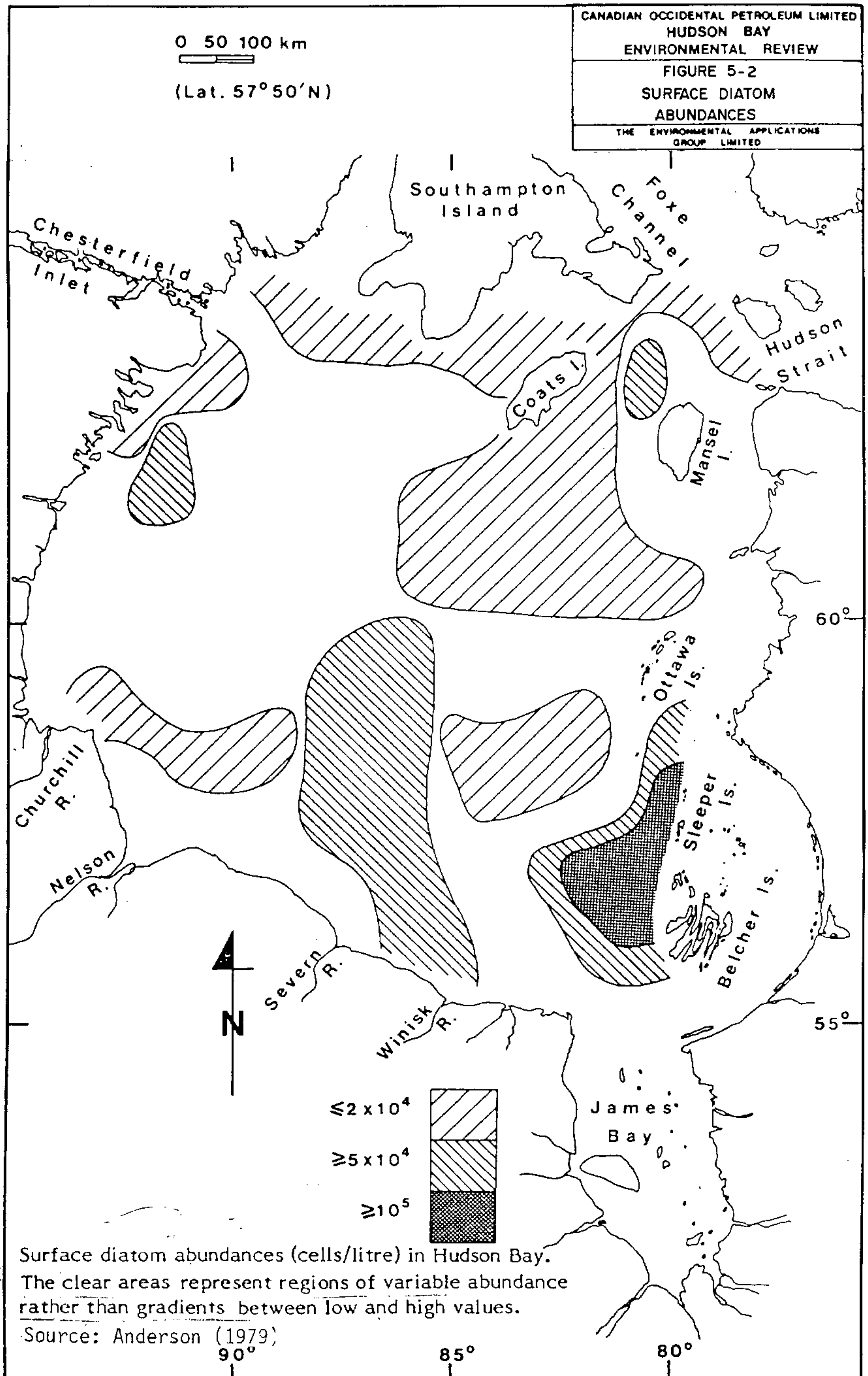
Hudson Bay and circulation patterns direct relatively nutrient-rich waters from the southwest coast and James Bay to this area, resulting in mixing and higher biomass. As well, this area receives warm James Bay water early in the spring, so that production may begin here sooner and continue later than in ice-covered portions of Hudson Bay.

Grainger (1982) examined factors affecting phytoplankton stocks and primary productivity near the Belcher Islands and found planktonic succession to be typical for arctic marine waters as described by Bursa (1963) although with a longer time interval than found in other arctic localities. As diatoms fell in numbers, planktonic ciliates increased conspicuously through August. The author suggested that grazing was the major cause of the diatom decline in August, occurring at a time when neither subsurface light nor nutrients appeared to play a limiting role.

Anderson and Roff (1980 a) found that the carbon : nitrogen ratios in Hudson Bay were similar to Pacific Ocean and North Atlantic values but were lower than for surface waters of the Arctic Ocean sampled under the ice. This suggested more productive conditions in Hudson Bay, compared with the Arctic Ocean, at least for the inshore. The authors notes that several authors since Huntsman (1954) have considered Hudson Bay generally to be a region of low productivity, and the biomass data and the existence of a well developed subsurface chlorophyll maximum throughout the offshore area of Hudson Bay were felt to support this position.

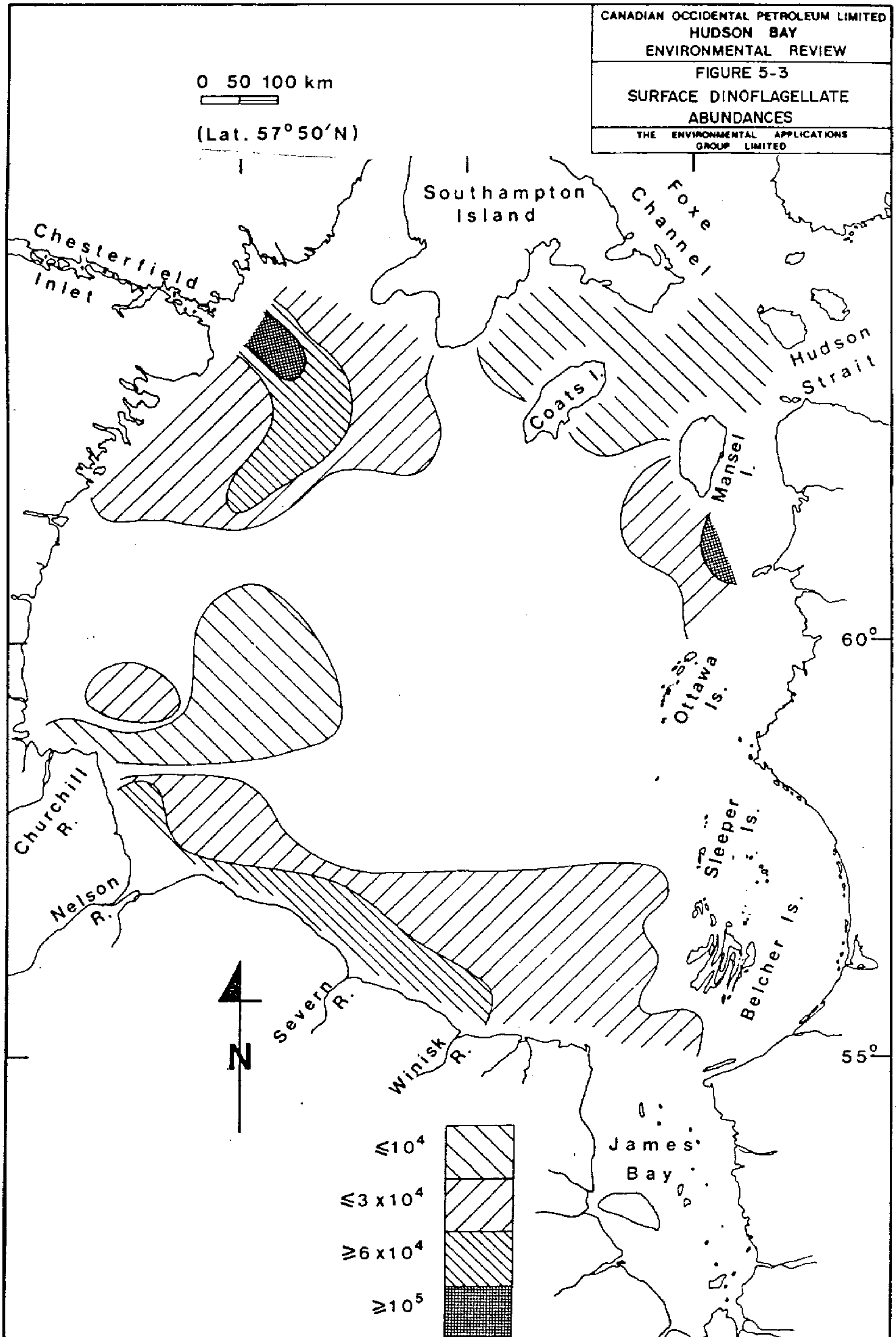
Perhaps one of the most surprising features of Hudson Bay noted by Anderson and Roff (1980a) was that despite the enormous freshwater runoff, the biomass supported is low. This may relate at least in part to the Bay's intense stratification, and the probability that the deepwater layer is only partially mixed with the surface layer each year (see section 4).

Periods of peak production probably occur earlier in Hudson Bay (Anderson and Roff 1980 a) relative to other Arctic waters where peak production occurs in late July to August (Grainger 1959, Bursa 1961). Chlorophyll a never approached bloom conditions and there was no evidence of seasonal changes in biomass from



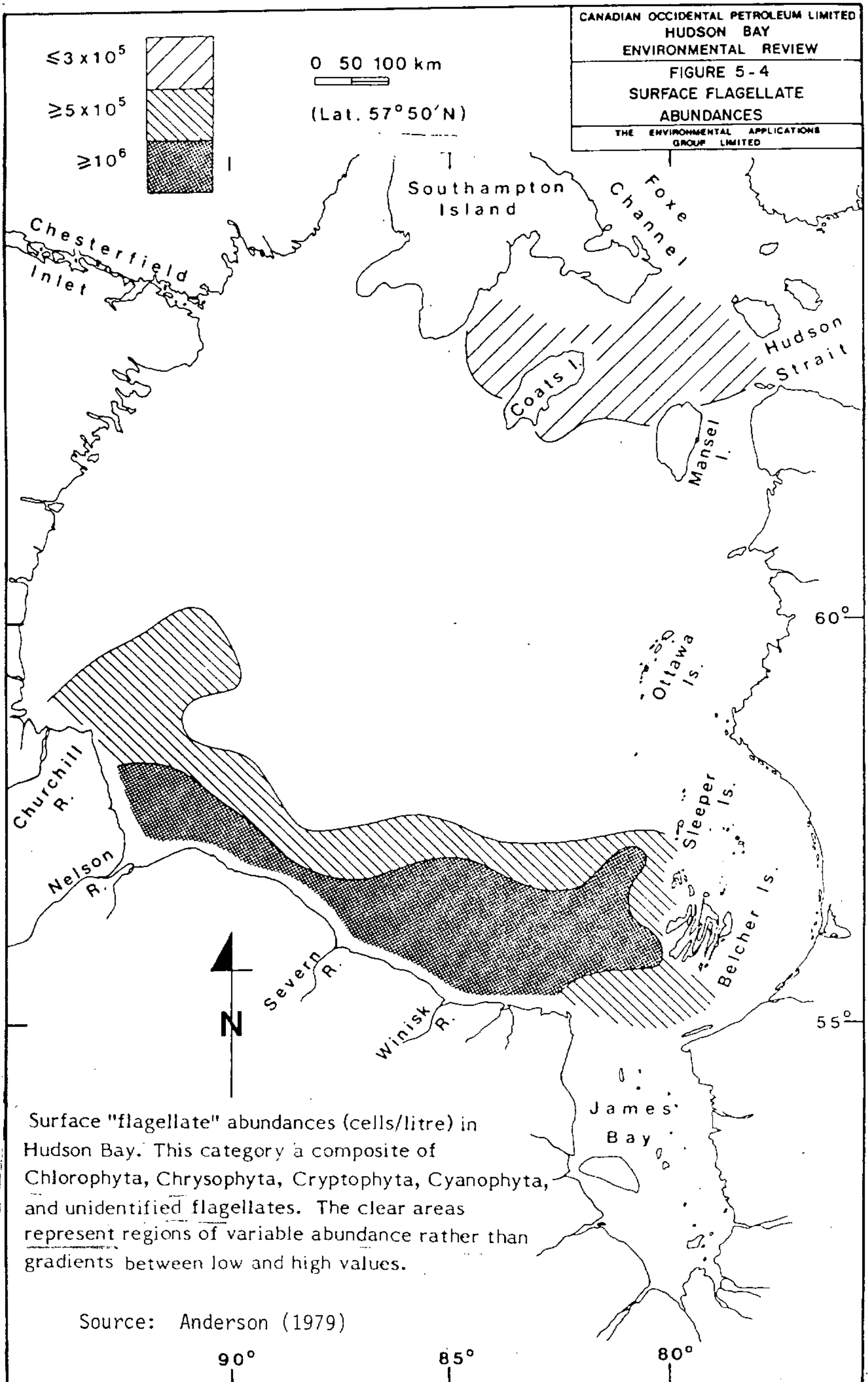
Surface diatom abundances (cells/litre) in Hudson Bay. The clear areas represent regions of variable abundance rather than gradients between low and high values.

Source: Anderson (1979)



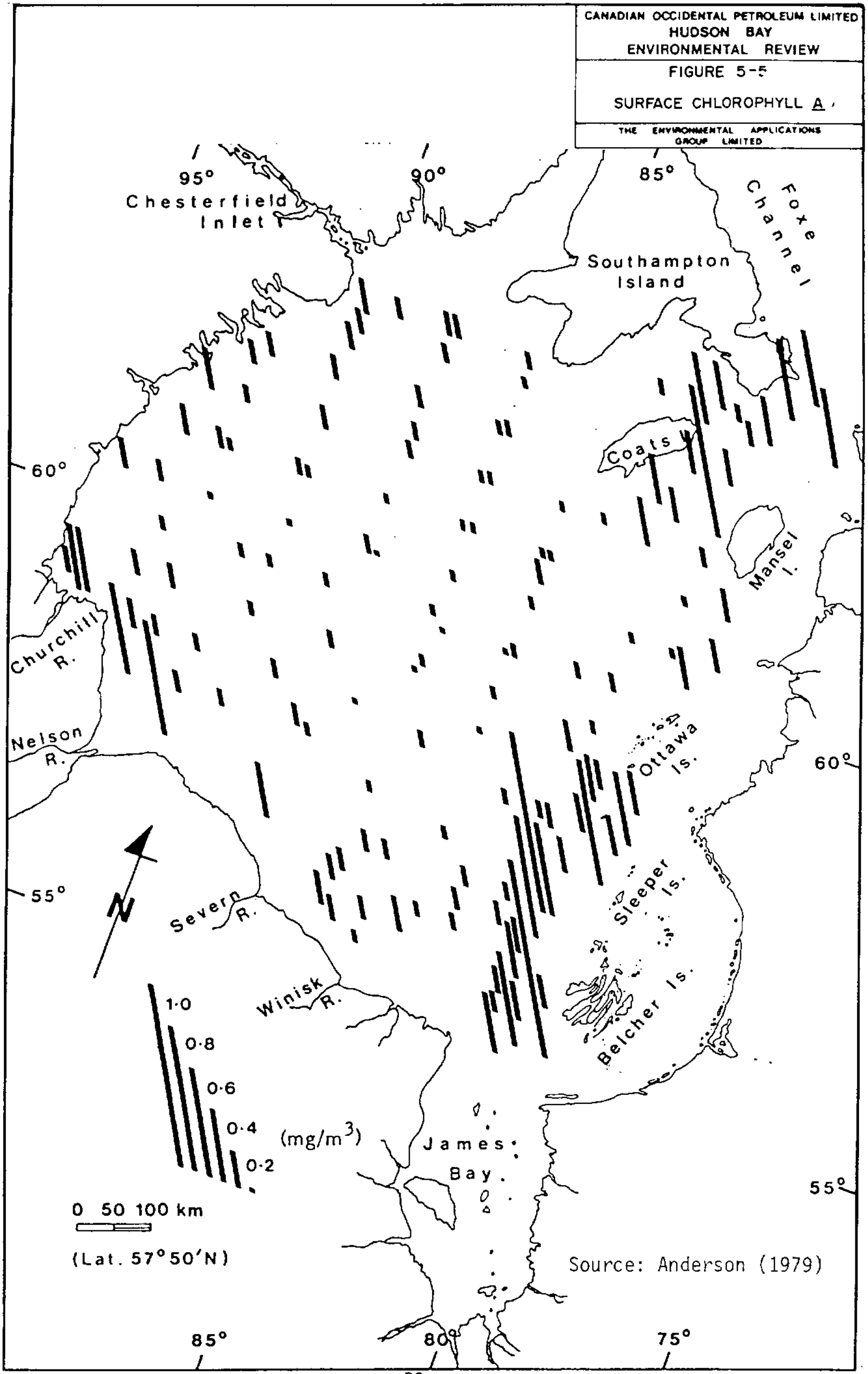
Surface dinoflagellate abundances (cells/litre) in Hudson Bay. The clear areas represent regions of variable abundance rather than gradients between low and high values.

Source: Anderson (1970)



Surface "flagellate" abundances (cells/litre) in Hudson Bay. This category a composite of Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, and unidentified flagellates. The clear areas represent regions of variable abundance rather than gradients between low and high values.

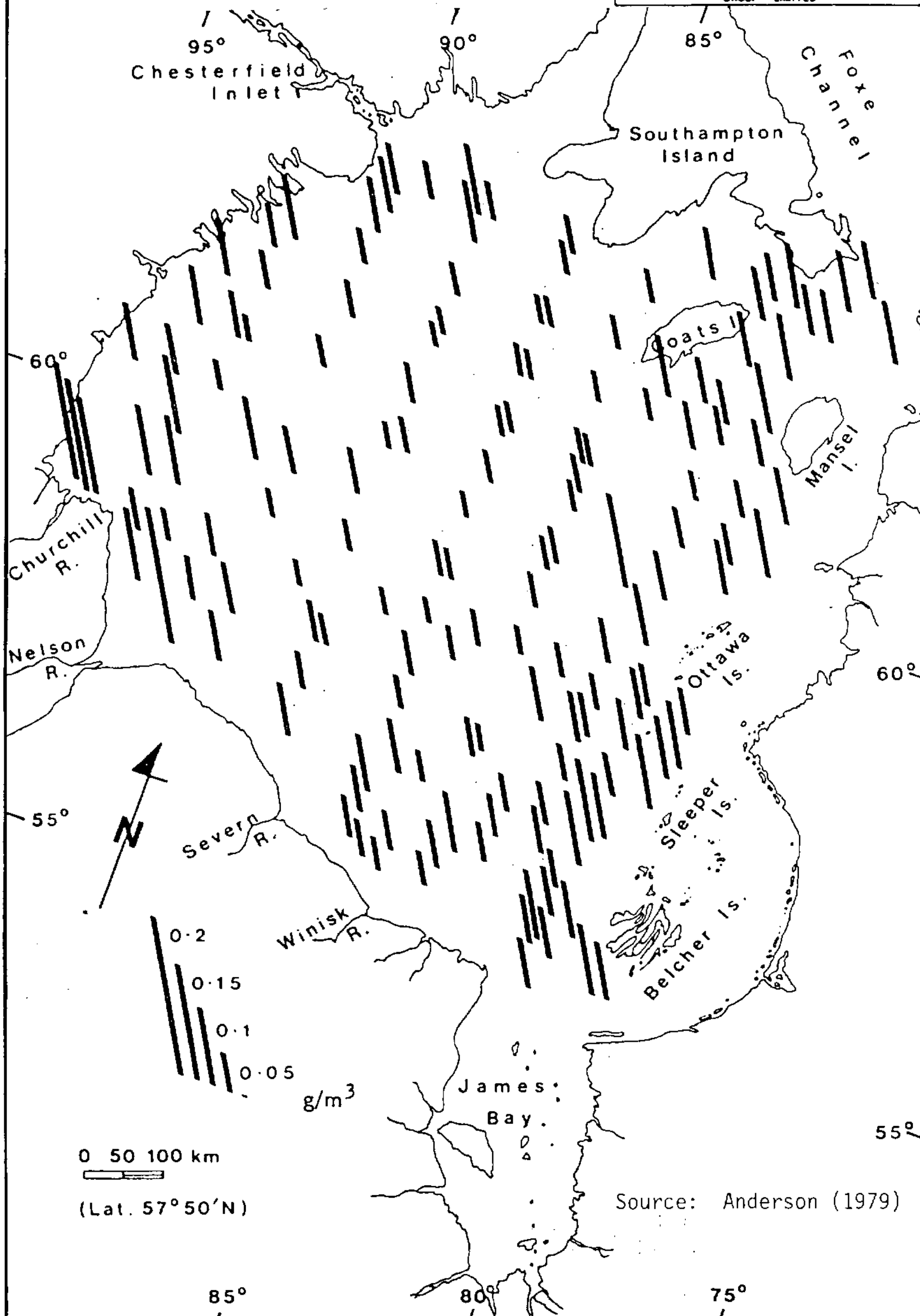
Source: Anderson (1979)


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 5-5
SURFACE CHLOROPHYLL A
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
95°
90°
85°
Chesterfield Inlet
Southampton Island
Foxe Channel
Coats I.
Mansel I.
60°
Churchill R.
Nelson R.
Ottawa Is.
60°
55°
Severn R.
Sleeper Is.
Belcher Is.
Winisk R.
N
1.0
0.8
0.6
0.4
0.2
(mg/m3)
James Bay
55°
0 50 100 km
(Lat. 57°50'N)
Source: Anderson (1979)
85°
80°
75°

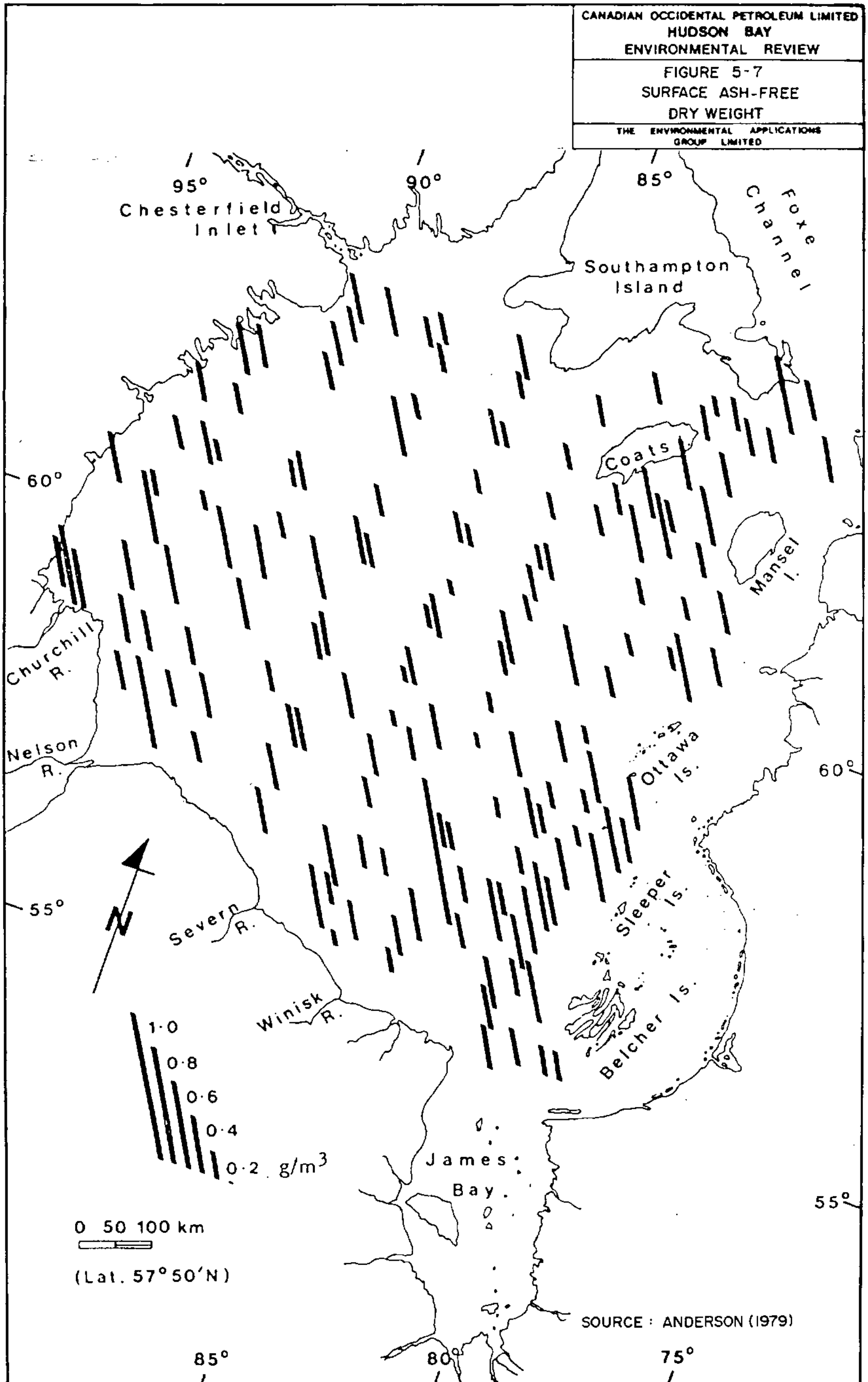
CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW

