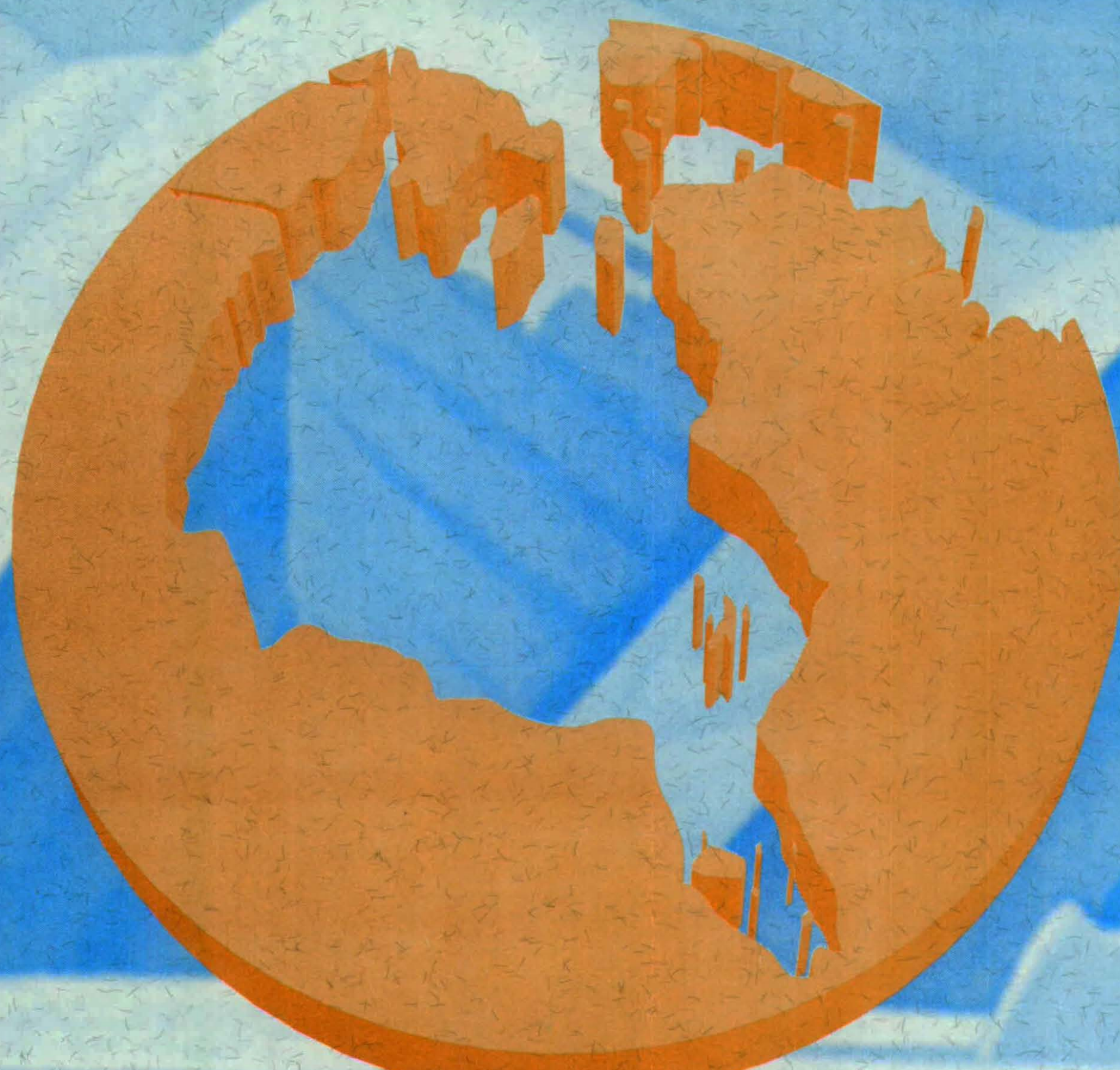
Canadian Arctic Resources Committee (CARC)

Environmental Committee of Sanikiluaq

Rawson Academy of Aquatic Science (RAAS)