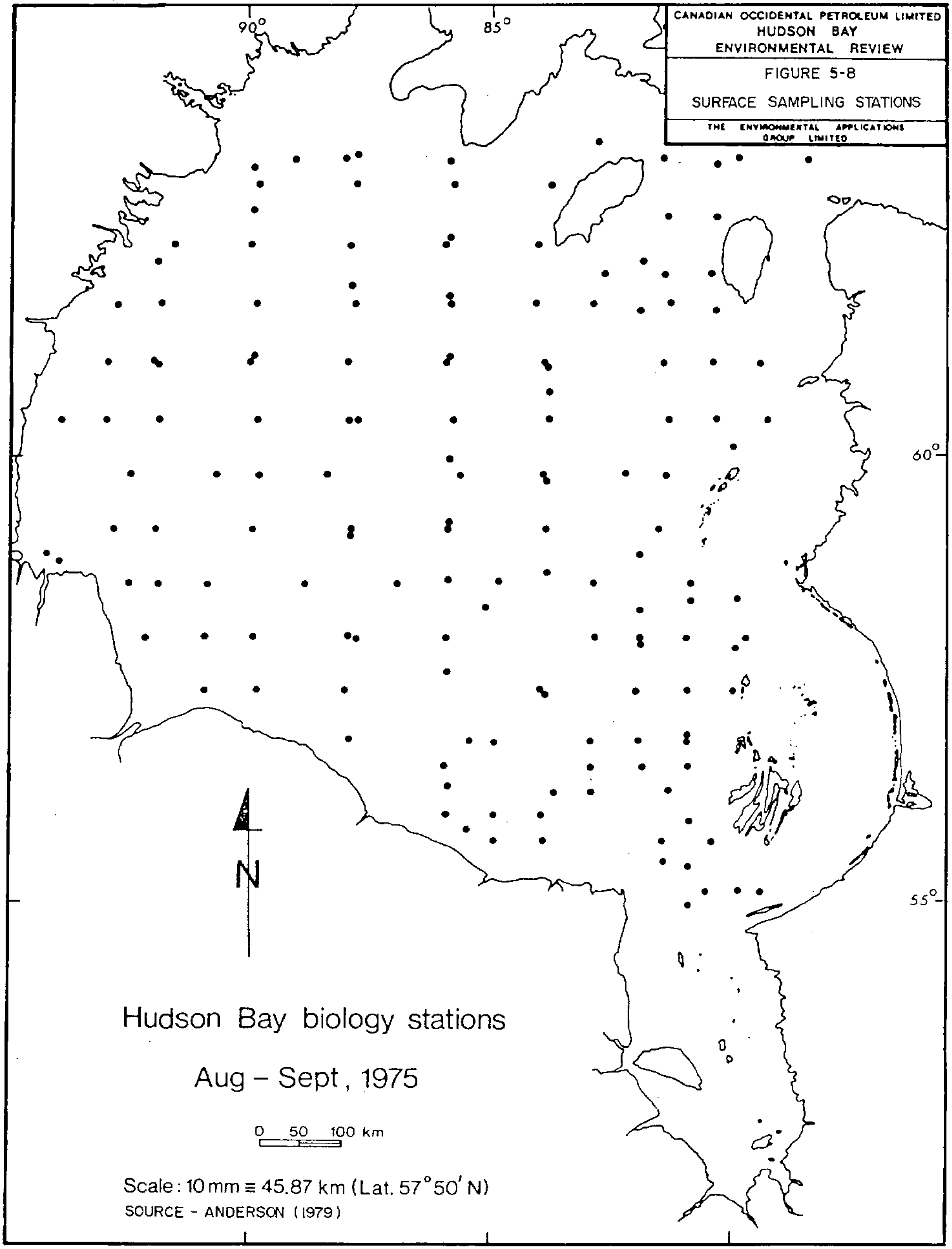
FIGURE 5-6
SURFACE PARTICULATE
ORGANIC CARBON

THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED



Source: Anderson (1979)


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 5-7
SURFACE ASH-FREE
DRY WEIGHT
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
95°
90°
85°
Chesterfield Inlet
Southampton Island
Foxe Channel
Coats I.
Mansel I.
60°
Churchill R.
Nelson R.
Ottawa Is.
60°
55°
Severn R.
Sleeper Is.
Belcher Is.
Winisk R.
N
1·0
0·8
0·6
0·4
0·2 g/m3
James Bay
55°
0 50 100 km
(Lat. 57°50'N)
SOURCE: ANDERSON (1979)
85°
80°
75°


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 5-8
SURFACE SAMPLING STATIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
90°
85°
60°
55°
N
Hudson Bay biology stations
Aug - Sept, 1975
0 50 100 km
Scale: 10 mm ≡ 45.87 km (Lat. 57°50′ N)
SOURCE - ANDERSON (1979)

July to the end of September. The authors felt that peak production in Hudson Bay probably occurs between May in the south and June in the north when the region is ice-covered. A seasonal chlorophyll a maximum may possibly develop within or just below the ice (Grainger 1977, Horner 1977), but biomass or production measurements of ice flora do not appear to have been made in Hudson Bay except for cursory investigations of diatoms that grow in sea ice (Dunbar and Acreman 1980).

While some primary production data are generally available, the exact nature of nutrient cycles and resulting productivity in Hudson Bay are still open questions. Most measurements are available for the open water (drilling) season, but winter measurements are sparse.

5.4 ZOOPLANKTON

Grainger (1968) reported about 50 zooplanktonic species for Hudson Bay, excluding the minute single celled Protozoa, of which several were considered Arctic indicator species, such as the medusa *Aeginopsis laurenti*, the copepods *Calanus glacialis* and *C. hyperboreus* and the amphipods *Gammarus wilkitzi* and *Parathemisto libellula*. He concluded that Hudson Bay is primarily Arctic in its invertebrate fauna, that a minor Atlantic element reaches at least into the northeast part of the Bay, and that the region showing the greatest concentration of species with apparent Atlantic (and Pacific) affinities, the southeast, remains as a refuge reflecting former rather than direct contemporary connection with the present fauna of those oceans.

Estimates of zooplankton quantity cited by Grainger (1968) indicated summer values ranging from 100 mg m^{-3} in the northeast, down to about 50 mg m^{-3} in southeast Hudson Bay and still lower in the shallow waters of the southwest. These can be compared with rich areas of the North Atlantic ($\sim$500 mg m^{-3}), the south Barcents Sea (>200 mg m^{-3}), the Laptev Sea (25 to 75 mg m^{-3}) and the central Arctic Ocean (<25 mg m^{-3} in the upper 100 m).

Dunbar (1975) summarized findings of Grainger (1959) which demonstrated the extreme annual oscillation in standing crop of Arctic zooplankton, (Foxe Basin), the very late seasonal development of blooms and the lack of a second (autumn) peak of production which is characteristic of temperate regions.

More recent evidence provided by Grainger (1982) reported that ciliates occurred in surprisingly large numbers at the Belcher Islands, reaching concentrations at least as high as $2 \times 10^4 L^{-1}$ and averaging about $6 \times 10^3 L^{-1}$ over the open water period. Free living ciliates are nearly all holozoic and are known to feed on bacteria, detritus, diatoms and small flagellates. In turn, they provide prey for a variety of larger zooplankters. Grainger (1982) concluded that the role of ciliates at the Belcher Islands appears to be a much more important one than has previously been recognized in northern marine waters. They are abundant and potentially important grazers on the primary producers as well as prey for the large zooplankton.

Among the planktonic invertebrates which are known to be important dietary components of Hudson Bay fish and mammals are *Parathemisto libella* and *Pseudalibrotus littoralis* (amphipods) which are among the principal food of the Arctic char and the Greenland cod, *Mysis oculata* (mysid) and *Thysanoessa raschi* (euphausiid) fed upon by the polar cod and a number of amphipods, euphausiids and shrimp which are dietary items of the ringed seal (Grainger 1959).

5.5 BENTHIC INVERTEBRATES

Bottom-dwelling invertebrate animals provide an important source of food for a number of Arctic fish, bird, and mammal species, largely in shallower areas. As well, the distribution, diversity and abundance of various worms, mollusks and other invertebrates are often good indicators of environmental conditions and sensitivity to disturbance. The make-up of the benthic community is generally controlled to a great extent by the substrate conditions and the availability of food.

Grainger (1968) surveyed available information on Hudson Bay invertebrates and found records of about 210 species of benthic invertebrates, including 59 from James Bay, 67 from Richmond Gulf and 202 from the main body of Hudson Bay. Table 5-1 summarizes these major invertebrate animal groups and the number of species in each.

In Grainger's view, the data in Table 5-1 reflect to some extent the uneven effort so far made in the study of the various animal groups of the Bay. Some, like the polychaetes and echinoderms were felt to be fairly well surveyed, along with the hydroids and bryozoans. Others, such as the sponges, medusae, molluscs and decapod crustaceans were less well known.

Although no quantitative benthic data were available to Grainger (1968) he estimated that Hudson Bay would be shown to support a benthic fauna in the order of diversity of the Laptev Sea (about 300 species, excluding protozoans).

Wacasey et al. (1976) reported zoobenthos data from samples collected throughout James Bay in 1959 and 1974. These are summarized in Table 5-2 and include 204 species. A considerable degree of agreement might be expected between the Hudson and James Bay benthic faunal lists, but some differences, particularly in relative abundances and overall standing crops would be expected due to differences in substrate, temperature, nutrient status and depth. Comparable data for central Hudson Bay do not appear to be available.

Little growth or production information is available for benthic invertebrates. Dunbar (1982) felt that the growth of Sagitta elegans (Dunbar 1962) and particularly Mytilus edulis (Lubinsky 1958) reflected Bursa's (1961) findings from phytoplankton studies that found western Hudson Strait to be considerably richer, in terms of standing crop, than northern Hudson Bay.

A few species of benthic invertebrates present in Hudson Bay are of commercial value elsewhere in North America, although numbers are not known. Grainger (1968) surmised that at least limited local use could be made of such forms as Mytilus (the mussel), Littorina (the periwinkle), Mya (the soft shell clam)

TABLE 5-1

MAJOR INVERTEBRATE ANIMAL GROUPS, AND THE NUMBER OF SPECIES IN EACH, KNOWN FROM THE HUDSON BAY REGION

Group	Species	Remarks
Porifera	1	*Sponges*. Benthic animals. Several more species may be expected in the region.
Hydrozoa	29	Small benthic plant-like hydroids and planktonic *medusae* (jellyfishes). A few additional medusae (only 5 are reported) may be expected to occur.
Actiniaria	3	*Sea anemones* or *flower animals*. Soft, radially symmetrical benthic forms.
Alcyonacea	2	*Soft corals*. Soft, branching forms. Benthic.
Ctenophora	1	*Comb jellies*. Often large, jellyfish-like animals. Planktonic.
Bryozoa	34	*Moss animals*. Hard, encrusting or branching forms, attached to solid objects. Benthic.
Polychaeta	27	*Bristle worms*. Segmented worms with lateral projections bearing bristles. Most benthic, a few planktonic.
Priapuloida	1	Stout segmented worms with large anterior spine-covered proboscis. Benthic.
Sipunculoida	1	Externally smooth worms with slender anterior and thicker posterior portions. Benthic.
Chaetognatha	1	*Arrow worms*. Slim, transparent, planktonic.
Pelecypoda	11	*Clams, mussels, scallops*, etc. Benthic molluscs with two more or less equal hinged shells. Several additional species expected.
Gastropoda	16	Snails, etc. Mostly benthic molluscs with a spiral shell.
Copepoda	30	Small, often cylindrical crustaceans, planktonic or benthic.
Cirripedia	2	*Barnacles*. Sessile, shell-covered forms as adults, planktonic as young.
Amphipoda	37	Usually laterally flattened crustaceans, benthic or planktonic.
Isopoda	3	Usually dorso-ventrally flattened crustaceans, benthic or rarely planktonic.
Mysidacea	1	Elongate, usually slender shrimp-like crustaceans. Planktonic or benthic.
Euphausiacea	3	Elongate, often more robust shrimp-like crustaceans. Planktonic.
Decapoda	8	*Shrimps, crabs*, etc. Benthic or planktonic. Probably several additional species may be expected.
Pycnogonida	6	*Sea spiders*. Spider-like, with eight long legs. Benthic.
Echinodermata	30	*Sea stars, urchins, cucumbers*, etc. Star-shaped or circular radially symmetrical animals. Benthic.
Ascidiacea	10	Sac-like, benthic animals.
Larvacea	1	Small, transparent, planktonic animals with clearly defined "head" and "tail".

Source: Grainger (1968)

TABLE 5-2

SPECIES OF INVERTEBRATES COLLECTED

FROM STATIONS IN JAMES BAY, 1959, 1974

Species	No.
ANNELIDA:Polychaeta	53
Ampharete acutifrons	
Amphicteis sundevalli	
Antinoella badia	
Antinoella sarsi	
Aricidea suecica	
Artacama proboscidea	
Asabellides sibirica	
Autolytus prismaticus	
Capitella capitata	
Chaetozone setosa	
Chaetozone sp.	
Chone sp.	
Cossura longocirrata	
Diplocirrus glaucus	
Ephesiella peripatus	
Eteone longa	
Euchone papillosa	
Exogone verugera ?	
Harmothoe imbricata	
Heteromastus sp.	
Lanassa venusta	
Laonome kroyeri	
Leiochone polaris	
Lumbrineris fragilis	
Lumbrineris minuta	
Maldane sarsi	
Melinna cristata	
Micronephthys minuta	
Myriochele oculata	
Mystides borealis	
Nephtys ciliata	
Nereimyra aphroditoides	
Nicolea zostericola	
Notomastus latericeus	
Paraonis sp. a	
Paraonis sp. b	
Pectinaria granulata	
Pectinaria hyperborea	
Pholoe minuta	
Pista maculata	
Polydora caeca	
Praxillella praetermissa	
Prionospio steenstrupi	
Rhodine gracilior	
Sabella crassicornis	
Sabellid	
Sabellides borealis	
Sabellides octocirrata	
Scalibregma inflatum	
Scoloplos armiger	
Spio filicornis	
Terebellides stroemi	
Tharyx acutus	
ARTHROPODA:Amphipoda	41
Acanthostepheia malmgreni	
Aceroides l. latipes	
Ampelisca eschrichti	
Anonyx sarsi	
Arrhis phyllonyx	
Atylus carinatus	
Boeckosimus affinis	
Boeckosimus edwardsi	
Byblis gaimardi	
Dulichia arctica	
Dulichia porrecta	
Dulichia spinosissima	
Ericthonius tolli	
Eusirus cuspidatus	
Gammaracanthus loricatus	
Gammarus oceanicus	
Halirages fulvocinctus	
Haliragoides inermis	
Haploops laevis	
Haploops setosa	
Hippomedon propinquus	
Ischyrocerus anguipes	
Ischyrocerus megalops	
Melphidippa sp.	
Metopa bruzelii	
Monoculodes sp.	
Monoculopsis longicornis	
Neohela maxima	
Onisimus litoralis	
Parathemisto abyssorum	
Parathemisto libellula	

TABLE 5-2 (cont'd)

Species	No.	Species	No.
ARTHROPODA:Amphipoda		ARTHROPODA:Pycnogonida	3
Paronesimus barentsi		*Nymphon glaciale*	
Pleustes panopla		*Nymphon hirtipes*	
Pontoporeia femorata		*Nymphon serratum*	
Rhachotropis aculeata			
Rozinante fragilis		ARTHROPODA:Tanaidacea	3
Stenopleustes pulchellus		*Leptognathia longiremis*	
Syrrhoe crenulata		*Sphyrapus anomalus*	
Tmetonyx cicada		*Typhlotanais finmarchicus*	
Unciola leucopis			
Westwoodilla megalops		ASCHELMINTHES:Nematoda	1
		Nematode	
ARTHROPODA:Cirripedia	1		
Balanus crenatus		BRACHIOPODA	2
		Atretia gnomon	
ARTHROPODA:Cumacea	6	*Hemithyris psittacea*	
Brachydiastylis resima			
Diastylis rathkei		CHORDATA:Ascidiacea	9
Diastylis scorpioides		*Boltenia echinata*	
Diastylis sulcata		*Molgula griffithsi*	
Eudorella emarginata		*Molgula* sp.	
Leucon nasica		*Pelonaia corrugata*	
		Styela coriacea	
ARTHROPODA:Decapoda	7	*Styela rustica*	
Argis dentata		Ascidian	
Eualus fabricii		Ascidian	
Eualus gaimardi		Ascidian	
Eualus macilentus			
Hyas coarctatus		COELENTERATA:Anthozoa	5
Pandalus montagui		*Actinostola spetsbergensis*	
Sabinea septemcarinata		*Bunodactis stella*	
		Gersemia rubiformis	
ARTHROPODA:Isopoda	2	*Tealia felina*	
Mesidotea sabini		Anemone	
Synidotea nodulosa			
		ECHINODERMATA: Asteroidea	6
ARTHROPODA:Mysidacea	1	*Ctenodiscus crispatus*	
Mysis litoralis		*Henricia eschrichti*	
		Leptasterias groenlandica	
ARTHROPODA:Ostracoda	3	*Leptasterias polaris*	
Cyprideis sorbyana		*Pteraster militaris*	
Cythereis dunelmensis		*Urasterias lincki*	
Cythereis sp. a			
		ECHINODERMATA: Crinoidea	1
		Heliometra glacialis	
		ECHINODERMATA: Echinoidea	1
		Strongylocentrotus droebachiensis	

TABLE 5-2 (cont'd)

Species	No.	Species	No.
ECHINODERMATA:Holothuroidea	3	*Musculus corrugatus*	
Myriotrochus rinki		*Musculus discors*	
Thyonidium sp.		*Mya pseudoarenaria*	
Holothuroid		*Mytilus edulis*	
		Nucula belloti	
ECHINODERMATA:Ophiuroidea	7	*Nuculana pernula*	
Ophiacantha bidentata		*Pandora glacialis*	
Ophiocten sericeum		*Pecten groenlandicus*	
Ophiopholis aculeatus		*Portlandia arctica*	
Ophiopus arcticus		*Thyasira gouldi*	
Ophiura robusta		*Yoldia h. hyperborea*	
Ophiura sarsi		*Yoldiella lenticula*	
Stegophiura nodosa			
		NEMERTINA	3
ECTOPROCTA	5	Nemertean	
Alcyonidium gelatinosum		Nemertean	
Cystisella saccata		Nemertean	
Kinetoskias arborescens			
Porella smitti		PORIFERA	7
Bryozoan		*Biemma* or *Tylodesma*	
		Halichondria panicea	
MOLLUSCA:Gastropoda	11	*Phakettia bowerbanki*	
Admete couthouyi		*Phakettia ventilabrum*	
Buccinum tenue		*Suberites domocula ficus*	
Cylichna alba		*Tetilla polyura*	
Cylichna occulta		*Tetilla sibirica*	
Littorina saxatilis			
Lunatia pallida		PRIAPULIDA	1
Margarites costalis		*Priapulus caudatus*	
Margarites olivaceus			
Nudibranch		SIPUNCULIDA	1
Philine finmarchia		Sipunculid	
Retusa obtusa			
		TOTAL	204
MOLLUSCA:Pelecypoda	21		
Astarte borealis			
Astarte crenata			
Astarte montagui			
Clinocardium ciliatum			
Crenella faba			
Hiatella arctica			
Lyonsia arenosa			
Macoma balthica			
Macoma calcarea			

Source: Wacasey et al (1976)

and some of the shrimps. Oysters, lobsters and the commercially used crabs and sponges were reported as being unknown in Hudson Bay and in Arctic waters generally. The clam *Mya truncata* is the dominant food species of the walrus (Mansfield 1958, Grainger 1968) which also feeds upon other clams, snails, sea cucumbers, shrimps, worms and ascidians.

5.6 MARINE PLANTS

Bursa (1968) summarized the few earlier works on bottom algae, and reported that forms found washed up on shores include *Laminaria* (kelp), *Agarum*, *Chorda filum*, *Fucus*, and *Alaria*. Inshore brackish shallows may contain dwarf tufts of *Pylaiella littoralis*, *Sphacelaria arctica*, red *Polysiphonia* or green *Enteromorpha* or *Cladophora*. Mud-covered flats likely are occupied by many individuals of only a few species of algae of which green *Vaucheria* is among the more common. Protected shallows and bays are covered with *Fucus vesiculosus* and some red algae. Deep water habitats include the largest seaweeds of the red and brown groups while tidal pools are overgrown by smaller red and brown algae including *Fucus* and kelp.

Habitat conditions are an important limiting factor for seaweeds, since a solid substrate is needed for attachment and the major part of central Hudson Bay has a substrate of mud, while in many coastal areas, ice scouring greatly impoverishes the attached algal flora (Bursa 1968).

Lee (1973) concluded that the low order of diversity of the Arctic algal species, the way they are distributed, and that the almost complete lack of endemics all point to a low level of adaptation. The author suggested that Arctic algal communities may indeed be relatively young in the course of ecological evolution, just as Dunbar (1968) had postulated for the Arctic ecosystem as a whole.

Plants other than algae are rarely found in Hudson Bay (Bursa 1968) and are represented mainly by *Zostera marina*, called eel grass although not a true grass. The long upright leaves are densely covered by sedentary diatoms and fine algae which are grazed by many animals.

6. FISH AND FISHERIES

6.1 INTRODUCTION

The Hudson Bay regional fish fauna can be categorized as (Hunter 1968):

1. Marine fish which live in a marine habitat throughout their entire lives, although some occasionally venture into brackish or fresh water.
2. Anadromous fish which spend a part of their lives in the sea but return to fresh water to spawn.
3. Freshwater fish which are normally in fresh water throughout their life cycle although some may venture into brackish or marine waters.

In general, the fish fauna is largely typical of Arctic regions and few species are present (Hunter 1968). Low abundance, slow growth rate and depressed productivity characterize the species in Hudson Bay and contiguous systems. Although little is known about the offshore portion of Hudson Bay, the most diverse fish community would be expected in the nearshore area where a wider range of habitats occurs and nutrient concentrations are generally higher.

6.2 OFFSHORE MARINE FISHES

Hunter (1968) summarized the marine species known to occur in Hudson Bay. Table 6-1 provides a summary of the 11 families and 31 species then known in Hudson and James Bays. More recent work in estuaries of the eastern James-Hudson Bay coast (Morin *et al*. 1980) has raised the totals to 22 families and 61 species. Marine species appear to account for less than one third of the species which use the inshore estuaries on the east coast.