HUDSON BAY PROGRAMME SUR LA BAIE D'HUDSON

THE ESTUARIES OF HUDSON BAY: A CASE STUDY OF THE PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF SELECTED SITES

F. Schneider-Vieira
R. Baker
M. Lawrence

North/South Consultants Inc.
202-1475 Chevrier Blvd.
Winnipeg, MB
R3T 1Y7

The Hudson Bay Programme

1994

Canadian Cataloguing in Publication Data

Schneider-Vieira, F. (Friederike)
The estuaries of Hudson Bay: a case study of the physical and biological characteristics of selected sites

Includes bibliographical references.
ISBN 0-919996-54-X

1. Estuarine ecology. 2. Hydroelectric power plants--Environmental aspects--Hudson Bay. I. Baker, R. F. (Randle Ferris). II. Lawrence, M. J. (Michael John), 1945 - . III. Hudson Bay Programme. IV. Title.

GB1230.H83S34 1994 574.5'26365'0916327 C94-900251-8

The Hudson Bay Programme 1994
Cover design, Graphix Design
Printed by the Canadian Arctic Resources Committee

This report was commissioned by the Hudson Bay Programme, however the views expressed herein are those of the author and do not necessarily represent those of the partners in the Hudson Bay Programme.

The Hudson Bay Programme acknowledges the financial support of: The Richard and Jean Ivey Fund, The Harold Crabtree Foundation, Walter and Duncan Gordon Charitable Foundation, The McLean Foundation, George Cedric Metcalf Charitable Foundation, Helen McCrea Peacock Foundation, Murphy Foundation Incorporated, John D. and Catherine T. MacArthur Foundation, The Molson Family Foundation, The EJLB Foundation, Government of the Northwest Territories, Indian and Northern Affairs Canada, Environment Canada, Environmental Innovation Program, Manitoba Hydro, Grand Council of the Crees (of Quebec), Mushkegowuk Tribal Council, Ontario Hydro, Hydro-Québec.

ABSTRACT

Hudson Bay, which drains 47% of the Canadian land mass, is ringed by estuaries, which form wherever the numerous large and small rivers empty into the bay. General estuarine processes are illustrated by descriptions of five sites encompassing the range of estuarine environments: 1) the Nelson estuary, a well-mixed estuary of the southwestern lowlands; 2) the stratified Churchill estuary, also in the southwestern lowlands; 3) the La Grande estuary, a stratified estuary of eastern James Bay; 4) the partially mixed Eastmain estuary, also of eastern James Bay; and 5) Chesterfield Inlet, a partially mixed estuary within the northwestern tundra. The first four estuaries have been affected by hydroelectric development involving either an increase (Nelson and La Grande) or a decrease (Churchill and Eastmain) in flow.

The estuaries and adjacent waters of Hudson Bay generally are nutrient poor and primary production based on phytoplankton appears to be relatively low. Organic debris appears to be an important basis for the estuarine food web. Densities of benthic animals generally increase from fresh to brackish waters. The location of peak benthic densities is variable and appears dependent on local conditions (e.g., variations in substrate, water flow).

Estuaries are important to many species of fish which move from the rivers into these areas to feed. Anadromous lake cisco and lake whitefish are often the most abundant freshwater species in the estuaries. Marine species, such as capelin and sand lance, also frequent the estuaries but less is known about their distribution. Beluga whales occur in several of the estuaries during the summer; largest numbers occur in the Nelson estuary.

The extensive studies conducted before and after hydroelectric development in the La Grande and Eastmain estuaries have not detected a change in the populations of anadromous lake cisco and lake whitefish, suggesting that neither flow decrease nor augmentation has affected these fish. By inference, the physical changes caused by hydroelectric development did not alter the food webs upon which these fish depend to the extent that the fish populations were affected. This conclusion is supported by studies of other portions of the food web in these areas.

1. Introduction

Estuaries form where the flow of the river meets the flood of the tide and mark the transition from a freshwater to a marine environment. Characteristically, an estuariy is defined as the area where river water mixes with and measurably dilutes sea water (Ketchum 1983). Local topography and the proportion of freshwater inflow to marine flow (from currents produced by tides and winds) determine whether mixing of fresh and marine waters occurs within the river or in the coastal water body. This report will consider brackish zones within the river as well as coastal areas with a noticeably dilute water column and/or plume as part of the estuary. The tidal portion of rivers, where the water is always fresh but the influence of tides is felt, will also be considered in the discussion of estuaries, because of the many interactions between these two areas.

Estuaries typically are more productive environments than adjacent marine waters because river inflow, terrestrial runoff, and upwelling of deep marine waters combine to transport nutrients to the estuary (McLusky 1981). Phytoplankton (microscopic algae) and other microorganisms proliferate in this nutrient rich environment, and form the basis of a food chain which culminates in fish, marine mammals and other predators. In many regions, estuaries provide essential habitat for commercial fishery species and have received extensive investigation, especially in the temperate areas of the United States (Haedrich 1983). The productive environment of estuaries can support a large number of organisms; however, the variability in the physical environment limits the numbers of species so estuaries frequently harbour high abundances of a few species (Haedrich 1983).

Freshwater inflow is the most important determinant of estuarine characteristics because of its effect on total salinity, ice formation, accumulation of nutrients and organic substances, and water circulation and residence time (Smayder 1983). Upstream developments, rather than human activity along estuaries themselves, are the major source of anthropogenic changes in the estuaries of the Hudson Bay basin (including Hudson Bay, James Bay, Foxe Basin and Hudson Strait). Pulp mills have been constructed along the upstream reaches of some of the rivers draining the Hudson Bay lowlands in Ontario. Many of the rivers draining southern areas have long been affected by hydroelectric development, but these early developments generally had less effect on flow than later developments. The largest of these early diversions involved several projects in the headwaters of the Albany, which together diverted 23% of its total drainage basin representing 15% of its flow (Canada 1985). Since the 1970's, major developments by Hydro-Québec on the La Grande/Eastmain systems and by Manitoba Hydro on the Churchill/Nelson systems have changed the physical and chemical nature of the estuaries of these rivers.

The following characterization of estuarine environments in the Hudson Bay basin begins with a description of the rivers entering the bay as creators of estuarine systems, followed by a general discussion of estuarine dynamics illustrated by detailed descriptions of five estuaries encompassing the scope of such environments in Hudson Bay. Comparison among these type cases will be used to describe general estuarine conditions and assess the effect of human activity on these environments.

2. The Rivers of Hudson Bay

Twenty-five large (mean annual flow greater than 283 $m^3 s^{-1}$) and numerous smaller rivers enter Hudson Bay and the surrounding area (Fig. 1, Table 1). The amount and seasonality of flow, as well as the water quality, are largely determined by the watershed, some characteristics of which are summarized in Table 1. Rivers entering northern portions of the study area tend to have lowest flows, and eastern, wetter areas, have a greater number of rivers with large flows. The Canadian Shield comprises the majority of the drainage basin in most areas, though rivers emptying into the southwestern portion of Hudson Bay traverse the Hudson Bay lowlands and some extend across the Interior Plains to the Western Cordillera.

Under natural flow regimes, rivers experience a pronounced runoff peak in spring, with reduced flows during summer and lowest flows in late winter (Fig. 2). Differences in annual flow patterns of rivers are related to the storage capacity of their drainage basins; rivers with a large storage capacity have less pronounced peak flows (compare Fig. 2, Seal River with a small storage capacity to Fig. 3, pre-1976 Nelson River, with a large storage capacity). Variability in interannual precipitation causes large differences in flow between years. With sufficient reservoir capacity, flow regulation for hydroelectric development reverses the natural seasonal pattern of flow, with flow highest during the winter (releasing stored water) and lowest during the summer, and little or no spring freshet. In 1976, flow of the Nelson River was regulated at Lake Winnipeg and augmented by waters from the Churchill River. The annual seasonal pattern of flow was reversed, with substantially higher flows occurring during the winter months (Fig. 3). Average flows during the summer months were only changed slightly by the 1976 development (Fig. 3). Despite flow augmentation and regulation, most maximum and minimum flows fall within the natural range. The Churchill River, on the other hand, experienced substantial flow reductions at all times of the year and now resembles a small coastal river, with a typical seasonal runoff pattern and large interannual variability (Fig. 4).

Similar changes followed flow regulation and augmentation of the La Grande River and diversion of the Eastmain River. Although annual flows fluctuate considerably, winter flows in the La Grande increased approximately six-fold over natural flows and the spring freshet was eliminated, but summer flows were not altered substantially (Fig. 5, Messier 1985). Flow of the Eastmain was reduced 90% by diversion in 1980, and it now resembles a small coastal river (Fig. 6).