Nearly all the true marine species were described by Hunter (1968) as being small, obscure, bottom-dwelling forms, occurring in low abundance and devoid of any apparent value in the economy. Greenland cod (*Gadus ogac*) and capelin (*Mallotus villosus*) are minor exceptions in that they are fished to some extent

TABLE 6-1

FAMILIES, GENERA AND SPECIES OF MARINE FISH OCCURRING IN HUDSON AND JAMES BAYS

Family and specific name	Common names
Rajidae	
Raja radiata Donovan	thorny skate
Osmeridae	
Mallotus villosus (Müller)	capelin
Gadidae	
Boreogadus saida (Lepechin)	arctic cod
Gadus ogac Richardson	ogac, Greenland cod
Cottidae	
Myoxocephalus scorpioides (Fabricius)	false seascorpion
M. scorpius (Linnaeus)	seascorpion
M. quadricornis (Linnaeus)	fourhorned sculpin
Gymnocanthus tricuspis (Reinhardt)	staghorn sculpin
Icelus bicornis (Reinhardt)	twohorned sculpin
I. spatula Gilbert and Burke	spatulate sculpin
Triglops pingeli Reinhardt	ribbed sculpin
T. murrayi Gunther	bartail sculpin
Agonidae	
Aspidophoroides olriki Lütken	arctic sea poacher
Cyclopteridae (including Liparidae)	
Careproctus reinhardi (Kroyer)	sea tadpole
Cyclopterus lumpus Linnaeus	lumpfish
Eumicrotremus derjugini Popov	leatherfin lumpsucker
E. spinosus (Müller)	Atlantic spiny lumpsucker
Liparis cyclostigma Gilbert	polka-dot snailfish
L. tunicatus Reinhardt	Greenland seasnail
L. koefoedi Parr	gelatinous seasnail
Stichaeidae	
Eumesogrammus praecisus (Kroyer)	fourlined snakeblenny
Stichaeus punctatus (Fabricius)	arctic shanny
Lumpenus fabricii (Valenciennes)	Greenland blenny
L. medius Reinhardt	stout eelblenny
Pholidae	
Pholis fasciata (Bloch and Schneider)	tissy, banded gunnel
Zoarcidae	
Gymnelis viridis (Fabricius)	unernak, fish doctor
Lycodes reticulatus Reinhardt	reticulated eelpout
L. pallidus Collett	arctic pale eelpout
Ammodytidae	
Ammodytes dubius Reinhardt	northern sandlance
A. hexapterus Pallas	Pacific sandlance
Pleuronectidae	
Hippoglossoides platessoides (Fabricius)	plaice

Source: Hunter (1968)

to supplement local food supplies on the Belcher Islands and in the case of capelin, at Churchill and south coast settlements where they occur.

In general, however, insufficient scientific effort has been expended to evaluate distributions and abundances of marine species in Hudson Bay, even in the open water season. It is possible that the Belcher Islands area, which was identified in recent work by Anderson and Roff (1980 a) as being more productive in terms of primary production might also attract and support fish capable of taking advantage of this improved food supply. There have been, however, no field data to support this speculation.

6.3 NEARSHORE FISH COMMUNITIES

The most productive areas in Hudson Bay for fish production appear to be in the nearshore zone, particularly in and around estuaries. In addition to a few marine fish observed in these environments, a number of anadromous and freshwater species occur. Recent work on the east coasts of Hudson and James Bays, largely encouraged by hydroelectric development, has done much to clarify the nearshore estuarine fish communities (Hunter et al. 1976, Morin et al. 1980).

Table 6-2 provides a classification of fish collected in these estuaries of Hudson and James Bays (Morin et al. 1980). Fifteen families and 38 species were taken, with James Bay sites containing more families and species. Ten species were present over the whole range (Rupert's Bay to Innuksuac), 24 in Hudson Bay and 35 in James Bay.

Morin et al. (1980) described faunal differences between coastal Hudson Bay and James Bay as a reduction in the number of freshwater species towards the north, favouring species that are more strongly euryhaline (able to tolerate a wide range of salinities). Comparing the southern Eastmain (James Bay) with the more northern Innuksuac (mid-Hudson Bay), the authors noted that in the lower reaches of the Innuksuac River there are no stenohaline (having a small range of salinity tolerence) freshwater species, although there are more diadromous species than in the Eastmain. Predatory niches in the southern

TABLE 6-2
A CLASSIFICATION OF ESTUARINE FISHES, ADAPTED FROM McHUGH (1967). THE PRESENCE OF EACH SPECIES IS INDICATED FOR THE ESTUARIES OF JAMES BAY AND HUDSON BAY

Category and species	*Region*	
	James Bay	*Hudson Bay*
1. Obligate freshwater species		
Hiodon tergisus	x	
Notropis hudsonius	x	
Notropis atherinoides	x	
Semotilus corporalis	x	
Rhinichthys cataractae	x	
Semotilus margarita	x	
Perca flavescens	x	
Stizostedion canadense	x	
Cottus bairdi	x	x
2. Freshwater species that occasionally enter brackish waters		
Esox lucius	x	x
Couesius plumbeus	x	x
Catostomus catostomus	x	x
Catostomus commersoni	x	x
Culaea inconstans	x	
Percopsis omiscomaycus	x	
Stizostedon vitreum	x	
Cottus cognatus	x	x
Cottus ricei	x	
3. Diadromous species		
Acipenser fulvescens	x	
Salvelinus alpinus		x
Salvelinus namaycush		x
Salvelinus fontinalis	x	x
Salmo salar		x
Coregonus artedii	x	x
Coregonus clupeaformis	x	x
Prosopium cylindraceum	x	x
Lota lota	x	x
Gasterosteus aculeatus	x	x
Pungitius pungitius	x	x
4. Truly estuarine species which spend their entire lives in the estuary		
Myoxocephalus quadricornis	x	x
5. Marine species which use the estuary primarily as a nursery ground, usually spawning and spending much of their adult life at sea, but often returning seasonally to the estuary		
Mallotus villosus	x	x
Ammodytes hexapterus	x	x
Ammodytes dubius		x
Lumpenus fabricii	x	x
Gadus ogac	x	x
Myoxocephalus scorpius	x	x
Myoxocephalus scorpioides	x	x
6. Adventitious visitors which appear irregularly in the estuary		
Clupea harengus		x

Source: Morin et al (1980)

river and estuary are filled by the walleye (*Stizostedion vitreum*), replaced by Greenland cod (*Gadus ogac*) and brook trout (*Salvelinus fontinalis*) in the Innuksuac estuary.

Of the marine species which use the inshore estuary (Table 6-2), the Greenland cod, four-horned sculpin, Arctic sculpin, and slender eelblenny are Arctic species (Morin *et al*. 1980), while the sand lance and the shorthorn sculpin are subarctic. The capelin, a subarctic-boreal species may be present due to its use of the warm upper water layer (Dunbar 1975). Higher water temperatures and lower salinities in the south of James Bay restrict the occurrence of arctic marine species.

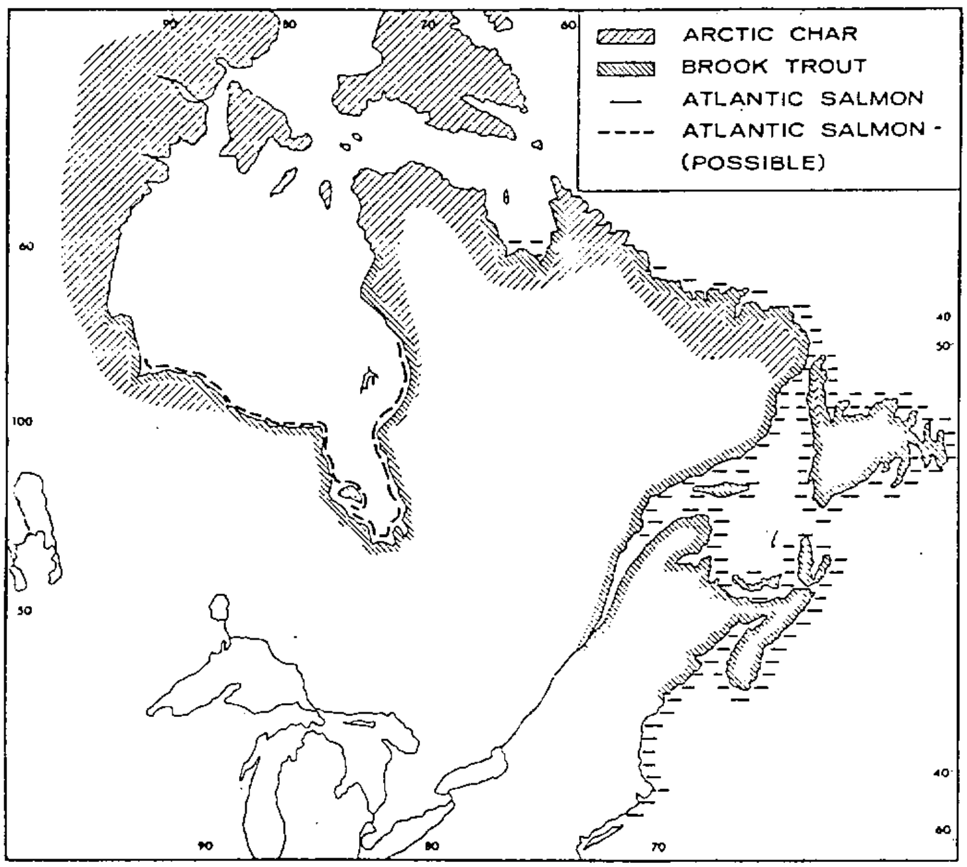
The distributions of two of the most important anadromous salmonids, sea run brook trout and Arctic char were described by Salonius (1973) (Figure 6-1). The Arctic char is clearly the northern species and the brook trout the southern, although some overlapping of range occurs along both the east and west coasts. That author also postulates that many of the inflowing rivers currently used for spawning by brook trout could be colonized by introduced Atlantic salmon.

The anadromous char and whitefishes are well known for their edible qualities and they constitute the major proportion of the fishery resources of the region (Hunter 1968). Following ice break-up, they move down river to feed in the coastal marine areas adjacent to the river mouth. Exodus to the sea is rapid and distribution is widespread in this area during the summer, becoming more concentrated into limited areas in fall when they return to fresh water. None of the chars or whitefishes is known to remain in the sea during the winter months.

Current research at the University of Western Ontario has utilized a 600 m fish weir across the mouth of the Sutton River on the southwest shore of Hudson Bay. Preliminary results have included some unanticipated findings (Peter Steele, Personal Communication). Steele has found that the sea-run brook trout in that area reach reprodutive age at 6 years at a length of about 500 mm. Trout enter the Bay from the Sutton River at 70 to 80 mm length at about 11 months old, much younger than the 3 year age noted in most previously studied populations. Trout aged 1 to 5+ re-enter the Sutton River in August to September and remain in freshwater until ice is out in the Bay. Trout of spawning age re-enter the river earlier, in July, remaining until ice is out.

FIGURE 6-1

PRESENT AND POSSIBLE OVERLAPPING RANGES OF ANADROMOUS SALMONIDS IN EASTERN CANADA.



Source: Salonius (1973)

Studies in the Beaufort Sea area suggest that in coastal waters, Arctic char feed almost exclusively on crustaceans (mostly amphipods and mysids) and fish (particularly fourhorn sculpins) although insects (especially chironomid larvae) are eaten in areas where there is a strong freshwater influence (McCart 1980).

Hunter et al. (1976) reported that stomach contents of fish caught in the La Grande estuary and from along the coast indicated a major dependence of some species upon the marine area for their food supply. For example, cisco (Coregonus artedii) stomachs in June and July contained capelin, sand lance, eelblenny and fish eggs, and in December, amphipods and euphausids. The authors noted that the distance which adult freshwater species will move offshore is not known, but probably most remain in the mixing zone of the estuary outflow.

A number of marine species (Table 6-2) were found to use estuaries on the east coast of Hudson Bay primarily as a nursery ground (Morin et al. 1980) usually spawning and spending much of their adult life at sea, but often returning seasonally to the estuary. Examples include capelin, sand lances, eelblennies, Greenland cod, and fourhorned and Arctic sculpins. Information on the composition and structure of the larval and juvenile fish community of the Eastmain River and estuary on the east coast of James Bay was provided by Ochman and Dodson (1982).

It is clear that the areas around river estuaries entering Hudson Bay represent a very important focus of fishery production. Marine species seek such areas because their nutrient inflows and mixing characteristics result in higher plant productivity and food density than are available elsewhere. As well, many marine species breed in estuarine areas. Freshwater and anadromous predators then move downstream in the summer to take advantage of this additional aggregated food supply.

Greendale and Hunter (1978) found, in the La Grande River estuary on eastern James Bay (Figure 1-1), that in June and July when capelin gathered in the area they contributed importantly to the diet of ciscoes and brook trout, as did eelblennies and sand lances which are common to the area. The lake whitefish, although generally considered a bottom feeder, was reported to feed on the abundant capelin in the summer, although bottom organisms such as mullusks, insect larvae and fish egges remained the basic diet.

6.4 FISHERY UTILIZATION

Hunter (1968) noted that the fisheries of Hudson Bay depend upon four anadromous species; Arctic char, brook trout, whitefish and cisco. Distribution varies according to species but in all cases the principal catch is coastal. The author reported that Arctic char are seldom taken in appreciable numbers south of Churchill on the west coast and Cape Jones on the east coast. It is the dominant species on the Belcher Islands, where the Inuit fish the species at 34 named sites, largely depending on anadromous stocks (Freeman 1982).

Fishery exploitation to date has been minimal and concentrated along the shorelines, mainly near river mouths where migrating runs can be intercepted.

Atkinson's (1976) conclusions with regard to other Arctic fisheries largely apply to Hudson Bay.

> "Although regularly taken and eaten by the Eskimoes, fish have seldom been an important item in their diet. The few studies that have been made generally show Arctic waters to be low in the production of fish. Except for local winter ice fishing by hand line, the fishing season is limited to only two to three months of the year. Low temperatures produce very slow growth in many varieties of fish, which in turn affects the processing and marketing of fish in that even the largest and oldest specimens may be below market size. The very heavy predation by birds and marine mammals alone would be sufficient to keep the stocks of fish at low levels of production. Finally, slow growth and poor recruitment together would make the Arctic fisheries difficult to maintain and sensitive to manage"(Atkinson 1976).

Dunbar (1975) in his major status review of biological oceanography in Canadian Arctic and sub-Arctic waters concluded that "it has been fairly satisfactorily established that exploitable commercial fishery resources of any practical size do not exist, and that fish as a group are not successful in Arctic water. This includes Hudson Bay."

Barber (1978) noted that several typically Arctic species, such as the Arctic cisco (Coregonus autumnalis) are not present in Hudson Bay even though conditions appear to be suitable for them. The high salinity in and adjacent to Hudson

Strait may be acting as a barrier to the entry of these species to prevent repopulation of Hudson Bay in post-glacial times.

Salonius (1973) similarly postulated that Atlantic salmon (Salmo salar) might at one time have been present in Hudson Bay prior to glaciation. Present habitat conditions suggest that Atlantic salmon could probably harvest the abundance of small marine forms more efficiently than Arctic char and brook trout (Salvelinus fontinalis) do now. In short, the present fish fauna of Hudson Bay may have been seriously depleted during glacial times, with subsequent events limiting the opportunities of some lost species to recolonize from their present ranges. The current fish community therefore may be considered somewhat impoverished even by Arctic standards in that some of the species best able to take advantage of available habitats and food supplies are not present.

Exploitation of fishery resources of Hudson Bay and tributary waters is principally for subsistence of the native populations (Buck and Dubnie 1968). The authors reported that even where a surplus over domestic needs may be available, production for "export" is likely to be uneconomic except for products such as Arctic char and sea run brook trout fillets. Limited quantities of Greenland cod and of whitefish, lake trout and ciscoes may be sold locally and in northern mining centres, but high transportation costs, distance to market, and high costs of limited and seasonal production are competative disadvantages to similar products produced elsewhere. The small scale of the available resource, which comprises top predators, makes the prospects for a commercial fishery unattractive.

Buck and Dubnie (1968) also provided a concise description of the nature of the Eskimo fishery. Fish are taken with nets, spears, lines and stone weirs, and camps are usually sited near to good fishing locations. The largest catches are made in coastal fisheries for the anadromous species when these are concentrated for spring and fall migration. Harvests of Arctic char, brook trout, whitefish and cisco for food, dog food and fox bait are largely in the fall season. Greenland cod is caught, chiefly for dog food, with nets and by hand-jigging, usually through leads or holes in the ice. Another marine species, the capelin, is taken with dip nets when it comes inshore to spawn in late July. Although more efficient methods could be used for taking more capelin, drying and storing facilities are largely lacking.

Sprules (1952) undertook early studies of the Arctic char of the west coast of Hudson Bay in the vicinity of Term Point and found that the species was of primary importance in the economy of the Eskimoes and was used in quantities as food for themselves and for their dogs. His studies concluded that char were not present in sufficient quantities to warrent the establishment of a commercial fishery in the area.

Nevertheless, a commercial fishery evolved on the west coast. Carder and Peet (1983) reported that following the closing of the nickel mine at Rankin Inlet in 1962, a commercial fishery for fish and marine mammals was initiated to alleviate economic distress. The project was supported by the federal Department of Indian and Northern Affairs and later by the Government of the Northwest Territories. One of the initial products of a cannery established at Daly Bay was canned Arctic char. Since fish populations of Daly Bay could not support the cannery, it was moved to Rankin Inlet in 1966 where fish resources appeared adequate to have a diverse, year round operation. When the market for marine mammal products declined in the 1960's, the cannery relied solely on fish processing. Canned products were shipped by air to Winnipeg for distribution until, in the 1970's, transportation costs created financial problems. The authors noted that transportation costs are a major constraint for the effective inter-settlement utilization of fish products. In 1976, the canning of fish was discontinued at Rankin Inlet and the export fishery has concentrated on supplying Arctic char, the species of primary interest, solely as a frozen product to southern markets.

Figure 6-2 shows commercial fishing areas for char on the west coast of Hudson Bay. The fishery occurs in August and early September when the fish return from the sea to freshwater. Gill nets are set in estuaries and river mouths (Carder and Peet 1983). Data for this fishery are tabulated by Carder and Peet (1983) and Carder (1983) for the period from 1973 to 1982. Yaremchuk and

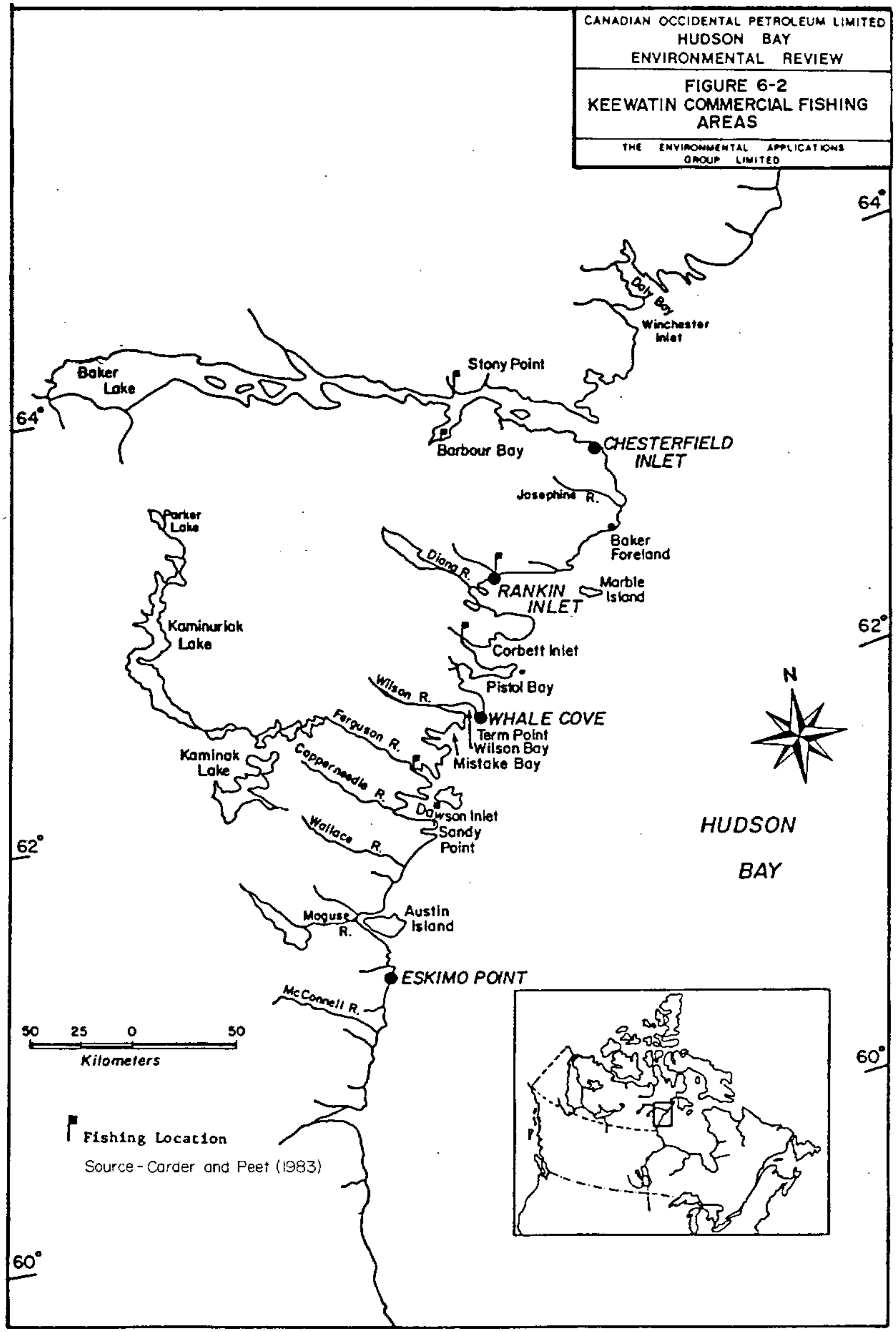

CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 6-2
KEEWATIN COMMERCIAL FISHING AREAS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
64°
Daly Bay
Winchester Inlet
Stony Point
Baker Lake
64°
Barbour Bay
CHESTERFIELD INLET
Josephine R.
Parker Lake
Baker Foreland
Diana R.
RANKIN INLET
Marble Island
Kaminuriak Lake
62°
Corbett Inlet
Pistol Bay
Wilson R.
N
WHALE COVE
Term Point
Wilson Bay
Ferguson R.
Mistake Bay
Kaminak Lake
Copperneedle R.
Dawson Inlet
Sandy Point
Wallace R.
HUDSON
BAY
62°
Austin Island
Maguse R.
ESKIMO POINT
McConnell R.
50 25 0 50
Kilometers
60°
Fishing Location
Source - Carder and Peet (1983)
60°

TABLE 6-3

COMMERCIAL HARVESTS OF MAJOR FISH SPECIES FOR SCHEDULE V REGION V. TOTAL FOR LAKE TROUT AND LAKE WHITEFISH INCLUDES HARVESTS REPORTED AS COMBINED TOTALS

Year	Harvest (kg round weight)									
	Lake trout	Lake White-fish	Lake Trout + Lake whfish	Broad White-fish	In-connu	Cisco	Yellow wall-eye	North-ern pike	Arctic Char anad-romous	Arctic Char land locked
1959	1305		1305							
1960									726	
1961	1261	299	2581						590	
1962									19667	
1963	20066	9720	157837						18556	
1964	121322	77018	198340				4	26	10877	
1965	79862	82168	162030						46184	
1966	55801	25363	81670						13702	
1967	1697	10348	23498							
1968	22750	19356	129181						60	
1969	15490	27406	73449						16217	
1970	33887	143558	177445						22399	
1971	22065	43028	65093						3987	
1972	33457	39967	73476						18350	
1973	32812	23123	55935						30260	
1974	7887	1569	9456			5398			62586	
1975	14732	39296	54028			2590			46964	462
1976	19257	1319	36281						38634	
1977									11392	
1978									16133	
1979	106	1	107						24051	
1980			3913						22836	
1981	181	45	226						37612	

Source: Yaremchuk and Wong (1983)

Wong (1983) summarized commercial harvests from 1945 to 1981 for this area (Commercial Fishing Region V - Keewatin, Table 6-3). Harvests of Arctic char since 1968 have ranged from 3987 kg to 62586 kg, with the 1981 total being 37612 kg (round weight).