Comparison of selected water quality parameters for the Nelson, Eastmain and La Grande rivers indicates that the first two rivers contain similar amounts of nitrogen, phosphorus, and organic carbon, and both contain slightly more of these nutrients than the La Grande (Table 2). The waters of the Nelson contain more dissolved solids (primarily carbonates), which is reflected in the much higher conductivity. Concentrations of dissolved and suspended substances in the La Grande and Eas*p1996Xstatus of

lakes with nitrogen and phosphorus concentrations within specified ranges; nitrogen concentrations in the Nelson, La Grande and Eastmain rivers are classified as oligotrophic while phosphorus concentrations are meso-eutrophic. Comparison of nutrient levels in these rivers to those of other areas is hindered by variations in techniques and large inter- and intra-annual variation in nutrient concentrations. Nutrient concentrations in the Nelson River are within the same range as those in the lakes and channels of the Mackenzie Delta (organic carbon 7 to 13 g m^{-3}; nitrogen 0.33 to 0.58 g m^{-3}; phosphorus 0.03 to 0.16 g m^{-3}, Anema et al. 1990). Rivers connecting the Great Lakes contain similar amounts of nitrogen (0.4 to 0.5 g m^{-3}) and less phosphorus (0.004 to 0.013 mg m^{-3}) (Edwards et al. 1989). However, nutrient concentrations in large rivers such as the Fraser are markedly higher (Northcote and Larkin 1989).

3. The Estuaries of Hudson Bay

Estuaries can be categorized by the manner in which fresh and salt waters mix (McLusky 1981). At the mouths of rivers, freshwater, being less dense than salt water, tends to flow out over the sea surface. If the freshwater input is large and there is relatively little mixing due to tides or winds, a fresh or brackish plume extends well out over the sea. The water column is described as stratified because there are two distinct layers: freshwater flows seaward at the surface and marine water, upwelling from deep within the ocean, flows landward at the bottom in proportion to the amount of freshwater outflow. Maximum mixing of these two layers occurs in frontal regions (i.e., where the thickness of the freshwater layer abruptly changes). As the amount of mixing due to tides and winds increases, the two-layered stratified structure becomes increasingly less well-developed until, in the extreme case, no stratification is evident. In an homogeneous estuary, there is a continuous gradation from fresh to marine waters with no vertical stratification. Extreme stratification with virtually no mixing between fresh and marine waters results from certain land-forms, such as narrow, deep fjords, where wind and tide-induced mixing is very limited.

Two productive mechanisms (food chains) exist in estuaries: one is based upon photosynthetic organisms such as phytoplankton (microscopic algae) and the other is based upon detritus (dead organic material) which is colonized by bacteria and other microorganisms. The sources of material for these two food chains may be either autochthonous (i.e., produced within the estuary itself) or allochthonous (i.e., derived from sources outside of the estuary in either the river or adjacent coastal waters). In general, autochthonous sources are primary production in the estuary and allochthonous sources are detritus from the river, but some estuaries support extensive beds of macrophytes which produce large amounts of detritus within the estuary. Studies in the Mackenzie River/Beaufort Sea estuary demonstrated that both food chains based on these two groups are significant, but their relative importance varies between years depending on water temperature and meteorological conditions (Parsons et al. 1989).

The effect of freshwater input on phytoplankton growth can be both positive and negative. Freshwater inflow brings nutrients (the most important being nitrogen, usually as nitrate, nitrite, urea, and ammonia, and phosphorus, usually as phosphate) to an estuary and increases upwelling and thus nutrient regeneration from deep waters. However, high freshwater inflow into stratified areas can increase vertical stratification to the extent that no mixing occurs between surface and deeper waters; conversely, in well-mixed areas, large inflows increase mixing to the extent that phytoplankton growth is impaired because they do not remain in well-lit surface waters. Rapid phytoplankton growth requires conditions under which periodic mixing provides nutrients to surface waters, but stratification is sufficient to maintain cells in well-lit surface layers.