Berkes (1979) examined Cree Indian domestic or subsistence fisheries on eastern James Bay, and found these to be characterized by large numbers of participants, low catches per day and per fisherman, but high catches per length of net used compared with commercial fisheries. This is a gill net fishery near the coast (<3 m depth) with whitefish and cisco dominating the harvests, although brook trout, suckers and other species are taken.

Most stocks appeared to be lightly utilized but in the vicinity of larger settlements, there was evidence that some stocks were overfished (Berkes 1979). The author concluded that the fish resource base of the region appears suitable for supporting local economic development with respect to recreational fisheries and native-run commercial fisheries for the local market as well as maintaining the domestic fishery. In subsequent work, Berkes (1982) described the relationships between energy subsidies and these Cree fisheries. He concluded that heavy dependence on energy subsidies makes northern bush economies vulnerable to the increasing costs of energy.

Freeman (1982) has produced a thoughtful paper on the dependence of two Inuit communities on marine resources from a man-environment perspective. That is he includes the role of hunting and fishing for marine species in socially important community and family activities as well as the protein or income derived from the harvest. He examined a community which occupies the land and waters surrounding Southampton Island, an area endowed with abundant and diverse resources, and a second example on the Belcher Islands, which benefits from less abundance and diversity of resources. In the latter case, with the exception of a few small landlocked fish populations, some Arctic hare and ptarmigan, and the important spring through summer availability of waterfowl, anadromous or marine species are the principal food animals sought after by Belcher Island Inuit.

The Ontario Ministry of Natural Resources has undertaken modest efforts to examine the feasibility of a commercial fishery in James Bay (Zalewski and Weir undated). The authors preliminary assessment was that a subsistence level of exploitation by local entrepreneurs is possible using gill nets provided sets are accessible at all tides and frequent checks are made to remove the catch. These stipulations were thought to reduce the practicality of James Bay fishing and may account for the minimal marine fishing effort by local people in southern James Bay. It was concluded that a commercial level of exploitation may be possible providing demand is sufficient to motivate capital intensive effort. At present, the study concluded that this does not seem to be the case. Cisco, lake whitefish, Arctic cod and sea run brook trout are potential target species.

The Ontario Ministry of Natural Resources notes that native fisheries (Cree) in the vicinity of Moosonee are starting to show some signs of exploitation (personal communication) and there is some interest in attempting to harvest stocks in James Bay away from the Moose River estuary. Provincial managers are not convinced that stocks are present to support a fishery of this nature, and may prefer to maintain brook trout runs to support a higher dollar game fishery. Existing recreational fisheries along the James Bay coast are based on anglers flying from Cochrane, Timmins, Kapuskasing, Big Trout Lake and Pickle Lake.

There are currently no commercial fisheries in the Manitoba portion of Hudson Bay (Manitoba Dept. of Natural Resources, J. O'Connor and G. Nelson, pers. comm.) although sport char fishing, based out of Winnipeg, takes place on the Knife and Seal Rivers and at Eskimo Point. Brook trout are also taken by sportsmen in conjunction with the goose hunt.

6.5 FISHERIES SENSITIVITIES

The present state of knowledge permits some generalizations about sensitive areas and times for fish populations. Estuaries, river mouths and adjacent coastal areas are the major sites of marine productivity in Hudson and James Bays. Nutrients from the rivers mix with marine waters in a zone of more varied habitat, resulting in a relative abundance of prey organisms.

Anadromous salmonids, including Arctic char and whitefish are present in the near-shore areas during summer. In the case of char, the most prized species, individuals will range fairly widely along the coast, perhaps reducing the chance that localized disturbances will have a major effect on any individual population (McCart 1980). However, since these char remain very close to shore when at sea, a widespread disturbance, such as an oil spill, affecting nearshore habitats along long stretches of the coast, could adversely affect Arctic char populations on an extensive scale.

A similar situation exists for other estuarine fish which appear to have a major dependence on the marine area for their food supply. An example is the cisco (Hunter et al. 1976) which feeds on capelin and sand lances. These estuarine and freshwater species do not likely range much beyond the mixing zone of the estuary outflow. In contrast, many of the Hudson Bay marine fish species appear to use estuaries primarily as a nursery ground, usually spawning and spending much of their adult life at sea, but often returning seasonally to the estuary (Morin et al. 1980).

Other than estuaries and associated coastal environments, the only area of potential interest would be an apparent zone of higher marine productivity west of the Belcher Island (Anderson and Roff 1970 a) which may attract higher than average concentrations of fish. This has not been documented, but in any case the Belcher Islands are populated by Inuit and Arctic char are fished at 34 named fishing sites, with the majority of cases being anadromous stocks that are exploited (Freeman 1982). Therefore the Belcher Island area can be considered quite sensitive with respect to fish populations.

Fish populations in the offshore portion of Hudson Bay are relatively insensitive to disturbance in the open water (drilling) season since all habitats are widely distributed and there is little potential for disruption of any unique aspect of the environment.

7. MARINE BIRDS, WATERFOWL AND SHOREBIRDS

7.1 INTRODUCTION

Hudson and James Bay coastal environments provide critical nesting, staging and migration habitat for large numbers of arctic and subarctic marine birds, waterfowl and shorebirds. Of particular note are colonies of Lesser Snow Geese, Canada Geese and Thick-billed Murres, and migration - staging areas associated with coastal marshes and tidal flats of the Hudson and James Bay Lowlands. These latter areas support numerous transient geese, waterfowl and shorebirds, which for Lesser Snow Geese, Canada Geese, Atlantic Brant, Thick-billed Murres, and for Hudsonian and Marbled Godwits, represent significant proportions of their respective North American populations. Also of interest are Common Eiders and Black Guillemots which are unique to the region in that they overwinter in open leads existing between landfast and pack ice.

Among the notable physical features of the region are its great diversity of shoreline habitats, and the fact that region coastlines provide a direct link between southern wintering areas and breeding areas in the Canadian arctic. Regional habitat structure is shown in Figure 7-1. Three principle habitat types are distinguished: tidal flats; associated coastal marshes, muskegs and pools; and cliff zones and headlands. Intervening areas are generally characterized by rugged coastlines supporting numerous shallow bays and offshore islands.

Brown and Nettleship (1975) have discussed the vulnerability of marine birds and related species to major oil spills and undersea blow outs. In this particular circumstance, however, it is important to stress that drilling locations would be positioned in the center of Hudson Bay. As such, the likelihood of contamination of shoreline areas is remote. This is particularly true of the potentially more sensitive avian environments associated with the west Hudson and James Bay lowlands, and Southampton Island at the north end of Hudson Bay. Both locations are on the leeward side of the Bay.

7.2 SPECIES GROUPS AND SENSITIVITIES

Breeding distributions, habitat preferences, relevant behavioral characteristics and sensitivities of marine birds, waterfowl and shorebirds inhabiting the study region are provided in Table 7-1. Maps showing species concentrations, breeding colonies, etc. are also provided. These materials were derived from a variety of sources which are listed with the references. In the interests of portraying information in a concise manner, references have been cited at the end of Table 7-1.

Murres and Guillemots

Two species are included in this group, the Thick-billed Murre which is a cliff nesting colonial species, and the Black Guillemot which also inhabits cliff zones as well as rocky shoreline areas. Black Guillemots may be found in colonies, but breeding birds are more likely to occur as scattered individuals or small groups. Both of these species spend considerable time sitting on the water and they are accomplished divers. Fish and various invertebrates are fed on by both species.

Thick-billed Murres nest at two locations in the study region, the Cape Wolstenholme-Digges Island area where approximately 1 million pairs nest, and at the north end of Coats Island which supports some 15,000 breeding pairs (Figure 1-1). Individuals are known to forage up to 150 km from colony sites (Gaston 1982). The Thick-billed Murre colony at Cape Wolstenholme-Digges Island is the largest such colony in Canada (Nettleship and Smith 1975), and it represents approximately 40 percent of the Canadian population of this species (Brown et al 1975). Overwintering occures in the waters off Newfoundland, with Hudson Strait being the route of migration. Murres arrive in the region later than most species, i.e. the peak spring migration is in early July. Fall migration is in mid to late September, coinciding with that of most other marine birds, waterfowl and shorebirds (Table 7-2). Some individuals overwinter in open leads between Southampton and Coats Islands.

Black Guillemots, because they nest as scattered individuals and groups, are less well known in terms of population size and areas of concentration. However, Walrus Island, lying between Southampton and Coates Island, has been cited by Bray (1943) as an important concentration area. Also of significance with respect to this species is the fact that it overwinters in coastal leads near breeding grounds. The Common Eider is the only other species which normally overwinters in the region. Leads are narrow open sections of water which parallel the coastline of most sections of Hudson and James Bay. They develop between the landfast ice and the offshore pack ice which is in a free-float state. Leads widen and close depending largely on protracted wind conditions and temperatures.

The Cape Wolstenholme-Digges Island area, and the Coats Island area are regarded here as being sensitive environments for avian species. Black Guillemots, although sensitive as a species, occur in low concentrations and are too widely distributed to justify defining specific sensitive areas, with the possible exception of the Walrus Island area between Coats and Southampton Islands.

Jaegers, Gulls and Terns

Members of this group breeding in the study region include the Pomarine, Parasitic and Long-tailed Jaegers; Glaucous, Iceland, Herring, Thayer's and Sabine's Gulls; and the Arctic Tern (Table 7-1). The greatest diversity of species occurs in the northeastern section of the region (Figure 7-3). Comparatively little use is made by this group of the James Bay area. Peak spring and fall migrations are in late May to early June, and mid-September, respectivley, coinciding with that of most other species (Table 7-2).

Rocky shores and cliff coasts are attractive to the majority of the gull species (Table 7-1), with Sabine's Gull being a notable exception. Arctic Terns also utilize rocky coastal areas, as well as a variety of other habitats. Breeding habitats utilized by jaegers are associated with tundra landscapes including inland and coastal areas. Of the species discussed, the Iceland, Thayer's and Sabine's Gulls show the most restricted distributions within the region. All three species occur only in northern areas, especially in the vicinity of Southampton and Coats Islands, and the west end of Hudson Strait. The Iceland Gull breeds at only a few Canadian locations. Its presence in the Cape Wolstemholme area is undoubledly related to the Thick-billed Murre colony.

Jaegers and gulls are for the most part opportunists adapted at stealing food from other avian species, as well as eggs and chicks. As such they are frequently associated with sea bird colonies, and with goose colonies. Jaegers prey heavily on lemmings during the breeding season, they also take fish, and harass gulls into giving up fish.

The nests of all species although frequently close to the water are normally sufficiently well back from the high tide line to avoid direct contamination from oil. However, foraging adults and juveniles would be susceptible to contact with surface oil while feeding on fish, as would migrating members of this group. Only the Thayer's Gull is regarded as having no sensitivity to accidental oil spills on Hudson Bay. Its activities in the region are largely confined to the north side of Southampton Island.

Most of the jaeger and gull species are sufficiently widespread and abundant so as to preclude the defining of specific sensitive areas. Moreover, most members of this group are sufficiently opportunistic that the relocation of nesting sites and colonies poses little problem. The only possible exceptions are the Iceland and Sabine's Gulls which have restricted distributions. The distribution of the Iceland Gull in the region coincides, as stated, with that of the Thick-billed Murre, and is therefore contained within the sensitive area described in connection with that species. Sabine's Gull although more widespread, still exhibits a restricted Canadian distribution. Its range within the study region is included in the sensitive area described for the Thick-billed Murre, and that described below for the lesser Snow Goose on Southampton Island. There is some evidence to suggest that gulls and terns are better able to avoid oil slick contamination than are other marine birds (Easton 1972).

Waterfowl

The importance of this group derives from their abundance in the region; marked aggregations during breeding, staging and migration; and from their importance as game birds. A considerable volume of literature is available on geese of the region (Hanson et al. 1972; Kerbes 1975, 1982; Curtis 1976; Bellrose 1976; Raveling and Lumsden 1977, Thomas and Prevett 1982, etc).

Of the greatest note are the large Lesser Snow Goose colonies at McConnel River (130,000 nesting pairs), the Boas River on Southampton Island (70,000 n.p.), and at Cape Henrietta Maria (55,000 n.p.), and the smaller colony of 5000 n.p. at Cape Churchill (Figure 7-4). Of equal note are the extensive breeding areas of the Canada Goose (Figure 7-5), and staging areas for both species along the south coast of Hudson Bay and more importantly in James Bay. Staging areas for the Atlantic Brant in James Bay are also important.

Lesser Snow Goose nesting colonies are associated with low tundra hummocks and ridges of coastal plain marshes, and with islands in braided river estuaries. The McConnel and Boas River colonies are of the latter type. Most nests are located sufficiently far back from the high tide water line to preclude contamination in the event of an oil spill. Moveover, adults and young fed primarily on sedges, grasses and other vegetation above the high tide water line. The nesting grounds of Canada Geese are more removed from the coastal environment, with nests being scattered through the interior of coastal muskegs and tundra pond areas (Table 7-1). The nests of Atlantic Brant are closer to the waters edge and are therefore more susceptible to oil contamination. Only a small breeding colony of this species occurs in the region (Figure 7-6).

The principle sensitivity of geese in the region to oil is during migration and staging. At this time birds congregate along the coastal lowland marshes of James and southern Hudson Bays (Figures 7-4 to 7-6). The concentration and number of birds at this time is staggering, 3.3 million Lesser Snow Geese, from 300,000 - 600,000 Canada Geese and 100,000 Altantic Brants.

During migration and staging, Lesser Snow Geese feed on emergent plants and sedges, primarily above the mean tide level. Canada Geese feed on similar plant materials both above and below the mean tide leve, and Atlantic Brant most commonly feed on the eelgrass below the mean tide level. The potential for direct oil contact for the latter two species is greater than that for the Lesser Snow Goose. Ross' Goose also occurs in the region at two locations (Figure 7-6), but numbers are too small to render this species of any real importance.

Breeding distributions of duck species in the study region are shown in Figure 7-7 and 7-8. Species descriptions are provided in Table 7-1. Surface feeding ducks, consisting of the Black Duck, Pintail, Green-winged Teal, Mallard and the American Widgeon, are associated with southern portions of Hudson Bay and with James Bay. The Hudson and James Bay lowlands, and associated coastal marshes and tidal flats, are particularly important to these species.

The nesting of all five species is generally sufficiently far removed from coastal marine waters to preclude the potential for oil contact at this time. The major sensitivity to oil contact is during molting, staging and migration, essentially in May-early June and again in September, when extensive use is made of low coastal marshes, tidal mud flats, and associated shallow waters. The Black Duck and the Green-Winged Teal are potentially the most sensitive of this group because of their heavy use of tidal mud flats.

The diving ducks, i.e. the Greater Scaup, Common Goldenye and the Red-breasted Merganser, also nest mostly in the interior in association with lakes, rivers, ponds etc., with little use of salt marsh areas. However, like the above species, extensive use of coastal waters occurs during molting, staging and migration (Table 7-2). The diving and surface resting habitat of these species makes them more vulnerable to oil contact than are the surface feeding ducks.

Sea ducks, including the Common and King Eiders, the Oldsquaw, and the scoters, are potentially the most sensitive of the duck species to oil contact. They are intimately associated with coastal marine waters and rarely come ashore except to nest. Moreover, even during the nesting period some possibly of oil contact is present for the eiders and oldsquaw during feeding. The Common Eider is also of note because this species overwinters in open leads off the Belcher Islands.

With respect to potentially sensitive areas, consideration should be given to the Lesser Snow Goose colonies shown in Figure 7-4, as well as to the whole of the James Bay coastline, and to the Hudson Bay coastline south and east from Cape Churchill with importance increasing towards James Bay. Molting, staging and migration areas along the James Bay and southern Hudson Bay coasts are critical to virtually all of the Region's geese and duck populations, as well as to a vast number of other waterfowl, particularly geese, which breed in other parts of the eastern arctic. Peak spring and fall migrations for waterfowl occur in May-early June, and in September-early October, respectively (Table 7-2). Also considered to be sensitive is the Belcher Islands area because of its importance to Common Eider during winter. Contamination of water by oil off the Belcher Islands in late summer could have a devasting impact to this segment of the Common Eider population, numbering an estimated 35,000 birds (Freeman 1980, Nettleship and Smith 1975, Manning 1976). The Common Eider in Hudson Bay is nominally referred to as the Hudson Bay Eider, and is considered to be a separate population of the species endemic to the Hudson Bay Region.

Shorebirds

Included in this group are 17 species of the Sandpiper group, and a lesser number of plovers, turnstones and phalaropes (Table 7-1). Breeding distributions of these species are shown in Figures 7-9 and 7-10. Sandpipers as a group are primarily associated with the Hudson Bay Lowlands and, in migration, with the James Bay. Southampton Island contains representation of several species, although many of these are uncommon to rare (Bray 1943). The spring migration of shorebirds coincides with that of most other species, but the fall migration is earlier, peaking in early to late August.

Certain members of the Sandiper group such as the Common Snipe, Spotted Sandpiper, the Purple Sandpiper, Baird's Sandpiper, and the Stilt Sandpiper are regarded here as not being sensitive to potential oil spills for reasons provided in Table 7-1. Virtually all of the remaining species are regarded as being sensitive only during staging and migration. Breeding grounds are by and large removed from the immediate salt water zones. During staging and migration, most of the 12 remaining species are found in association with mud flats, tidal pools, coastal marshes and beaches.

The sensitivity of this group to potential oil spills is generally much less than that of other groups discussed because individuals wade in shallow waters, but generally do not swim. Direct contact of feathered body parts with oil is therefore less likely than with marine birds and waterfowl. Direct contact could, nevertheless, still pose a potential problem. It is the feeding grounds and the potential for ingesting oil contaminated animal foods that is of the most concern. Population estimates for the number of shorebirds using the coastal zones of south Hudson Bay and James Bay (particularly the west and south coastline) are not available, but the number of birds is known to number in the millions, again with significant proportions of total populations of many of the species involved.

Two species are of specific importance, these are the Hudsonian and Marbled Godwits. The Hudsonian Godwit is only known to breed in three isolated and small locations, two of which are in the study region. These are the Nelson River to Cape Churchill area, and the Sutton River mouth area, both in the Hudson Bay Lowlands coastal region.

Breeding grounds for this species are removed from the potential of oil spill threat, but the majority of the total population of this species is potentially sensitive during fall staging and migration when tidal mud flats are used for foraging (Table 7-1). Curtis and Allen (1976) reported concentrations of 10,000 Hudsonia Godwits along the west James Bay coast opposite the Akimiski Island area.

Marbled Godwits also occur in this area, with confirmation of breeding for this species in James Bay being established in 1975 by Morrison et al. (1976). This is a disjunct population, well removed from the main breeding range of the southern Canadian Prairies and adjacent prairies of the United States. The species occurs in the region in considerable numbers and occupies much the same habitats in migration and staging as does the Hudsonian Godwit. Marbled Godwits have been noted from the entire west and south coasts of James Bay including Akimiski Island, with concentrations occuring in the vicinity of Akimiski Island and the adjacent mainland.

Plovers, turnstones and phalaropes show breeding distributions concentrated toward the north end of the study region (Figure 7-10). During migration and staging plovers and turnstones are most abundant in the lowland coastal environments of southern Hudson Bay and James Bay. Sensitivity of this group to oil spills is also mainly during migration (Table 7-1), especially mud flat areas. Phalaropes are potentially the most sensitive of this group because they sit on offshore waters, frequently in large flocks and often well removed from the coastline. Red and Northern Phalaropes are among the few birds of the region that utilize the open seas during migration.

Concerning potential sensitive areas, all shorelines and coastal environments of the study region are heavily used by shorebirds, but the main areas of potential concern are the extensive tidal mud flats and coastal marshes of southern Hudson Bay and James Bay used during staging and migration. These correspond, by and large, to areas used by waterfowl for staging and migration. If one area were to be singled out as being the most important for shorebirds it would be the west and south coasts of James Bay including the Akimiski Island area.

7.3 RESOURCE UTILIZATION

Waterfowl of the region are a noted resource of local and international importance. Large numbers of geese and ducks are taken annually by native hunters of the region, particularly in the James Bay area but also at other locations. As well, ducks and geese of the region, but particularly the latter, form an integral part of the waterfowl hunting resource throughout eastern and central North America.

Although there are no definitive expenditure figures, economic benefits derived from the utilization and support of waterfowl hunting in North America can be measured in the millions of dollars (Mr. P. Rekowski, Director of Wildlife Branch, Canadian Wildlife Service, Prairie Region, personal communication). Boyd et al (1982), for example, estimated that the annual kill of Lesser Snow Geese from the eastern Canadian Arctic between 1964 and 1979 averaged 356,000 birds in the United States, 47,000 by non-Native Canadians, and 51,000 by Native Canadians, for a grand total of 454,000 geese.

Data from Coach and Raible (1975) show that for Manitoba, Ontario and Quebec combined, the kill of Canada Geese is normally 2-3 times greater than that of Lesser Snow Geese, and that the annual duck kill for the three provinces normally exceeds that of Lesser Snow Geese by a factor of about 35-40. Nearly all of the Canada and Lesser Snow Geese taken by hunters in the three provinces would be from popuations utilizing the Hudson-James Bay area for breeding and/or migration. The majority of ducks taken, on the other hand, would be from populations based outside of the Region (Bellrose 1976).

Recent figures for Ontario show that about $50,000,000 - $55,000,000 dollars is spent by small game hunters in Ontario (Ontario Ministry of Natural Resources 1982 Statistics). A minimum of about 1/3 of this amount involves expenditures for waterfowl hunting. Extrapolation beyond this point is not warrented, but the magnitude of the expenditure by waterfowl hunters is clear.