Organic detritus (i.e., particles of dead plants and animals) originates from river and terrestrial runoff and plant growth within the estuaries. Detritus is colonized by microorganisms, and the resulting aggregates provide nourishment for larger animals. Dissolved organic carbon, released by senescent and dead organisms, can also provide nourishment for microorganisms. The quality of organic carbon-containing compounds as a food source increases with the nitrogen content. Live organisms have a carbon:nitrogen ratio in the vicinity of 9:1 and, after death, nitrogenous compounds are preferentially used by bacteria, and the carbon: nitrogen ratio rises as increasingly refractory material remains.

Invertebrates are the primary consumers of both phytoplankton and organic particles containing detritus and associated microorganisms. Thus, they form the next trophic level (i.e., step in the food chain) and in turn are an important food item for many fish species. Most invertebrates are either zooplankton (small animals with limited locomotory capability that live in the water column) or benthos (animals that live in or on the sediments). The distribution of an invertebrate species within an estuary is strongly influenced by the range of salinity that it can tolerate; because salinity in estuaries is subject to large fluctuations, many species are euryhaline, meaning that they can tolerate a wide salinity range.

The distribution of both living and non-living particles is strongly influenced by circulation, and in many estuaries this is considered the primary determinant of phytoplankton distribution (Roff et al. 1980). In many estuaries, concentrations of particles are elevated in the middle region because of the interaction of net surface seaward flow and bottom landward flow (Officer 1983). In stratified estuaries, particles also accumulate in frontal regions where maximum mixing occurs between brackish surface waters and deep marine waters.

The high production and concentration of food items within estuaries often support large numbers of organisms of higher trophic levels (i.e., higher in the food web). Estuaries are used as feeding areas by both typical freshwater and marine fish species, and as spawning and nursery areas by many marine species (Haedrich 1983). Consideration of higher trophic levels in this report will be limited to fish and marine mammals; estuaries often provide critical habitat for other species, particularly waterfowl (Stewart et al. 1991, Stewart et al. 1993), but consideration of these groups is beyond the scope of this report.

General estuarine processes in Hudson Bay are illustrated by descriptions of five estuarine regions encompassing the range of estuarine types in the area. The five estuaries are as follows: 1) the Nelson estuary is a well-mixed estuary of the southwestern lowlands; 2) the Churchill estuary, also in the southwestern lowlands, is stratified; 3) the La Grande estuary, a stratified estuary of eastern James Bay; 4) the Eastmain, also of eastern James Bay, grades from a partially mixed estuary to a stratified plume; and 5) Chesterfield Inlet, within the northwestern tundra, changes from a partially mixed to a stratified estuary. The first four estuaries have been affected by hydroelectric development; consequently a relatively large amount of information exists for these areas. Conditions before and after development will be discussed where appropriate. These type examples will serve as the basis for a description of the estuaries of Hudson Bay as a whole, including the use of the entire estuarine region by marine mammals, primarily whales.

3.1 Nelson Estuary

3.1.1 The Physical Environment

The Nelson estuary is formed in the broad funnel-shaped mouth of the Nelson River where it enters southwest Hudson Bay (Fig. 7). Port Nelson, where the Nelson River abruptly widens, marks the upstream limit of saline intrusion, but tides affect river depth an additional 23 km upstream. A narrow, deep, central channel runs from Port Nelson well out into the estuary. On either side of this channel are extensive flats of sand and clay, which are exposed at low tide (Baker 1990).

Tides of up to 4.8 m, shallow depth, and strong winds combine to create strong onshore and offshore currents that vertically mix the water column to create an homogenous estuary, with little vertical stratification except in the deep central channel (Baker 1989, Baker et al. 1993). At high tide, salinity increases uniformly from 0‰ at Port Nelson to 25‰ 25 km offshore (Fig.

8). At low tide, brackish inshore waters extend seaward, considerably reducing salinity compared to the high tide condition. The mean annual discharge of the Nelson River from 1977 to 1990 was approximately 2965 m^3 s^{-1}. However, this large freshwater input constitutes only three to four percent of the total water volume moving on- and offshore in a single tide. Flow regulation at Lake Winnipeg and flow augmentation by diversion of the Churchill River in 1976 increased mean annual flows by approximately 26%, with increased flows occurring during the winter months.

3.1.2 Nutrients and Primary Producers

Concentrations of the nutrients nitrogen and phosphorus are relatively low in the estuary (Table 3). This is expected since both the Nelson River and the marine waters of Hudson Bay contain few nutrients. Concentrations of dissolved phosphorus are approximately three times higher in marine than in freshwaters, suggesting a marine origin, and levels of nitrogen, though more variable, are also a half times higher in marine than in fresh waters (Table 3).