TABLE 7-1

MURRES AND GUILLEMOTS

SPECIES	BREEDING DISTRIBUTION	HABITAT PREFERENCES	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Thick-billed Murre	-circumpolar distribution, with several large colonies throughout the eastern Canadian arctic and temporate zones; -most such colonies along the fiord coasts of Baffing Island, Labrador and Newfoundland -within the study region colonies are located on Coats Island (15,000 pairs) and at Cape Wolstenholme-Digges Island (1,000,000 pairs)	-breed in colonies on cliff coasts -forage in coastal areas and in open water -migration is via Hudson Strait to wintering grounds off eastern Newfoundland	-feed on fish and marine invertebrates -forage as far as 150 km from nesting colonies	-populations in some areas, particularly off west Greenland have suffered massive mortality as a result of being caught in nets set for salmon -diving birds are extremely sensitive to oil spills -the Cape Wolstenholme-Digges Island Colony is the largest such colony in the Canadian arctic -SENSITIVE DURING BREEDING AND IN MIGRATION
2. Black Guillemot	-most coastal areas of eastern Canada from the Bay of Fundy in the south to Ellesmere Island in the north, also on Greenland -within the study region occurs along the east coast of Hudson Bay, the Foxe Peninsula Southampton Island, Coats Island west of Southampton Island	-rock and cliff coasts, including islands -winters in leads within the breeding range, which in the study region occur in the vicinity of Southampton Island, down the east coast of Hudson Bay and in the Belcher Island area, also James Bay north	-usually noncolonial -one of two species which regularly winters in the study region (the other species being the Common Eider) -feed on small fish, crustaceans, mollusks and other invertebrates	-some concentrations of birds known to occur such as on Walrus Island between Southampton and Coats Island, but by and large the species is scattered -concentrations are most likely to occur in winter in response to open water conditions -this diving bird is extremely vulnerable to oil spills because it resides in the area year round -SENSITIVE AT ALL TIMES

TABLE 7-1 (cont'd)

JAEGERS, GULLS AND TERNS

SPECIES	BREEDING DISTRIBUTION	HABITAT PREFERENCES	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Pomarine Jaeger	-east coastal area of Hudson Bay north of Port Harrison, southern Baffin Island, part of Southampton Island, and at selected locations in the western arctic	-breeding habitat includes low tundra and coastal plains -in migration associated primarily with offshore marine waters	-migration appears to be primarily to either the Atlantic or Pacific Oceans with little use of Hudson Bay waters in summers	-open water in the Hudson Strait area used by this species in migration -use of coastal waters to catch fish during nesting -SENSITIVE DURING BREEDING AND MIGRATION
2. Parasitic Jaeger	-breeds throughout the whole of the Canadian tundra; in the study region absent from James Bay and the southeast coast of Hudson Bay	-breeding habitat includes a variety of tundra landscapes -open ocean and coasts used in migration	-often tends to be colonial in nesting -likely to be found in association with gulls from which it steals food	-locations of specific colonies not known, species is widespread -SENSITIVE DURING BREEDING AND MIGRATION
3. Long-tailed Jaeger	-breeding distribution almost identical to that of Parasitical Jaeger except not found south of 60° north latitude	-nesting similar to above species -open ocean and coasts used in migration	-catches its own fish more than do other jaegers -feeds on lemmings during breeding	-confined to northern half of region -associated with open water and coasts primarily in migration -SENSITIVE MAINLY DURING MIGRATION
4. Glaucous Gull	-breeds throughout nearly all of the Canadian arctic; within the Hudson Bay area is restricted to Southampton and Coats Islands and to the east coast of Hudson Bay north from the Little Whale River	-nests on arctic cliffs near coasts, on islands and in lagoon areas -migration tends to follow coastlines	-tends to nest in colonies -feeds on a variety of vertebrates including fish, birds and small mammals -some individuals over winter in Hudson Bay	-no known exceptionally large breeding colonies in the study area -a widespread, comparatively common species -SENSITIVE DURING NESTING AND MIGRATION
5. Iceland Gull	-Canadian breeding distribution limited to Cape Wolstenholme, portions of Baffin Island bordering Hudson Strait and parts of the Atlantic, and to west Hudson Strait islands	-breeding associated with coastal cliffs and rocky islands -in migration associated with coastal waters of Hudson Strait and the Atlantic Ocean	-a colonial species, but positions of major colonies, if known, are not defined	-restricted Canadian breeding distribution -SENSITIVE DURING NESTING AND MIGRATION
6. Herring Gull	-the most widespread gull species in Canada, absent only from the Prairies, the B.C. coast and from much of the arctic archipelago	-breeds in a variety of habitats from rocky areas and cliffs to tundra ponds -during migration likely to be found anywhere in the vicinity of water	-frequently occurs in large flocks -a scavenger often noted at dump sites	-extremely common and abundant -SENSITIVE DURING NESTING AND MIGRATION
7. Thayer's Gull	-restricted largely to the arctic archipelago north and west from Southampton Island, also on Coats Island	-primarily a cliff nesting species -migration is westward	-winters on Pacific coast	-Southampton Island population nests on north side of island -migration takes it westward out of Hudson Bay region -NOT A SENSITIVE SPECIES

TABLE 7-1 (cont'd)

JAEGERS, GULLS AND TERNS

8. Sabine's Gull	-southern half of Southampton Island, Coats Island, the Fox Basin and parts of the south-western arctic archipelago	-nesting on low wet tundra, low coasts and islands -in migration associated with coastal waters	-main migration thought to be across the pole, also possibility of an overland route to the Maritimes	-restricted distribution in the region -SENSITIVE PRIMARILY DURING THE BREEDING SEASON
9. Arctic Tern	-breeds throughout Canada north from Hudson and James Bays, and in the Maritimes	-nests in a variety of habitat types adjacent to salt or fresh water -associated with marine environments outside of nesting season	-nests in colonies	-widespread and common in the region -found in association with shorelines and open sea waters -SENSITIVE DURING BREEDING AND MIGRATION

TABLE 7-1 (cont'd)

GEESE AND SWANS

SPECIES	BREEDING DISTRIBUTION	HABITAT PREFERENCES	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Lesser Snow Goose	-major breeding grounds in Hudson Bay and Foxe Basin lowlands, and in the Coronation Gulf area -also breeds at Wrangle Island in Siberia	-nesting associated with low tundra hummocks and ridges on coastal plains - small islands in braided river channels also heavily utilized -during migration salt and freshwater coastal marshes are heavily used, as well as fens and ponds of upland sites	-strongly colonial, with colonies being quite dynamic -eastern arctic population district from western populations -extended flights during migration -nests well above tide level -feeding during migration normally above mean tide level in sedge marshes	-vast majority of the 3.3 million lesser snow geese inhabiting the eastern arctic nest at 4 main locations three of which are in the study region (Southampton Island, McConnell River, Cape Henrietta Maria) -all lesser snow geese utilizing the eastern arctic use the James Bay coast and portions of the Hudson Bay lowlands coast as a staging area in spring and fall -SENSITIVE DURING STAGING AND MIGRATION
2. Canada Geese	-breeds throughout the arctic and in the southern Prairies -Hudson James Bay lowlands, and the western Ungaua Peninsula bodering Hudson Bay are among the most heavily utilized areas	-preferred nesting sites include inland fens, bogs, tundra pool and lake environments and river deltas -small islands in ponds are particularly attractive -in spring migration tend to concentrate at stream and river mouths and along the tide edge -in the fall along coastal marshes, mud flats and inland fens	-congregate in large flocks -colonial, but not to the extent that snow geese are -nesting grounds dispersed -feeding in migration above and below the mean tide level	-from 300,000 - 600,000 Canada Geese use the Hudson Bay area for breeding and staging -breeding takes place primarily in the interior -during staging and migration coastal marshes of Hudson and James Bay are used extensively -SENSITIVE DURING STAGING AND MIGRATION
3. Atlantic Brant	-major breeding grounds scattered throughout the arctic archipelago, along the Alaskan coast, and in the vicinity of the Beaufort Sea -the only breeding colony within the study region occurs on Southampton Island in the Boas River mouth area	-nesting associated primarily with rivers deltas and tidal flats -during staging and migration associated with tidal marshes usually below the low tide zone where they feed extensively on eelgrass	-nests are placed closer to the waters edge then those of other geese, normally within 30-50 cm of high tide -use of coastal areas below low tide is extensive during migration	-staging in James Bay area in spring is brief, normally about 2 wks -during the fall migration as many as 100,000 birds (more than half of the total population) stage in the James Bay area where they feed on eelgrass -SENSITIVE DURING STAGING AND MIGRATION, POTENTIALLY SENSITIVE DURING BREEDING
4. Whistling Swan	-major breeding areas are in the central and western arctic primarily in the areas of Queen Maud Gulf, Beaufort Sea and coastal Alaska -some breeding occurs at the north end of the study region at scattered locations	-nesting associated primarily with inland tundra lakes and ponds -during migration	-breeding within the study region is scattered with small numbers being present -migration flights along with major or traditional stop-overs -stop-overs in James Bay likely to be associated mostly with deltas and estuaries	-nesting is well removed from coastal areas -during migration, stop-overs are widely spaced and swans stop only in some groups, never as a large flock -MINOR SENSITIVITY DURING MIGRATION

TABLE 7-1 (cont'd)

DUCKS
SURFACE FEEDING DUCK

SPECIES	BREEDING DISTRIBUTION	HABITAT PREFERENCES	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Mallard	-throughout most of Canada south of the treeline and westward from southern Quebec -main breeding grounds are in southern Prairies -in study region breeds from southern James Bay westward to mouth of Nelson River	-in breeding, marshes, ponds, lakes, and quiet sections of rivers bordered by grasses and shrubs -in migration, similar habitats, more rarely mud flats; salt and freshwater marshes most important	-gather in large flocks during migration -staging is most important in the fall -feed primarily on aquatic plants and seeds, and to some extent on invertebrates	-normally nest in or adjacent to freshwater habitats -sensitivity to oil spills greatest during migration when salt marshes are more heavily utilized -SENSITIVE DURING MOULTING STAGING AND MIGRATION
2. Black Duck	-Canadian breeding grounds restricted primarily to Ontario, Quebec and the Maritimes south of the tree-line	-breeding habitats similar to those of Mallard except more strongly associated with wooded areas -in migration and staging makes heavier use of mud flats	-similar to Mallard -feeds much more heavily on invertebrates compared to most ducks, hence its association with tidal mud flats in migration	-nesting is normally well removed from the immediate coastline -highest potential for exposure to oil is when feeding on mud flats -SENSITIVE DURING MOULTING STAGING AND MIGRATION
3. Pintail	-breeds throughout most of Canada including the mainland lower arctic in some areas -main breeding grounds in Prairies and Mackenzie Delta -within study region found south of Chesterfield Inlet and Povungnitak	-habitat use for nesting is similar to that of the Mallard except nest are rarely on water -in migration similar to Mallard	-similar to Mallard	-nesting normally in comparatively dry locations -together with the Black Duck, this is most numerous surface feeding duck in the region -SENSITIVE DURING MOULTING, STAGING AND MIGRATION
4. Green-Winged Teal	-all of Canada south of the treeline -within study region, occurs south from McConnell River and from Cape Jones	-habitat preferences similar to those of Mallard	-feeding similar to Mallard, but make more use of mud flats	-similar to above species -abundance in region slightly less than Black Ducks and Pintails -SENSITIVE DURING MOULTING, STAGING AND MIGRATION
5. American Widgeon	-primarily a western species with major breeding ground in Prairies -within study region occurs from Cape Churchill eastward to James Bay	-habitat preferences similar to those of Mallard, except that drier nest sites are preferred	-feed more on vegetative parts than on seeds -eelgrass is important food in coastal areas	-much less common than other surface feeding ducks -low importance in the region -NOT A SENSITIVE SPECIES

TABLE 7-1 (cont'd)

DIVING DUCKS

SPECIES	BREEDING DISTRIBUTION	HABITAT PREFERENCES	BEHAVIOR	SENSITIVITY AND COMMENTS
6. Greater Scaup	-major breeding grounds are in Alaska and the Mackenzie Delta -in study region occurs along south coastal region of Hudson Bay south from McConnell River, and along the east coastal area of James Bay north to the Richmond Gulf	-nesting in association with marshes, lakes, ponds -nests can be floating or considerably removed from water -nesting not generally associated with salt water -feed in shallow water salt and fresh	-feed primarily on mollusks and other subsurface animal food	-salt water bays and coasts used heavily during migration -major migration route from the northwest passes through southern Hudson and James Bays -SENSITIVE DURING STAGING AND MIGRATION
7. Common Goldeneye	-breeds throughout Canada south of the treeline	-nests in wooded areas near water -use of coastal waters south from Cape Churchill and Cape Jones	-nesting is primarily in tree cavities -feeds on crustaceans, insects, crabs, mollusks	-nesting associated with wooded areas and freshwater -makes use of shallow coastal waters during migration -SENSITIVE DURING THE FALL MIGRATION
8. Red-breasted Merganser	-breeds throughout most of Canada south of the high arctic, and excluding the prairies -also breeds on southern Baffin Island	-nest in a variety of habitats adjacent to water (salt and fresh) -associated primarily with coastal waters and large lakes during the nonbreading season	-feeds primarily on fish and to a lesser extent on crustaceans	-common migrant and resident near most coastal areas -SENSITIVE AT ALL TIMES
		SEA DUCKS		
9. Oldsquaw	-breeds throughout the Canadian arctic north from Akimski Island and northern James Bay	-nesting associated with tundra lakes and ponds -at other times extensive use is made of coastal waters	-migration parallels coasts -very deep diving species -feed on a variety of invertebrates -a few winter in the Belcher Islands areas	-abundant migrant and nesting species in most areas -arrives earlier and leaves later than most duck species
10. Common Eider	-breeds throughout the eastern arctic north from Akimiski Island, also in parts of the western arctic	-normally nest close to the sea, usually on small islands -other than during nesting are associated with coastal waters	-frequently colonial -islands chosen for nesting to avoid predation by foxes -feed primarily on mollusks and other invertebrates	-colonies known from the Belcher Islands, Chesterfield Inlet, Cape Dorset, and elsewhere -one of the few bird species to winter in the region - major wintering grounds occur in the Belcher Island leads, wintering concentrations also occur in leads west and south of Southampton Island -SENSITIVE AT ALL TIMES

TABLE 7-1 (cont'd)

11. King Eider	-breeds throughout the Canadian arctic and subarctic coastal regions with the notable exception of James Bay, the east coast of Hudson Bay, and the south coastal area of Hudson Strait	-breeding habitat includes coastal marshes, islands, tundra ponds and lakes -nests placed above the highwater mark -at all other times associated with coastal waters	-not colonial -deep diving, feeding on mollusks and other individuals	-most abundant north of the Hudson Bay Lowlands, particularly on arctic islands -the major migration route for birds inhabiting the study region is via Hudson Bay Strait to the south coast of Greenland where wintering occurs -SENSITIVE AT ALL TIMES
12. Black Scoter	-believed to nest in large numbers in the Hudson James Bay lowland interior of Ontario	-presumably bogs, muskeg lakes and ponds -in the summer and fall large numbers of Black Scoters utilize coastal areas of James Bay, and Hudson Bay east from the Manitoba border	-the exact nesting area of this species is unknown -nonbreeding males and post breeding birds gather in large rafts in coastal waters of south Hudson and James Bays	-during the summer and fall large concentrations remain along coastal waters especially during the moult, also in open water -the most abundant diving-sea duck of the James Bay-Southern Hudson Bay area
13. Surf Scoter	-main breeding area associated with Mackenzie River watershed, also breeds along the south coastal region of Hudson Bay, and in north central Quebec including areas adjacent to James Bay and the Richmond Gulf	-nesting associated with open forest, usually a considerable distance from water -gather into rafts in coastal waters for moulting	-feed on mollusks and other invertebrates	-during the post breeding period can be found throughout the James Bay area, and along the south Hudson Bay coast, sometimes well out from the coast -SENSITIVE DURING THE POST BREEDING PERIOD
14. White-winged Scoter	-breeding distribution restricted to western Canada including areas of Manitoba which border Hudson Bay	-nest in deep woods well removed from water -during the post breeding season concentrate in coastal areas	-similar to other scoters	-similar to other scoters -SENSITIVE DURING THE POST BREEDING PERIOD, NONBREEDING MALES SENSITIVE IN SUMMER

TABLE 7-1 (cont'd)

SANDPIPERS

SPECIES	BREEDING DISTRIBUTION	PREFERRED HABITATS	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Common Snipe	-breeds throughout Canada south from the tree line, and along coastal areas of Hudson Bay and James Bay from south of the Manitoba-NWT border eastwards to Cape Jones	-during the breeding season, found in association with freshwater marshes, bogs, wet meadows, etc. -in migration, associated with the above habitats as well as the upper salt marshes.	-solitary when nesting and feeding -migrate in small flocks, mainly at night	-a widespread, comparatively common species -use of salt marshes is limited and confined largely to the migration period. -not particularly common in the study region -NOT A SENSITIVE SPECIES
2. Whimbrel	-Canadian breeding distribution restricted to the Beaufort Sea coastal area, portions of the Yukon, to coastal regions of Hudson Bay between the Wilson River and Cape Henrietta Maria, and to Southampton Island	-during the breeding season, found in association with wet and dry tundra areas, especially inland -in migration, associated with tidal mudflats, beaches, lakeshores, and fresh and salt water marshes	-migrates in small to medium flocks, frequently in association with other sandpipers	-a locally common species, with a large portion of its breeding ground associated with Hudson Bay coastal regions -a large segment of the Canadian population migrates along the Hudson Bay shoreline where tidal and mud flats are used extensively -common to abundant in areas of occurrence -SENSITIVE DURING MIGRATION
3. Spotted Sandpiper	-breeding distribution similar to that of the Common Snipe, i.e., south from the tree line including coastal regions of Hudson and James Bays	-breeding associated with a variety of shoreline types, bordering freshwater lakes and ponds to a lesser extent, and salt water; also associated with streams -in migration, same as above	-usually does not form flocks in migration	-a widespread and very common Canadian species -not particularly associated with Coastal areas -NOT A SENSITIVE SPECIES
4. Greater Yellowlegs	-breeds within a broad band of boreal forest extending from British Columbia to Newfoundland -within the study area, restricted to the James Bay region and extreme southern Hudson Bay	-breeding habitat associated with open marshy ground and freshwater pools -during migration, is associated with salt marshes, tidal pools, and more rarely, mud flats	-migrate in flocks, frequently in association with the lesser Yellowlegs and other shore birds	-apparently quite common in migration along the James Bay coastlines, but not along those of southern Hudson Bay -the preference of this species for brackish water and high water tidal pools makes them less susceptible to oil spills compared to species which more readily utilize open mud flats -LOW SENSITIVITY, CONFINED TO MIGRATION PERIOD
5. Lesser Yellowlegs	-breeding range extends from from northern British Columbia and the Yukon eastwards to James Bay; range does not extend much beyond the tree line, or south of 53^{o} north latitude -in study region, confined to Hudson Bay coastal region south from the Manitoba-NWT border, and to much of the James Bay area	-habitats utilized during nesting and migration similar to those described above for the Greater Yellowlegs, except that a stronger nesting preference is observed for areas of open woodland interspersed with muskeg, bogs, ponds, and lakes	-behavior is similar to that of the Greater Yellowlegs, with which it is commonly associated with during migration	-considered to be more sensitive that the above species because it is more common and widespread along the southern Hudson Bay shoreline from Fort Churchill eastward to Cape Henrietta Maria -SENSITIVE DURING MIGRATION

TABLE 7-1 (cont'd)

SPECIES	BREEDING DISTRIBUTION	PREFERRED HABITATS	BEHAVIOR	SENSITIVITY AND COMMENTS
6. Knot	-main breeding ground is the high arctic north from Viscount Melville Sound, also breeds at selected other arctic locations including Southampton, Coats and Mansel Islands where it is apparently rare as a breeding species	-nesting primarily associated with upland sites -during migration, frequents mud flats, beaches, and rocky shores	-form very large flocks during migration	-an uncommon to common migrant along the west coasts of Hudson and James Bays, and inland west of Hudson Bay -little data available on this species -SENSITIVE DURING MIGRATION
7. Purple Sandpiper	-Canadian breeding range includes Southampton, Coats Mansel and the Belcher Islands, as well as large portions of Baffin Island, Devon Island, and Somerset and Cornwallis Islands	-nests above the high water mark and frequently quite far inland -during migration it frequents rocky coasts, and less often beaches and muddy pools	-migrat in moderate sized flocks, frequently with other species -migration mainly east of Hudson Bay via the Atlantic coastline	-apparently rare to very uncommon as a breeding bird in the region, except on the Belcher Islands where it is the commonest shorebird -migration mainly east of Hudson Bay -NOT A SENSITIVE SPECIES
8. Pectoral Sandpiper	-breeds in the western arctic, on Southampton and Coats Islands, and along the west coastal region of Hudson Bay from Eskimo Point eastward to Cape Henrietta Maria	-breeds in tundra meadows or any other moist upland grassy sites -similar habitats used in migration	-apparently migrate in close association with other species such as Hudsonian Godwits and Semipalmated Sandpipers -most common as a migrant in the study region in the fall	-coastal habitats such as salt marshes or mud flats -utilized to some extent during migration, particularly the fall migration -SENSITIVE DURING MIGRATION
9. White-rumped Sandpiper	-Canadian breeding grounds include the Arctic coast from Chesterfield Inlet west to the Mackenzie delta, and many of the arctic islands including Southampton Island and much of Baffin Island	-west and moist grassy tundra and other upland sites are preferred for breeding -mud flats and beaches are used extensively during migration	-form large flocks frequently in association with other species	-among the most common of the shorebirds in the Foxe Basin area -common migrant along coasts of Hudson and James Bays -SENSITIVE DURING MIGRATION
10. Baird's Sandpiper	-breeds throughout the Canadian arctic west and north of Southampton Island and the Fox Peninsula -breeding range within the study region confined to the northwest area of Roes Welcome Sound	-nests primarily on upland sites -drier portions of muddy areas, usually vegetated, and beaches also used during migration	-migrate primarily through the interior west of Hudson Bay	-breeding range is well removed from Hudson Bay proper, and comparatively little use is made of the Hudson and James Bay shoreline by this species -NOT A SENSITIVE SPECIES
11. Least Sandpiper	-breeding grounds primarily associated with the boreal forest tundra transition zone and the lower arctic from Newfoundland to the Yukon -within the study region breeds in the Hudson Bay area south from Chesterfield Inlet and Port Harrison, including northern regions of James Bay -also reported from Coral Harbour area of Southampton Island	-during the breeding period, prefers bogs and inland marshes -during migration, associated with the above habitats as well as with coastal marshes and less commonly, mud flats	-migrate in flocks, frequently in association with other species	-more associated with inland areas compared with most other sandpiper species -when observed in marine coastal areas it is primarily associated with upper reaches of the tidal zone and drier sites -LOW SENSITIVITY, CONFINED TO MIGRATION PERIOD

TABLE 7-1 (cont'd)

SPECIES	BREEDING DISTRIBUTION	PREFERRED HABITATS	BEHAVIOR	SENSITIVITY AND COMMENTS
12. Dunlin	-breeding range borders the west side of Hudson Bay from the Nelson River mouth in the south to the Melville and Boothia Peninsula in the north; also breeds on Southampton and Coats Islands, at Cape Henrietta Maria, and near the Beaufort Sea	-breeding habitats include moist to wet tundra and coastal salt marshes -during migration, mud flats, flooded grassland and beaches are used	-migrates in large numbers, often with other species	-observed in considerable numbers at Fort Churchill and at Cape Henrietta Maria, the west coast of Hudson Bay is presumably the major migration route for this species -SENSITIVE DURING MIGRATION, LOW SENSITIVITY DURING NESTING
13. Stilt Sandpiper	-west side of Hudson Bay between the Nelson River and Eskimo Point; at Cape Henrietta Maria, and in the vicinity of Coronation Gulf and the Beaufort Sea	-nests in wet tundra and in the vicinity of ponds and lakes -mainly inland during migration using habitats described above, occasionally on beaches	-principle migration route spring and fall is through the Prairie provinces	-little use of immediate coastal areas, primarily a bird of freshwater coastal marshes, pools, ponds, and lakes -NOT A SENSITIVE SPECIES
14. Semipalmated Sandpipers	-coastal regions of Hudson and north James Bays to the Mackenzie delta in the northwest and to Baffin Island in the northeast, also the coast of Labrador	-nesting in wet sedgegrass tundra, and ponds frequently associated with sandy areas -in migration associated with the the above habitats, and more commonly with beaches and mud flats of coastal sites	-migrates in large flocks	-one of the most abundant species in the region, large numbers migrate along both coasts of Hudson and James Bays -SENSITIVE DURING MIGRATION
15. Hudsonian Godwit	- only three significant breeding areas, two of which, the Nelson River mouth to Cape Churchill area and the Sutton River mouth area, are within the study region; the third area is the Mackenzie delta area	-nesting on wet grassy-sedge tundra -during autumn migration found on mud flats, beaches and sand bars of the Hudson and west James Bay coasts -spring migration is mainly overland	-migration is strongly concentrated in autumn, associated primarily with mud flats	-extremely local breeder -sensitive during the fall migration because most of the Canadian population is concentrated along Hudson and James Bay tidal flats, particularly in the vicinity of the Albany River on James Bay -VERY SENSITIVE DURING MIGRATION
16. Sanderling	-breeds throughout much of the arctic archipelago north and west from Southampton Island	-nesting in upland rocky areas -during migration found in association with sand beaches and mud flats of salt and freshwater	-common to uncommon spring migrant, and a common fall migrant along west coasts of Hudson and James Bays	-quite uncommon in the study region including Southampton Island, except during migration -SENSITIVE DURING MIGRATION
17. Marbled Godwit	-principle breeding grounds is in the Prairie region of Canada and adjacent parts of the United States -a disjunct breeding population has recently been discovered in James Bay	-presumably nests in coastal marshes, likely above the high tide level, and also possibly in grassy - sedge tundra -during migration, extensive use is made of coastal marshes, tidal creeks, mud flats and beaches	-gathers in large flocks during migration where it associates with other shorebirds	-the James Bay population of this species is likely separate from the main species assemblage which nests in the Prairies and is therefore of biogeographical interest -SENSITIVE DURING MIGRATION