Amounts of suspended and dissolved organic carbon in the estuary are comparable to levels reported as typical of estuaries by McLusky (1981) and comparatively high for northern waters (e.g., in the Bering Sea dissolved organic carbon ranged from 1.0 to 1.85 g m^{-3}, Hood 1983; suspended organic carbon in Hudson Bay was 0.07 g m^{-3} in inshore waters and 60-70% less in offshore waters, Anderson and Roff 1980a). The decrease in dissolved organic carbon concentrations offshore in the Nelson estuary suggest that it originates from river inflow (Table 3). The high carbon:nitrogen ratio (up to 36) suggests that this may be humic material originating from bogs. The amount of suspended carbon peaks in the middle zone of the estuary (Table 3). Highest concentrations of suspended organic carbon are recorded at high tide, when strong tidal currents resuspend detrital material from the sediments.

Phytoplankton biomass is highest in the nearshore and lowest the furthest offshore. Biomass in the nearshore region is comparable to that observed in two up-river forebays of generating stations (Schneider and Baker 1993), but only sixty percent of that recorded in Stephens Lake along the same river system (Livingston 1989, Janusz 1990). Most phytoplankton collected in the nearshore regions of the estuary are freshwater species, indicating that phytoplankters originating in the river either accumulate or continue to grow in the estuary.

Relatively little comparative information from other areas of Hudson Bay is available for phytoplankton biomass, but the concentration of the photosynthetic pigment chlorophyll *a* provides a rough estimate of phytoplankton biomass. In the Nelson estuary, values range from 0.40 to 5.10 mg m^{-3} during the ice-free season. This is considerably more than averages reported from surface waters of marine Hudson Bay during the ice-free season (0.28 mg m^{-3} in shallow coastal waters and 0.09 mg m^{-3} in central areas, Anderson and Roff 1980a) but less than peak values for a deep chlorophyll maximum (0.3-10.75 mg m^{-3}, Anderson and Roff 1980b).

3.1.3 Higher Trophic Levels - Invertebrates and Fish

The abundance of zooplankton in the estuary is greater than in the marine waters of Hudson Bay (Baker et al. 1993). Copepods dominate the zooplankton fauna, accounting for 98% of individuals. The most abundant species, *Acartia clausi* and *Eurtyemora herdmani*, are characteristic of coastal waters of the temperate North Atlantic and differ from the arctic marine species seen in the central regions of the bay (Roff and Legendre 1986). Copepod numbers are lowest in the inshore region (12 m^{-3}), peak in the middle region of the estuary (5000 m^{-3}), and decline in the offshore, marine region (1600 m^{-3}) (Baker et al. 1993). Several other groups, such as larval barnacles and mysids (*Mysis litoralis*), are also common, although patchy in distribution (Baker et al. 1993).

The benthos in the Nelson estuary is dominated by burrowing organisms, such as polychaete and oligochaete worms, and insect larvae, primarily chironomids (Table 4). The species composition shifts from one dominated by chironomids and oligochaetes in the freshwater areas to polychaete worms in marine areas. In fall, densities of benthos in the brackish areas of the estuary are approximately sixteen times those of riverine regions, due to extremely large numbers of polychaetes. The distribution of the benthos is extremely patchy, and densities vary between 0 and 383,000 individuals m^{-2}.

A total of 40 fish species representing 16 families have been identified from the lower Nelson River and estuary (Table 5). Many typical freshwater species use the nearshore waters of the Nelson estuary to varying degrees, but primarily for benthic and pelagic feeding during the summer. In the lower Nelson River, the longnose sucker is the dominant species, though nearshore waters provide a nursery area for juvenile lake whitefish as well as juvenile longnose suckers (Baker 1990). Longnose suckers consume benthic material, including both living organisms and detritus. The diet of lake whitefish in the nearshore regions is predominantly freshwater insect larvae, bivalves, gastropods, and forage fish (Baker 1989).