TABLE 7-1 (cont'd)

PLOVERS AND PHALAROPES

SPECIES	BREEDING DISTRIBUTION	PREFERRED HABITATS	BEHAVIOR	SENSITIVITY AND COMMENTS
1. Semipalmated Plover	-throughout main land portions of the NWT and the Yukon, parts of the arctic islands and coastal areas of Quebec and Maritimes	-nesting habitat includes beaches, gravel ridges etc. -during migration uses mud flats, beaches, pond and lake margins	-a very abundant species found in large flocks	-use of marine beaches and beach ridges for nesting -extensive use of shoreline areas during migration -SENSITIVE DURING MIGRATION AND NESTING
2. Golden Plover	-Baffin Island, Southampton Island and Fort Churchill area westwards to the Yukon	-upland areas preferred for nesting -during migration, makes use of coastal beaches and mud flats, as well as the above habitats	-travels individually or in small flocks	-moderately common along the shores of Hudson and James Bay during migration -SENSITIVE DURING MIGRATION
3. Black-bellied Plover	--Baffin Island west to Amundsen Gulf -within study region confined to Southampton and Coats Islands and to the Foxe Basin	-nests in a variety of habitats with preference for gravel and stony ridges	-similar to the above	-moderately common as a coastal migrant on Hudson and James Bays -SENSITIVE DURING MIGRATION
4. Ruddy Turnstone	-Southampton Island and much of the arctic archipelago	-nesting primarily in upland areas -associated with all coastal environments during migration	-frequently travels in large flocks	-common migrant along the shores of Hudson and James Bays -SENSITIVE DURING MIGRATION
5. Red Phalarope	-west side of Hudson Bay from Manitoba-NWT border north, Hudson Strait and Southampton Island; scattered localities throughout the arctic archipelago	-breeding associated with coastal freshwater ponds and shallow lakes -in migration associated primarily with open water and less commonly with coastal reaches	-a buoyant species which readily sits on the open sea	-an abundant species in much of its range -SENSITIVE DURING MIGRATION
6. Northern Phalarope	-breeds throughout the Hudson Bay region north to Baffin Island, east to Labrador and west to the Yukon	-breeding habitat similar to above -in migration uses open ocean and sea-coast, and to a lesser extent interior lakes and ponds	-frequently seen in large flocks	-one of the more abundant breeding birds in the region -SENSITIVE DURING MIGRATION

References used in preparing Table 7-1.*

General:

Bray 1943
Brown et al 1975
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Freeman 1970b
Godfrey 1966
Jehl and Smith 1970
MacPherson and McLaren 1959
Manning 1952, 1976
Nettleship 1977
Nettleship and Gaston 1978
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Peck 1972
Sutton 1932
Todd 1963

Murres and Guillemots:

Gaston 1982, a,b
Lumsden 1959
Tuck 1961

Jaegers, Gulls and Terns:

Blomquist and Elander 1981

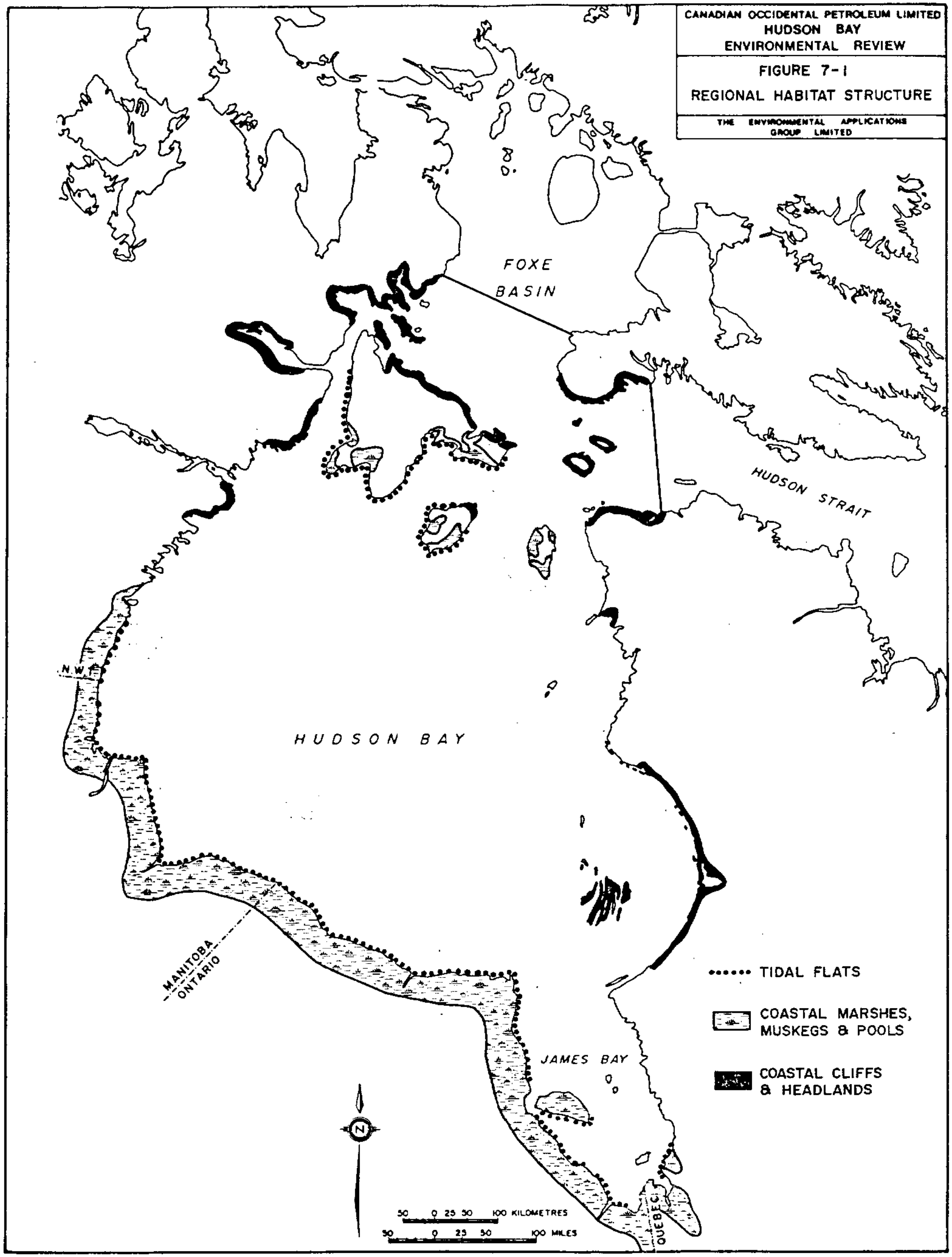
Waterfowl:

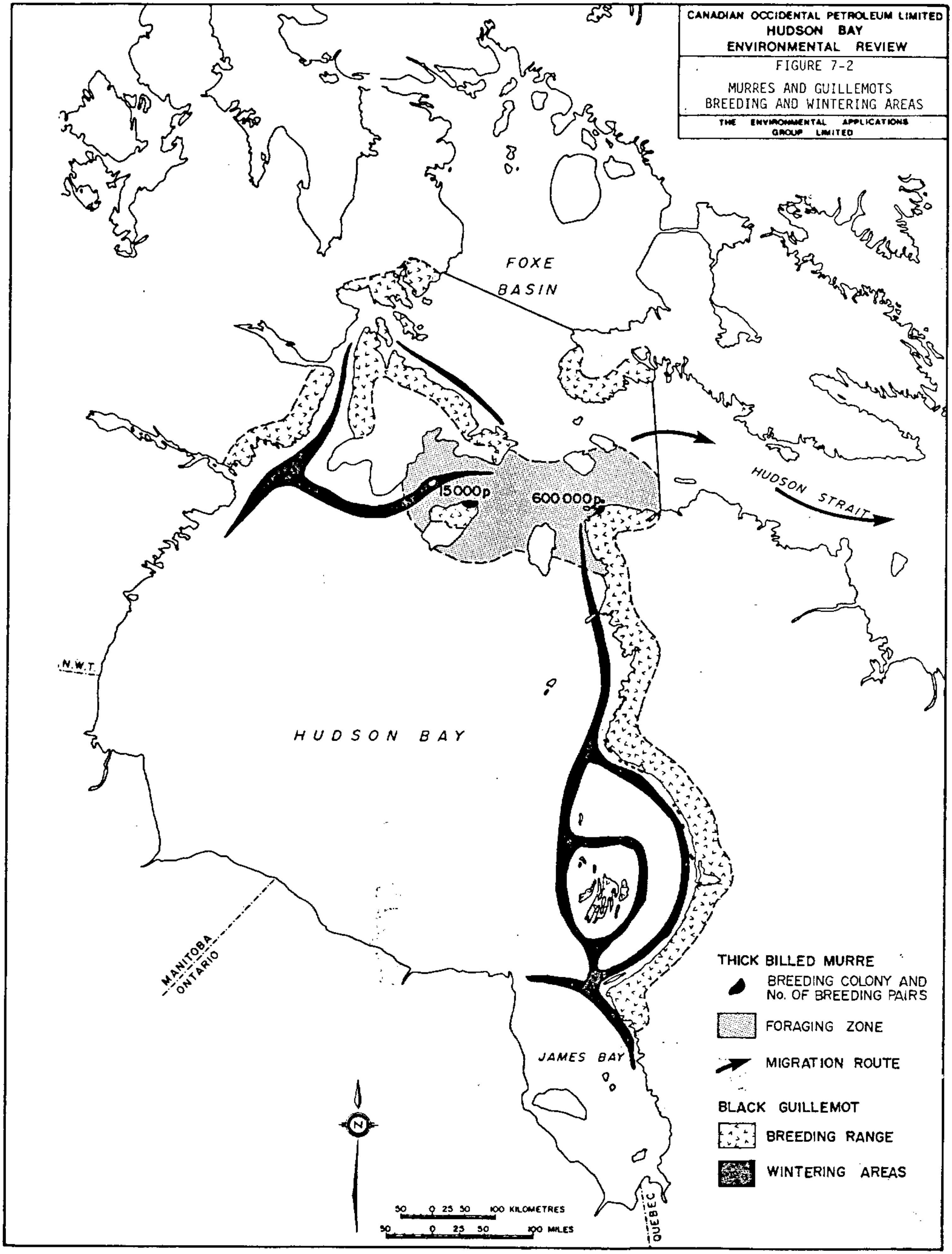
Bellrose 1976
Blokpoel 1974
Boyd et al. 1982
Curtis 1976
Freeman 1970 a
Hanson et al 1972
Kerbes 1975, 1982
Raveling and Lumsden 1977
Ross 1976
Ryder 1967
Thomas and Prevett 1982

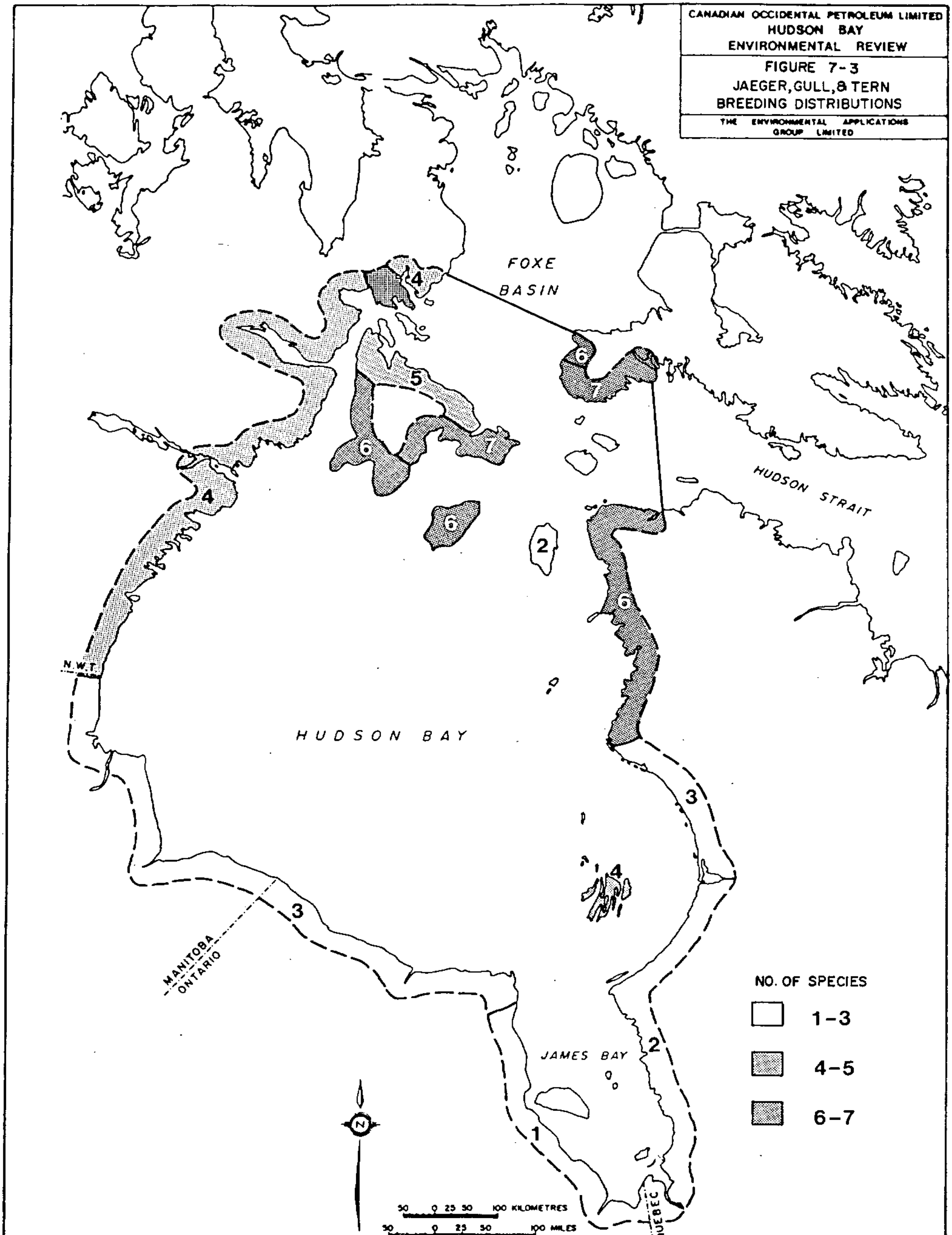
Sandpipers, Plovers and Phalaropes:

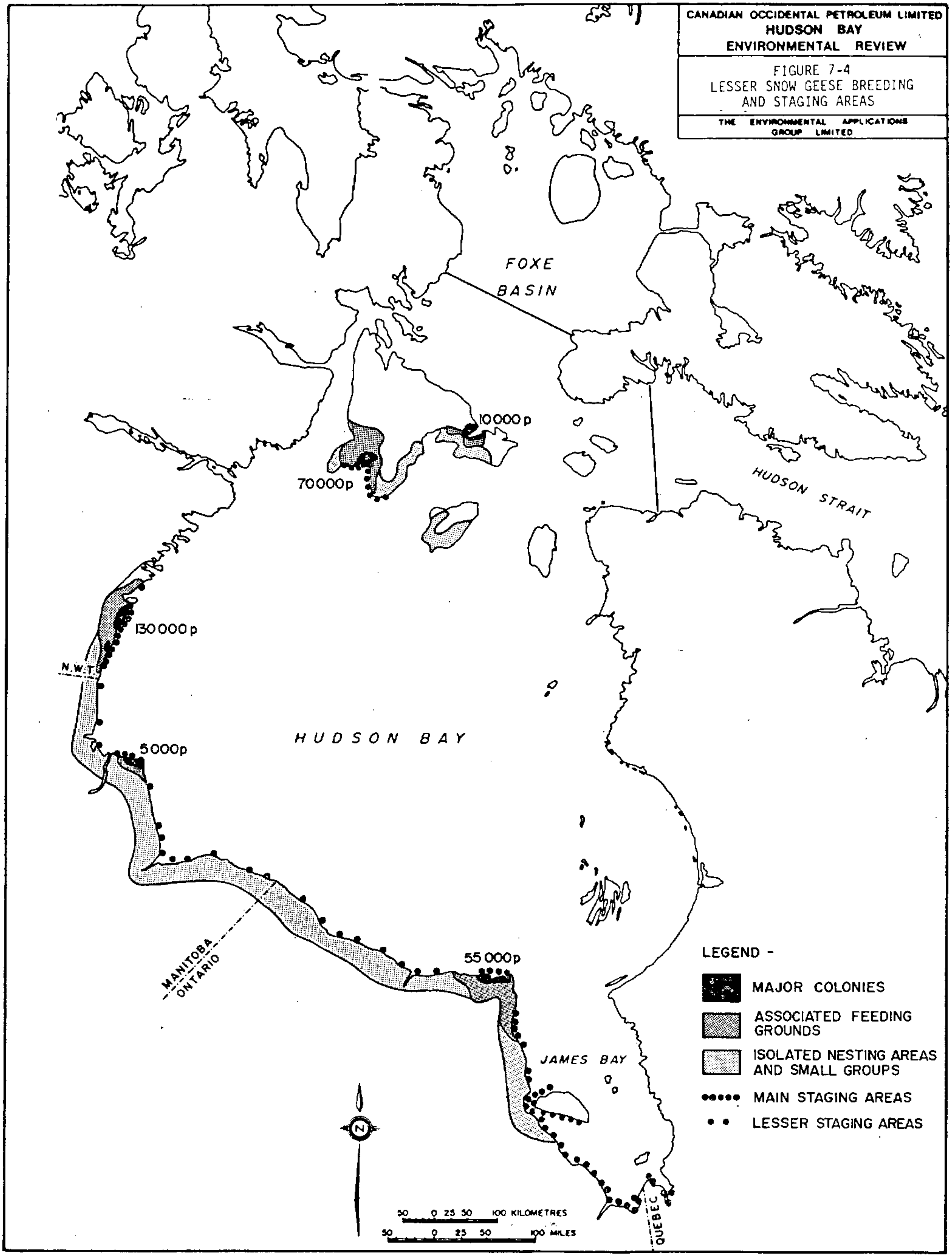
Hope and Shortt 1944
Morrison et al 1976

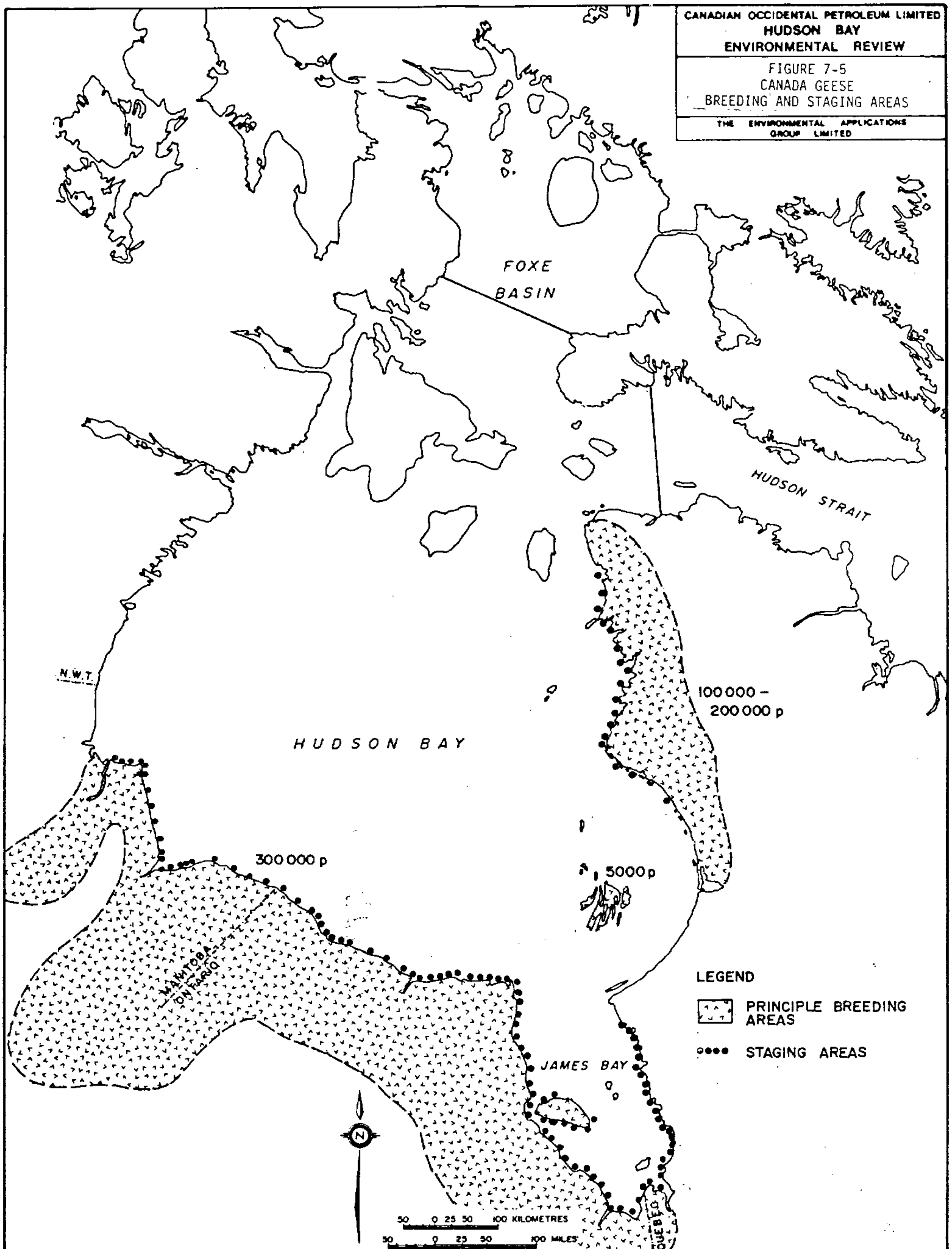
* these same references were used in compiling Table 7-2

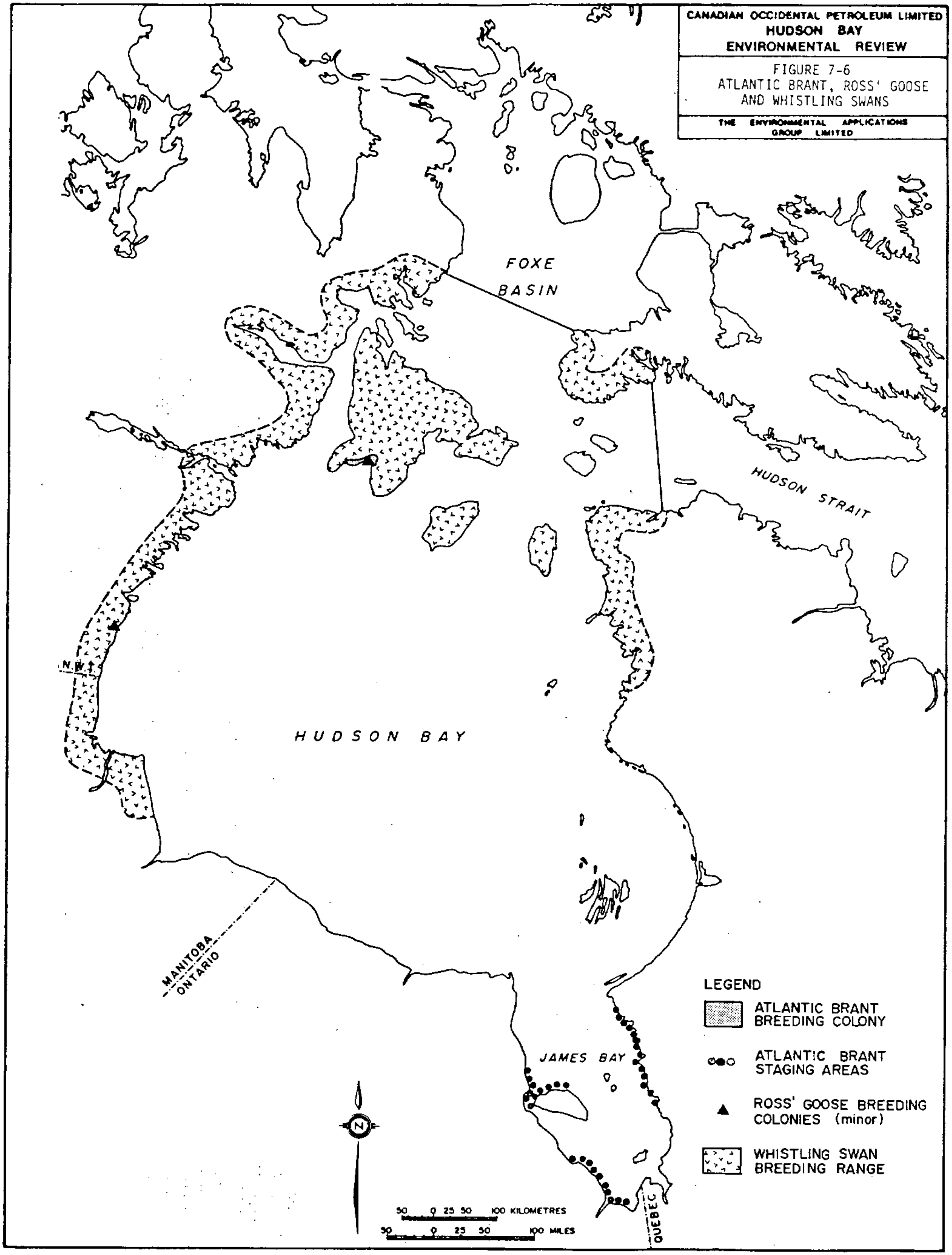

CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-1
REGIONAL HABITAT STRUCTURE
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
TIDAL FLATS
COASTAL MARSHES, MUSKEGS & POOLS
COASTAL CLIFFS & HEADLANDS
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-2
MURRES AND GUILLEMOTS
BREEDING AND WINTERING AREAS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
15000p
600000p
N.W.T.
HUDSON BAY
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
THICK BILLED MURRE
BREEDING COLONY AND No. OF BREEDING PAIRS
FORAGING ZONE
MIGRATION ROUTE
BLACK GUILLEMOT
BREEDING RANGE
WINTERING AREAS
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-3
JAEGER, GULL, & TERN
BREEDING DISTRIBUTIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
4
5
6
7
6
7
4
6
2
6
3
4
3
2
1
NO. OF SPECIES
1-3
4-5
6-7
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-4
LESSER SNOW GEESE BREEDING
AND STAGING AREAS
THE ENVIRONMENTAL APPLICATIONS
GROUP LIMITED
FOXE
BASIN
HUDSON STRAIT
10000p
70000p
130000p
N.W.T.
5000p
HUDSON BAY
MANITOBA
ONTARIO
55000p
JAMES BAY
QUEBEC
LEGEND -
MAJOR COLONIES
ASSOCIATED FEEDING GROUNDS
ISOLATED NESTING AREAS AND SMALL GROUPS
MAIN STAGING AREAS
LESSER STAGING AREAS
N
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-5
CANADA GEESE
BREEDING AND STAGING AREAS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
N.W.T.
100 000 - 200 000 p
300 000 p
5000 p
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
N
LEGEND
PRINCIPLE BREEDING AREAS
STAGING AREAS
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES



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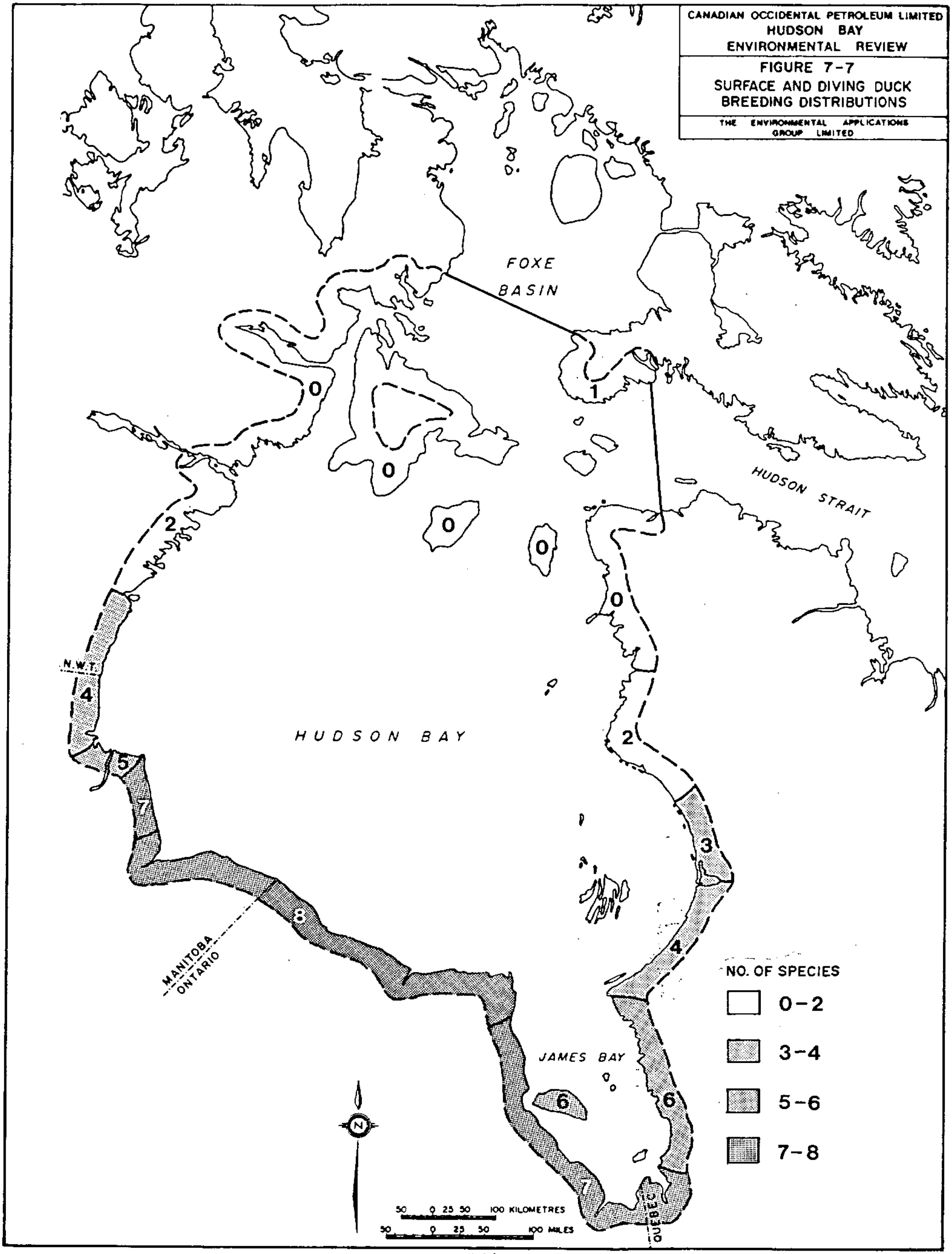
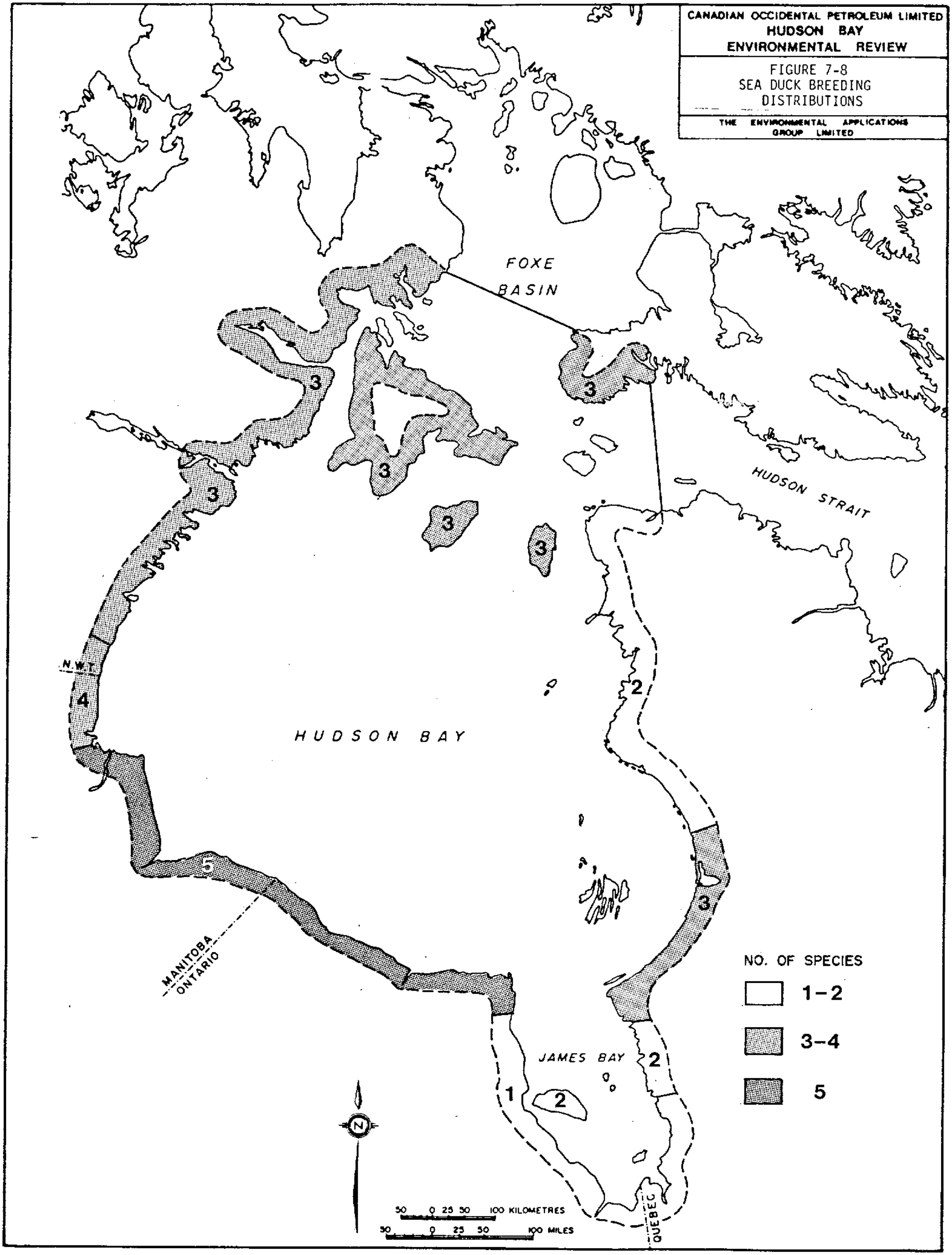
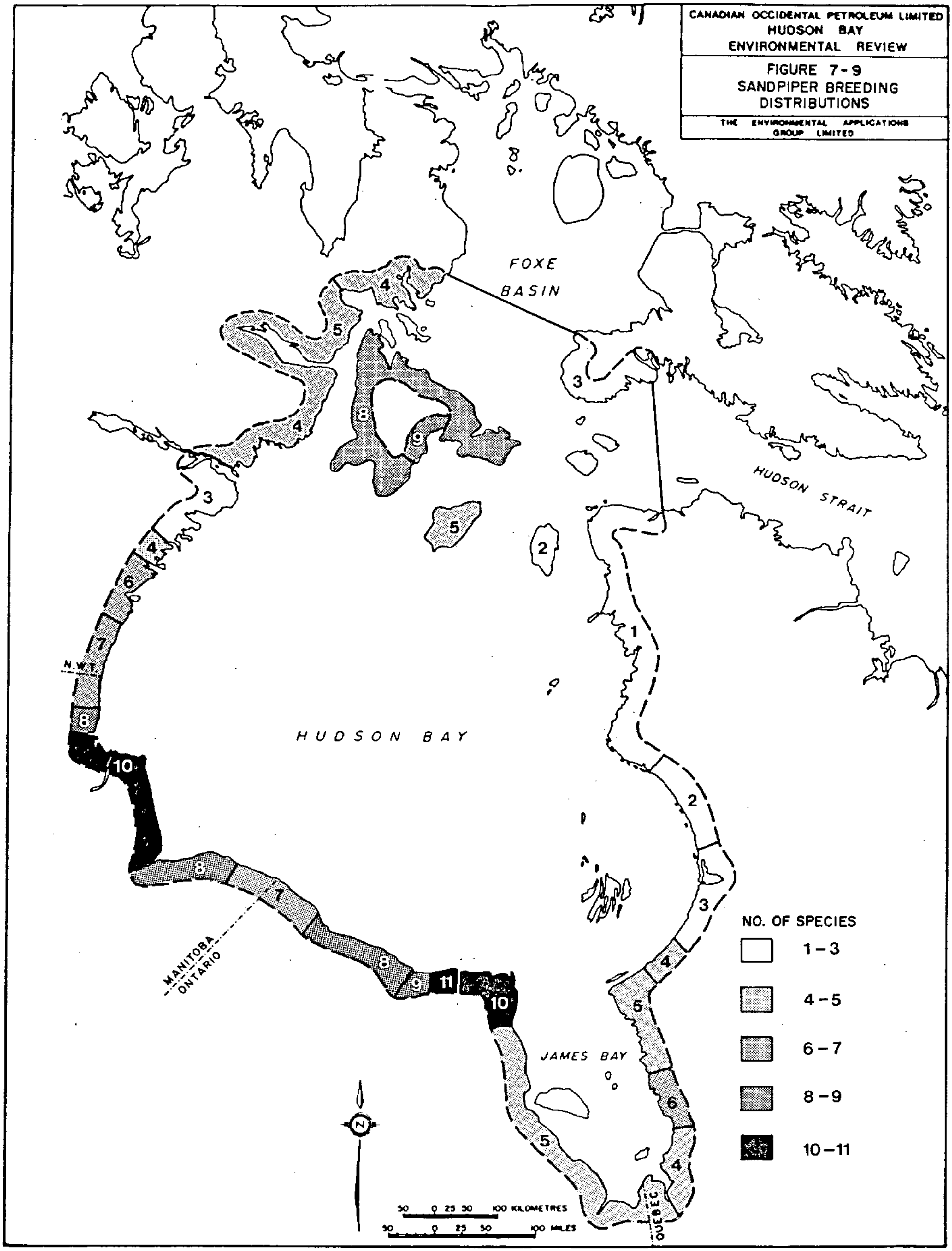
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-6
ATLANTIC BRANT, ROSS' GOOSE AND WHISTLING SWANS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
N.W.T.
MANITOBA
ONTARIO
JAMES BAY
QUEBEC
LEGEND
ATLANTIC BRANT BREEDING COLONY
ATLANTIC BRANT STAGING AREAS
ROSS' GOOSE BREEDING COLONIES (minor)
WHISTLING SWAN BREEDING RANGE
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES
N



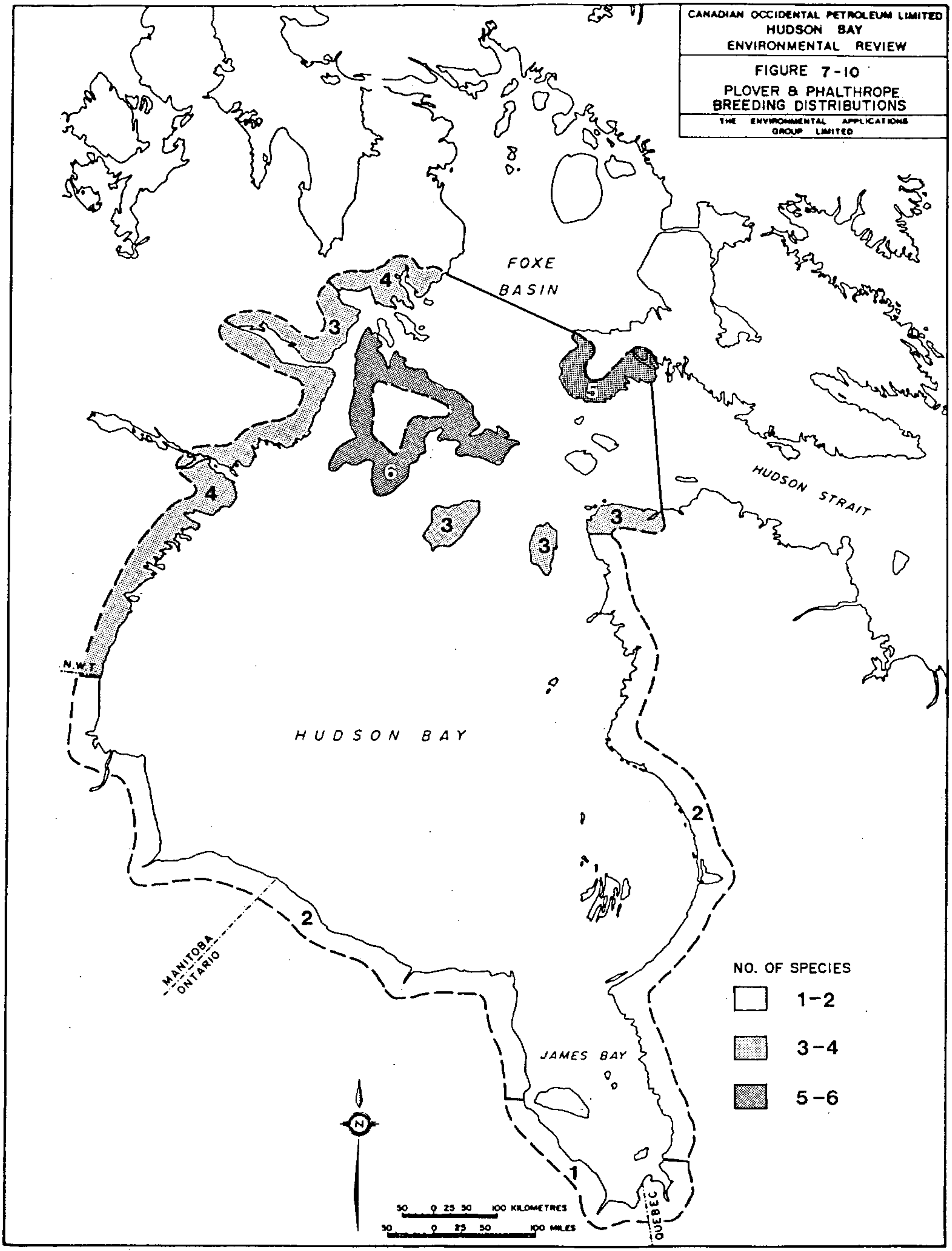
CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-7
SURFACE AND DIVING DUCK
BREEDING DISTRIBUTIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
NO. OF SPECIES
0-2
3-4
5-6
7-8
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES



CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-8
SEA DUCK BREEDING
DISTRIBUTIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE
BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
NO. OF SPECIES
1-2
3-4
5
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES



CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-9
SANDPIPER BREEDING
DISTRIBUTIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE
BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
NO. OF SPECIES
1-3
4-5
6-7
8-9
10-11
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES



CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 7-10
PLOVER & PHALTHROPE
BREEDING DISTRIBUTIONS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
NO. OF SPECIES
1-2
3-4
5-6
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

TABLE 7-2
MIGRATION AND NESTING CHRONOLOGY
OF SPECIES AND SPECIES GROUPS

Species	Location	Spring Migration/Staging			Nesting		Fall Migration/Staging			Overwintering in Region
		Arrival	Peak Numbers	Departure	Egg Dates	Hatching	Initiation	Peak Numbers	Final Departure	
Murres and Guillemots										
1. Thick-billed Murre	North Hudson Bay	ℓ. June - e. July	e. July	N/A	e. July - e. Aug.	e. - ℓ. Aug.	m. Sept.	m. - ℓ. Sept.	Oct.	- some individuals
2. Black Guillemot	Hudson Bay	N/A	N/A	N/A	e. - ℓ. July	e. - ℓ. Aug.	N/A	N/A	N/A	- normal behaviour
Jaegers, Gulls and Terns										
1. jaegers	Hudson Bay	e. - m. June	m. June	N/A	m. June - e. July	m. July - e. Aug.	ℓ. Aug.	m. Sept.	e. Oct.	-
2. gulls	Hudson Bay	e. May	ℓ. May	N/A	e. June - e. July	ℓ. June - ℓ. July	m. - ℓ. Aug.	m. Sept. - e. Oct.	e. Nov.	- some individuals
3. Arctic Tern	Hudson Bay	ℓ. May	e. June	N/A	m. June - m. July	m. July - e. Aug.	m. Aug.	ℓ. Aug. - m. Sept.	m. - ℓ. Sept.	-
Geese and Swans										
1. Lesser Snow Goose	James Bay	e. - m. May	e. - m. May	m. May	N/A	N/A	e. Sept.	ℓ. Sept. - e. Oct.	ℓ. Oct.	-
	South Hudson Bay	e. - m. May	m. - ℓ. May	N/A	ℓ. May - m. July	ℓ. June - ℓ. July	ℓ. Aug.	e. - m. Sept.	m. - ℓ. Sept.	-
	North Hudson Bay	ℓ. May - e. June	e. - m. June	N/A	e. June - m. July	e. - ℓ. July	m. - ℓ. Aug.	e. Sept.	m. - ℓ. Sept.	-
2. Canada Goose	James Bay	m. Apr.	ℓ. Apr. - e. May	N/A	e. - ℓ. May	e. - ℓ. June	e. Sept.	ℓ. Sept. - e. Oct.	ℓ. Oct.	-
	South Hudson Bay	ℓ. Apr. - m. May	m. - ℓ. May	N/A	m. May - e. June	m. June - e. July	ℓ. Aug.	m. Sept.	ℓ. Sept. - e. Oct.	-
	North Hudson Bay	m. May - e. June	e. June	N/A	m. - ℓ. June	m. - ℓ. July	ℓ. Aug.	e. Sept.	ℓ. Sept.	-
3. Atlantic Brant	James Bay	ℓ. May - e. June	ℓ. May	e. June	N/A	N/A	e. Sept	m. Oct.	ℓ. Oct.	-
	North Hudson Bay	e. - m. June	m. June	N/A	m. - ℓ. June	m. - ℓ. July	ℓ. Aug. - e. Sept.	e. Sept.	m. Sept.	-
4. Whistling Swan	James Bay	e. - m. May	m. May	ℓ. May - e. June	N/A	N/A	m. Sept.	m. - ℓ. Sept.	m. - ℓ. Sept.	-
	North Hudson Bay	ℓ. May - e. June	e. June	N/A	e. - m. June	e. - ℓ. July	ℓ. Aug. - e. Sept.	e. Sept.	m. Sept.	-
Ducks										
1. Surface Ducks	James Bay	m. April - e. May	e. - ℓ. May	N/A	m. May - e. June	e. - ℓ. June	ℓ. Aug.	e. - m. Sept.	m. - ℓ. Oct.	-
	South Hudson Bay	e. - ℓ. May	ℓ. May	N/A	ℓ. May m. June	m. June - e. July	ℓ. Aug.	e. - m. Sept.	e. Oct.	-
2. Diving Ducks	James Bay	e. - ℓ. May	m. - ℓ. May	N/A	m. - ℓ. June	ℓ. June - e. July	ℓ. Aug.	e. - m. Sept.	m. - ℓ. Oct.	-
	South Hudson Bay	ℓ. May - m. June	e. - m. June	N/A	ℓ. June - e. July	m. - ℓ. July	ℓ. Aug.	e. - m. Sept.	e. Oct.	-
3. Sea Ducks	South Hudson Bay	ℓ. April - ℓ. May	m. - ℓ. May	N/A	m. June - e. July	e. - ℓ. July	ℓ. Sept.	ℓ. Sept. - e. Oct.	ℓ. Oct.	Common Eider
	North Hudson Bay	ℓ. April - ℓ. May	m. - ℓ. May	N/A	m. June - m. July	m. July - e. Aug.	e. Sept.	ℓ. Sept.	e. - m. Oct.	-
Sandpipers	James Bay	e. May - e. June	ℓ. May	N/A	e. June - e. July	ℓ. June - m. July	e. Aug.	m. - ℓ. Aug.	e. - m. Sept.	-
	Hudson Bay	ℓ. May - m. June	ℓ. May - e. June	N/A	m. June - m. July	e. - ℓ. July	ℓ. July	e. - ℓ. Aug.	e. Sept.	-
Plovers and Phalaropes	James Bay	m. - ℓ. May	ℓ. May - e. June	ℓ. May - e. June	N/A	N/A	e. Aug.	m. - ℓ. Aug.	e. - m. Sept.	-
	Hudson Bay	e. - ℓ. June	m. - June	N/A	m. June - m. July	e. July - e. Aug.	ℓ. July	e. - ℓ. Aug.	m. - ℓ. Sept.	-