Salinity increases with distance from the river mouth, but a band of brackish water extends all along the Hudson Bay coast, potentially providing fish tolerant of higher salinity with a large feeding area. Movements between estuaries have also been documented. For example, a lake cisco tagged during an upstream spawning migration in a tributary stream of the lower Nelson River was recovered 11 months later at the mouth of the Churchill estuary (Lawrence and Baker 1994). This fish migrated at least 400 km, including 290 km in the brackish waters between the Churchill and Nelson estuaries. Anecdotal reports indicate the capture of three additional tagged lake cisco during the same period; further research is required to determine if this large-scale movement is a common phenomenon. Although large-scale migrations of lake cisco have not been documented in northern Canadian waters, the closely related arctic cisco, *Coregonus autumnalis*, is known to move at least 500 km along the coast of the Beaufort Sea (Moulton 1989 and references therein).

The Nelson River, unlike the La Grande, does not appear to have a large anadromous fish population and does not support a large fishery in its coastal region. Numbers of lake cisco and lake whitefish are relatively low, while brook trout are captured incidentally. Lake cisco appear to forage in the estuary or coastal waters of Hudson Bay during the summer months, entering the Nelson River in large numbers only in fall during migrations to some larger tributary streams to spawn (MacDonell et al. 1992). Overwintering appears to occur near the mouth of the Nelson River or within the estuary itself (MacDonell et al. 1992). Adult lake whitefish use the estuary to a small degree for foraging; most of their activities (foraging, spawning and overwintering) are conducted in tributaries and specific sites in the Nelson itself (Baker 1990, MacDonell and Bernhardt 1992).

In offshore regions of the estuary, sand lance is very abundant (Baker et al. 1993). Larval sand lance and capelin have been captured throughout the estuary, suggesting that these species may spawn nearby. Fourhorned sculpin, ninespine stickleback, threespine stickleback, and two species of prickleback are present in low abundance.

3.2 Churchill Estuary

3.2.1 The Physical Environment

The Churchill estuary, on the southwestern coast of Hudson Bay, lies within an enclosed basin approximately 13 km long and up to 3 km wide, which forms the harbour of the Port of Churchill at the downstream end (Fig. 9). Most of the basin is shallow (low tide depth less than 3 m), except for the lower 2 km where depths reach 21 m in the narrow passage to Hudson Bay. Most of the basin is sandy or rocky. At high tide, no saline intrusion is evident in the upper 3 km, downstream of which bottom salinity rapidly increases to 25‰ by km 7 (Fig. 10). At high tide, this transitional zone is vertically stratified and at low tide an irregular plume of brackish surface waters extends at least 6 km beyond the mouth of the basin.

Diversion of the Churchill River in 1976 reduced annual flows to approximately 27% of their natural values, but no pre-diversion information is available to assess changes in the structure of the estuary.

3.2.2 Nutrients and Primary Producers

Concentrations of nitrogen and phosphorus in the surface waters of the Churchill estuary are comparable to those observed in the Nelson estuary (Table 6). Levels of total dissolved nitrogen are highest in the middle regions of the estuary. Concentrations of dissolved phosphorus in marine waters are approximately 2.5 times higher than in the river, suggesting a marine origin for this nutrient.

3.2.3 Higher Trophic Levels - Invertebrates and Fish

Large differences in the species composition of the benthic invertebrates occurs between upper and lower parts of the basin: oligochaetes and amphipods predominate in the upper regions of the estuary; polychaetes and bivalves are most abundant in the lower portion; and polychaetes, with occasional dense patches of oligochaetes, are the most numerous benthos in nearshore regions of Hudson Bay (Table 7). Densities of benthic organisms in the brackish area of the basin (km 0 to 7) and the marine waters of Hudson Bay are approximately equal, and only one-third those of the lower portion of the basin. The large number of organisms in the downstream portions of the estuary could be related to the large amounts of organic debris which have accumulated in depositional regions and the increased amounts of suspended organic material available to filter-feeding animals in this region of strong tidal currents.

Fish in the lower Churchill River have not been the subject of extensive study and little has been published. In a recent study of one tributary stream, longnose suckers were the most abundant species in spring and fall catches (Table 8, Remnant and Bernhardt 1994). In the brackish waters of the basin during summer, capelin are very abundant, cisco are present in significant numbers, and sand lance, fourhorned sculpin, and prickleback occur in low abundance (Table 8, Lawrence and Baker 1994).