Legend: e. - early m. - mid ℓ. - late

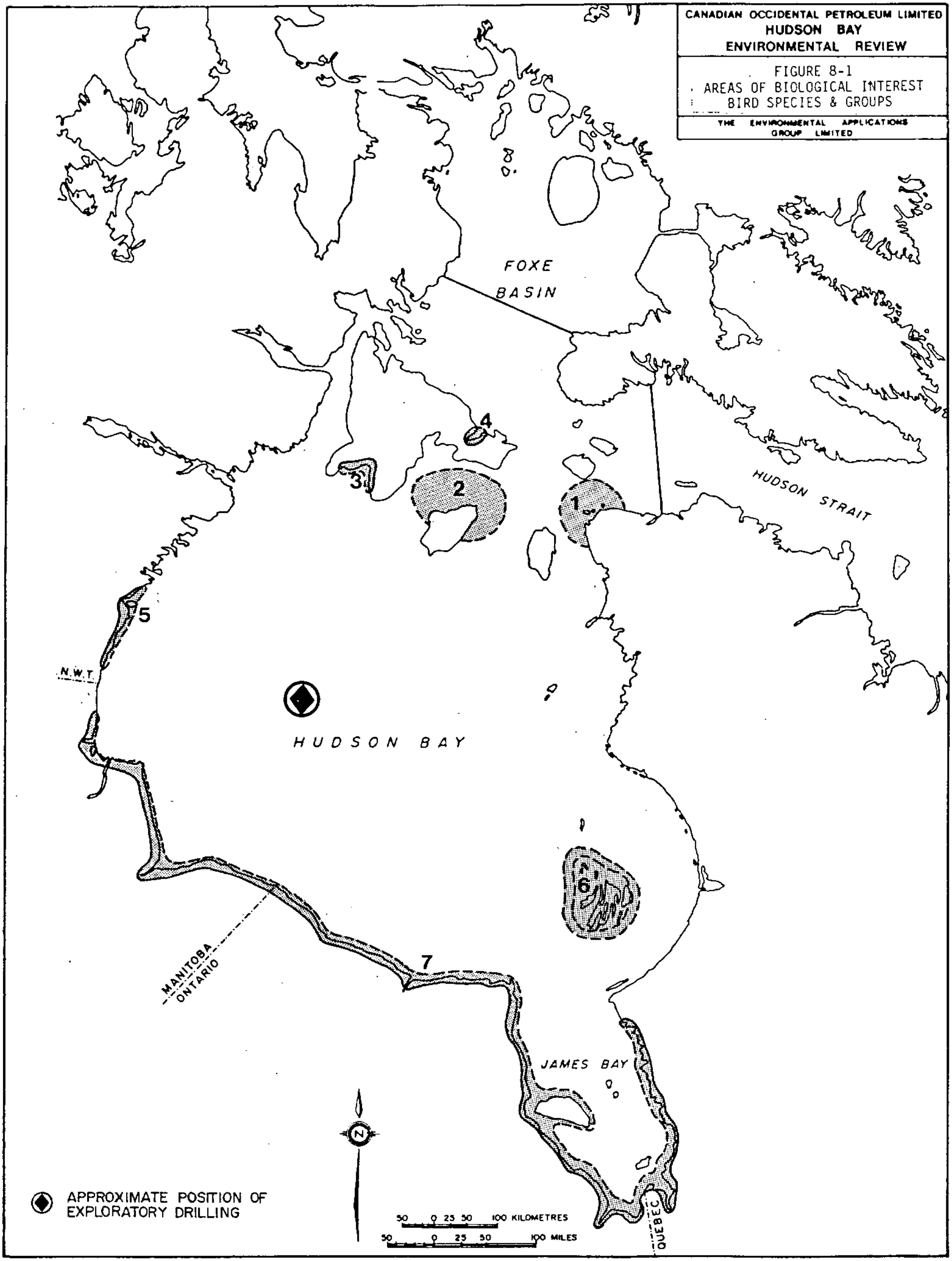
8. SENSITIVE AREAS AND CONTINGENCY PLANNING

Areas of biological interest, or sensitivity, described herein relate primarily to bird distributions with some consideration given to fish species. Areas important to marine mammals are also included for completeness. For clarity, separate areas are shown for birds and mammals. There is, nevertheless, considerable overlap in areas important to the two groups.

Marine Birds

With respect to sensitivity to oil contamination, marine birds, waterfowl and shorebirds are collectively viewed here as being the most sensitive biological element in the Hudson Bay region. Certain of the marine mammals constitute the only other group of comparable sensitivity. This sensitivity relates largely to the extensive use of inshore and coastal waters, and to the use of tidal marshes, mud flats and beaches. The nature of feathered insulation and the structure of flight features is such that once birds become oiled, their chances of survival, especially in cold climates, are extremely low. Feeding areas for the majority of species, particularly the tidal marshes and mud flats, are also sensitive to oil contamination. Under certain circumstances some such areas could take up to 10 years to recover their productivity following heavy oil contamination.

Seven areas of noted biological importance to marine birds and related species are described and shown in Figure 8-1. All of these locations define areas of high concentrations of either several species, or large aggregations of individuals of one or a few species. Lesser Snow Goose colonies of the Boas River delta and the McConnell River area, and Thick-billed Murre colonies of the Cape Wolstenholme-Digges Island area are the best examples of the latter type. Areas 1 through 6 are specific in nature and are comparatively well defined. Area 7 differs from these in that it is considerably more extensive and has importance to a greater number of individual birds and species. Also, although considered as a single unit, there are sections of Area 7 that are more important than others.


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 8-1
AREAS OF BIOLOGICAL INTEREST
BIRD SPECIES & GROUPS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
1
2
3
4
5
6
7
N
APPROXIMATE POSITION OF EXPLORATORY DRILLING
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

Area 1 - Thick-billed Murre Colony at Cape Wolstenholme-Digges Island

- sustains the largest breeding colony of this species in Canada with approximately 1,000,000 breeding pairs (i.e. approximately 40% of the Canadian population)
- the murre is a diving species which also rests on the water and is therefore among the species of birds most likely to be physically contacted by oil slick
- the Iceland Gull which also breeds in colonies and has a restricted Canadian Breeding distribution occurs in this area
- this site has been recognized as an International Biological Programme Site with recommendations for protection (Nettleship and Smith 1975)

Area 2 - Thick-billed Murre Colony on Coats Island; Black Guillemot Breeding and Wintering Area on Walrus Island

- the northern tip of Coats Island supports a breeding colony of 15,000 pairs of Thick-billed Murres, one of two such colonies in the study region
- Walrus Island is a known concentration area for the Black Guillemot, another seabird very sensitive to oil spills, and one of the only two avian species that overwinters in the region
- Glaucous Gulls, Herring Gulls, and the rare and endangered Peregrin Falcon also breed on cliffs of Coats Island
- walrus and polar bear are abundant at both Coats Island and in the case of Walrus Island some 3,000 walrus use this area
- the north end of Coats Island has been recognized as an International Biological Programme Site with recommendations for protection (Nettleship and Smith 1975).

Area 3 - Lesser Snow Goose Colony of the Boas River Delta Area

- an estimated 70,000 pairs of Lesser Snow Geese breed in this area along with Altantic Brant
- although much of the breeding ground is immediately removed from the potential influence of oil spills, significant portions of the area could become impaired if oil slicks were to be accompanied by storms
- this site is one of the major Snow Goose colonies in the arctic and has international biological importance, it is recognized as an International Biological Programme Site, and the main breeding ground is contained within the Federal Henry Gibbons Migratory Bird Sanctuary

Area 4 - Lesser Snow Goose Colony at East Bay

- an estimated 10,000 pairs of Lesser Snow Geese breed in coastal marsh zones surrounding the Bay
- sensitivity to oil spills from Hudson Bay is minor because of geographical location

Area 5 - Lesser Snow Goose Colony of the McConnell River Area

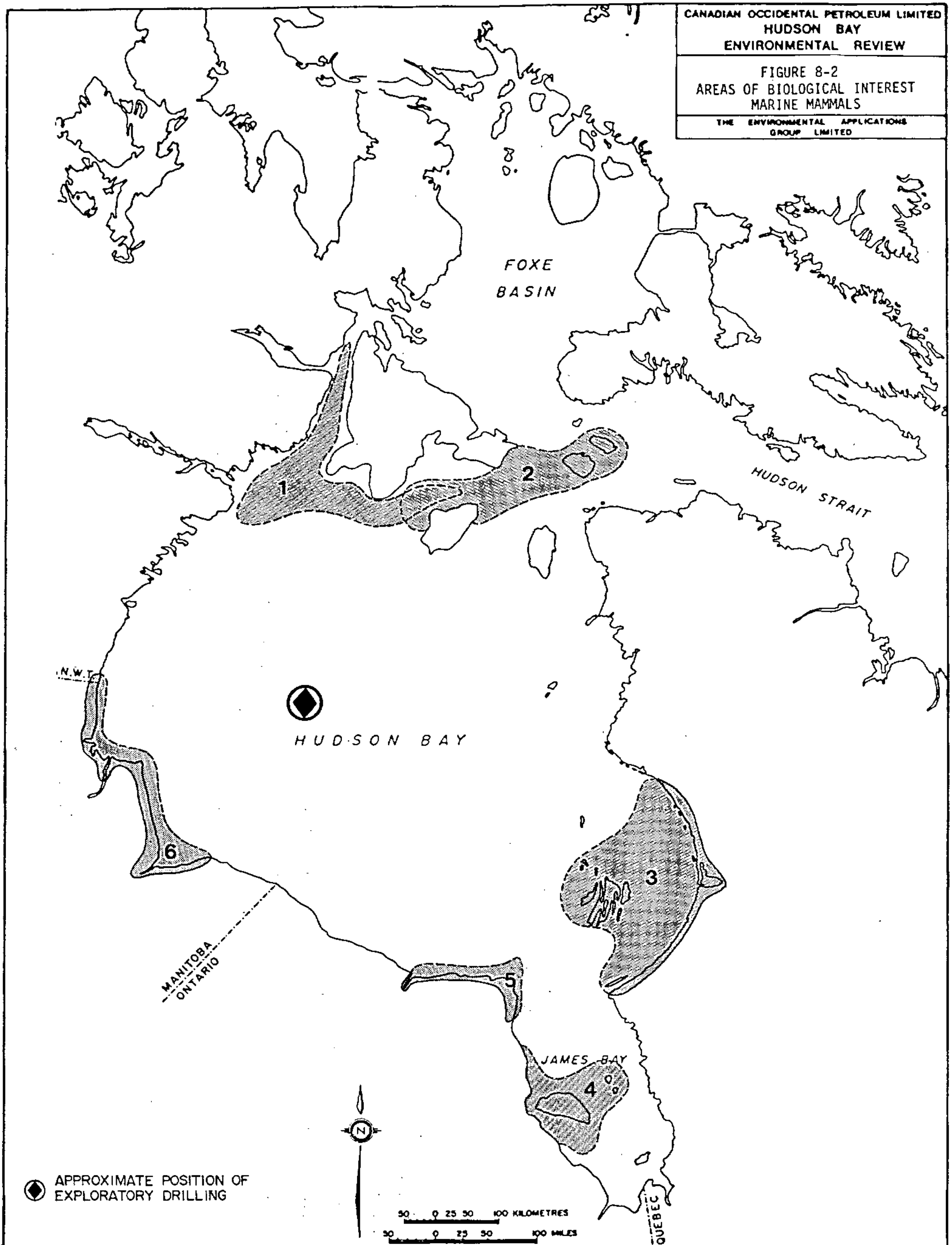
- three separate colonies in this area totalling ~130,000 breeding pairs with all colonies being associated with river deltas
- general sensitivity is similar to that of Area 3, above
- this site is also one of the major Snow Goose colonies in the arctic and has international biological importance, it is recognized as an International Biological Programme Site; and the main breeding ground is contained within the Federal McConnell River Migratory Bird Sanctuary

Area 6 - The Belcher Islands Common Eider Wintering Area

- approximately 35,000 Common Eiders, virtually the whole of the Hudson Bay population of this species, overwinter in open leads off the Belcher Islands
- Black Guillemots are also likely to concentrate in this area during winter
- waters off the Belcher Islands are also of critical importance to several species of marine mammals including numbers of polar bear, walrus and seals
- this site has been recognized as an International Biological Programme Site with recommendations for protection (Nettleship and Smith 1975)

Area 7 - Coastal Marshes and Tidal Flats of the Hudson Bay Lowlands and James Bay

- coastal marshes and tidal mud flats of from 1-10 km in width extend more or less continuously for over 2,000 km between Rupert Bay in Quebec to Cape Churchill
- several smaller bays, estuaries and mud flat zones occur along the remainder of the Quebec coast of James Bay
- the major importance of this region is as a moulting, staging and migration area for millions of geese, ducks and shorebirds
- south and west coasts of James Bay, including Akimiski Island are utilized most heavily, but all areas are of importance
- specific areas of note within Area 7 include the following:
    - the Lesser Snow Goose colonies of Cape Henrietta Maria and Cape Churchill (55,000 and 5,000 breeding pairs)
    - staging areas for Lesser Snow Goose along the west and south coasts of James Bay
    - staging areas for Canada Geese along the whole of the James Bay coast
    - staging areas for Atlantic Brant in the vicinity of Akimiski Island, and the south and northeast coasts of James Bay
    - shorebird staging and breeding areas associated with Akimiski Island and adjacent coastal areas of James Bay, with particular reference to the Hudsonian and Marbled Godwits
    - the Nelson River estuary


CANADIAN OCCIDENTAL PETROLEUM LIMITED
HUDSON BAY
ENVIRONMENTAL REVIEW
FIGURE 8-2
AREAS OF BIOLOGICAL INTEREST
MARINE MAMMALS
THE ENVIRONMENTAL APPLICATIONS GROUP LIMITED
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
JAMES BAY
N.W.T.
MANITOBA
ONTARIO
QUEBEC
1
2
3
4
5
6
APPROXIMATE POSITION OF EXPLORATORY DRILLING
50 0 25 50 100 KILOMETRES
50 0 25 50 100 MILES

Marine Mammals

A literature review of marine mammals of the Hudson Bay-James Bay region was undertaken for Canadian Occidental Petroleum Limited by LGL (1983). Also included in this work are results of Canadian Occidental's Wildlife Observer Programme for 1982. The programme entailed a recording of direct sightings by local Inuit observers on board of the Western Wind, a 200 ft. seismic exploration ship utilized by Canadian Occidental Petroleum Limited. A similar programme run in 1983 will provide additional information.

Based on data provided by LGL, and a further review of the literature, 6 areas are identified as being of noted biological importance to marine mammals. These are described below and are shown in Figure 8-2.

Area 1 - Roes Welcome Sound and Fisher Strait

- one of the major open water areas of the Canadian Arctic during the winter months (Smith and Rigby 1981) which is used extensively by beluga whales, walrus and a number of seal species
- thought to be the major wintering area of the 10,000 or so population of beluga whales that congregate in summers in the Nelson-Churchill-Seal Rivers area of the west coast of Hudson Bay
- also likely to be the major wintering area of walrus herds based in the Walrus-Coats-Nottingham Islands area
- also apparently serves as the only location in Hudson Bay where narwhals and bowhead whales are regularly encountered

Area 2 - Walrus-Coats-Nottingham Islands Area

- one of a handful of major walrus concentration areas in the Canadian Arctic, with estimates of abundance ranging between 2,000-3,000 individuals (Reeves 1978)
- by far the most significant walrus concentration area in the Hudson-James Bay region
- year round habitat is provided by this area, with winter use extending to Roes Welcome Sound

Area 3 - Belcher Islands-Richmond Gulf Area

- this area is important because of the complexity and variety of ice conditions which prevail throughout the winter months; extensive areas of land fast ice, open leads and pack ice are all present

- walrus, harp, ringed and bearded seals occur in reasonable abundance; the area is also used extensively by polar bears and provides limited wintering habitat for beluga whales
- the Belcher Islands have been recognized as an International Biological Programme Site with recommendations for protection (Nettleship and Smith 1975)

Area 4 - Akimiski and the Twin Islands

- ice conditions are similar to those described for the Belcher Islands area
- most noted as a high concentration area for polar bears, includes several known denning sites
- Twin Islands are recognized as an International Biological Programme Site and have been designated as the N.W.T. Twin Islands Game Sanctuary (Nettleship and Smith 1975)

Area 5 - Cape Henrietta Maria Polar Bear Denning Area

- one of the more important polar bear denning areas in the Hudson Bay area, also contains a small walrus hauling out area associated with Manchuinagush Island and Neskamagige Cape
- contained within Ontario's Polar Bear Provincial Park

Area 6 - Nelson River-Cape Churchill Area

- beluga whales concentrate in summer in estuarine areas of the Nelson (7,000 individuals), Seal (1,000 individuals), and the Churchill Rivers (500 individuals)
- also a major polar bear denning area
- this area has no formal or proposed protection status

Other minor areas have been identified by the Federal Department of the Environment and the Department of Fisheries and Oceans (1980). These include the Hopewell Islands and the Ottawa Islands. Both areas have some importance to marine mammals, but to a lesser extent than the areas listed above.

Fisheries

With respect to fish and other marine resources, the present state of knowledge permits some generalizations. Estuaries, river mouths and adjacent coastal areas are the major sites of marine productivity in Hudson and James Bays. Nutrients from the rivers mix with marine waters in a zone of more varied habitat, resulting in a relative abundance of prey organisms.

Anadromous salmonids, including Arctic char and whitefishes are present in the nearshore areas during summer. In the case of char, the most prized species, fish will range fairly widely along the coast, perhaps reducing the chance that localized disturbances will have a major effect on any individual population (McCart 1980). However, since these char remain very close to shore when at sea, a widespread disturbance, such as an oil spill, affecting nearshore habitats along long stretches of the coast, could adversely affect Arctic char populations on an extensive scale.

A similar situation exists for other estuarine fish which appear to have a major dependance on the marine area for their food supply. An example is the cisco (Hunter et al. 1976) which feeds on capelin and sand lances. These estuarine and freshwater species do not likely range much beyond the mixing zone of the estuary outflow. In contrast, many of the Hudson Bay marine fish species appear to use estuaries primarily as a nursery ground, usually spawning and spending much of their adult life at sea, but often returning seasonally to the estuary (Morin et al. 1980).

Only one significant, well defined fisheries area has been identified in the region comprising rivers in the vicinity of Chesterfield Inlet, Rankin Inlet, Whale Cove and Eskimo Point. This area is important as a commercial fishery for Arctic char.

Other than estuaries and associated coastal environments, the only area of potential interest would be an apparent zone of higher marine productivity west of the Belcher Island (Anderson and Roff 1970a) which may attract higher than average concentrations of fish. This has not been documented, but in any case the Belcher Islands are populated by Inuit and Arctic char are fished at 34 named fishing sites, with the majority of cases being anadromous stocks that are exploited (Freeman 1982). Therefore the Belcher Island area should be considered sensitive with respect to fish populations.

Endangered Species

None of the species listed or discussed in the preceding sections have been identified as rare or endangered species on official Canadian or provincial lists. The Eskimo Curlew is an endangered species, Federally and provincially, but the species has no importance in the Hudson Bay-James Bay area. A minor migration route of this species once followed the west coasts of Hudson and James Bay. However, the only recent sighting in the area was of two individuals on the west coast of James Bay in 1976 (Gollop and Shier 1978). Breeding of the Eskimo Curlew is thought to take place in the western arctic, and the main migration route follows the Atlantic coastline. The present world population is estimated at about 20 individuals.

Many authorities would consider the Hudsonian Godwit and the James Bay population of the Marbled Godwit to be at the very least, extremely sensitive, because of greatly restricted breeding ranges. A strong case could also be made concerning the sensitivity of walrus (Reeves 1978), and the polar bear (Stirling et al.1980).

Comparative Risk

It is important to stress that the areas of biological interest described relate to the inherent importance of these areas to the organisms themselves. The choice of these areas does not take into consideration the probability of their contamination by oil spills. Indicated drilling locations are all in the central portion of Hudson Bay, and are well removed from all areas of biological interest (Figure 1-1). The closest distance to shore is around 250 km to Cape Churchill. The Churchill-Eskimo Point-Whale Cove area is approximately 300 km from the exploration area. Proximity of the exploration area to the eastern shore varies from 541 km to Inoucdjuac, to 580 km to the Belcher Islands, and 700 km to Cape Jones at the entrance to James Bay.

Should an oil spill occur, contingency plans are designed to quickly contain the spill in the immediate vicinity of the rig. In the remote event of a major and prolonged oil spill, available wind and current data suggest that on average the spill would move towards the southeast. Prevailing winds during the open-water season are from the northwesterly sector with a most frequent speed of 5-10 m/sec. Extreme geostrophic wind speeds may average over 25 m/sec for periods over 4 days (see Section 2). Drifter buoy measurements indicate daily passages of up to 20 km per day during storm passages (see Section 3). As a first order estimate, based on available data and oil spill trajectory analysis off the Hibernia oil field (EAG, 1983), the spill could travel from 10 to 50 km per day. Thus for the minimum 250 kilometre distance, it appears that the shortest time for an oil spill to reach shore would be in the vicinity of 5 days and on average probably longer than 10 to 15 days. Over this period of time, the spill is likely to be highly degraded and emulsified with over 90 percent of the volatiles evaporated.

Oil Spill Contingency Planning

The Atmospheric Environment Service developed an oil spill trajectory model for real time usage (Sahota and VenKatesh 1978). Real time models are intended for application at the time of the actual spill event and require as input into the model the most up-to-date information on winds, currents, and sea state. These same parameters have to be provided as forecasted quantities to predict the spill behavior over the following period of hours or days.

Scenario type oil spill models are required for the contingency plan to assess the potential spill behaviour prior to any actual accident occurring. In order to predict responses to mean and extreme situations, scenario models require, as input, data representative of the events to be synthesized. Meteorological and oceanographic data would be supplied on a time-series basis and the accuracy of predictions by a given model would depend on the representativeness of data chosen for testing.

There are two fundamental types of scenario models. There is the deterministic model which utilizes measured data to produce model results which would be identical whenever the model is run with the same input fields. Interpretation of the results would result from analysis of a number of model runs on a time-averaged basis. Statistical scenario models on the other hand utilize synthetic data as generated by a statistical process from basic parameters to provide the input fields to the model. Each model run would have a different predicted output. The model would then have to be run repeatedly for a significant analysis of the results on a statistical basis.

The AES real time model was developed in a deterministic mode and later converted to scenario use by Hydrospace Marine Services (1981) with specific applications in the Hibernia - Ben Nevis oil fields. In their study, constant geostrophic winds as derived from gridded pressure data were used as input data. The Environmental Applications Group (1983) subsequently modified the model to include spatially varying wind input data.

Analysis of the available data (Section 2 and 3) indicates sufficient data exist for Hudson Bay to run an oil spill trajectory model for contingency planning.

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