3.3 La Grande Estuary

3.3.1 The Physical Environment

The La Grande estuary includes both a freshwater, riverine portion formed within the lowest 37 km of the La Grande River, and a large plume which extends well out into James Bay (Fig. 11). Hydroelectric development beginning in 1978 diverted the upper drainage basins of the Eastmain, Opinaca and Caniapiscau rivers to cause an increase in the annual flow of the La Grande River from 1,700 to 3,400 m^3 s^{-1} (Roy and Messier 1989). Winter flows in the La Grande were substantially increased and the spring freshet was eliminated, but summer flows did not change significantly from pre-development values.

The river banks are primarily clay, with a border of moraine along the north shore. Extending approximately 10 km upstream of the river mouth and further downstream into James Bay is a delta composed of many sand islands. Under both natural and augmented flow conditions, the river banks and delta of the La Grande are active. River banks are eroding, and though fine material is carried beyond the delta, sands are deposited in the delta to form banks in the vicinity of the river mouth, which then propagate in a westerly direction out into James Bay. The natural rate of bank erosion and sand bank formation and migration within the delta has increased following flow augmentation (SEBJ 1990). The clay river bed is not actively eroding and fine materials are carried out into James Bay; a significant amount of fine material appears to be deposited almost 10 km from the mouth of the river between Loon and Strommes islands (SEBJ 1990).

The combination of strong river flow and relatively weak tides (1.2 m) prevents saline intrusions beyond the river mouth. River flow at all times is sufficient to predominate at the river mouth; tidal influences are only felt as an acceleration or deceleration of river flow (SEBJ 1990). Under natural conditions, there was a typical salt wedge pattern over the sill at the river mouth; generally salinity was less than 2‰ in the first kilometre upstream of the sill and intrusions further upstream were only caused by storm surges (Messier et al. 1986). Under present operating conditions, a minimum flow requirement of 900 m^3 s^{-1} prevents any saline intrusion above the river mouth (D. Messier, Hydro Québec, pers. comm.).

River flow during all seasons is sufficient to produce a surface plume of reduced salinity over the more saline waters of James Bay. During summer, the plume is on average 1 to 2 m thick, increasing to 6 m in some areas, particularly in frontal regions (Messier 1985). Its limits generally coincide with the coastal shelf (up to 20 m in depth) but are strongly affected by wind and tidal action. Discharge alterations due to hydroelectric development have not markedly changed its size during the summer (Messier et al. 1986). Mixing between fresh and marine waters is generally limited to the frontal regions at the margin of the plume.

The size of the La Grande plume during the winter has increased from 750 km^2 under natural conditions to 2300 km^2 under discharges of more than 3000 m^3 s^{-1} (Fig. 12, Messier et al. 1986). Further increases in discharge (to 4000 m^3 s^{-1}) did not cause plume expansion beyond the land-fast ice zone because of vigorous wind and tide-induced mixing beyond the land-fast ice (Messier et al. 1989). Below this upper limit, the size of the plume is directly proportional to freshwater input and inversely proportional to the mixing produced by tides (Freeman et al. 1982).

Creation of upstream reservoirs caused an increase of 1°C in mean winter temperature and a decrease of 3 to 5°C in mean summer temperature in the river, but no temperature modifications are detectable at the mouth of the river (SEBJ 1990). The period of ice cover in the river was also reduced from 25 to 18 weeks, though ice cover in James Bay was modified only at the river mouth (Messier 1985, SEBJ 1990).

3.3.2 Nutrients and Primary Producers

Waters entering the La Grande estuary are generally poor in nutrients, and the ranges of concentrations of these substances recorded after development are comparable to those recorded before (SEBJ 1990).

In the plume itself, nutrients such as nitrate occur in low concentrations and appear to originate from the upwelling of deep waters of James Bay (Grainger and McSween 1976). Nitrate concentrations were not changed significantly by hydroelectric development (Freeman et al. 1982). In contrast, river inflow seems to be the primary source of detritus and dissolved organic carbon (Freeman et al. 1982), and input of these substances has increased since regulation (Messier et al. 1986). Table 9 indicates the concentrations of nutrients within a salinity gradient along the coast of James Bay within the plume of the La Grande River. Suspended substances, especially organic carbon, are clearly associated with less saline water, indicating that they originate in the La Grande itself or one of the other coastal rivers, or from the extensive coastal beds of eelgrass (SEBJ 1990). Substances associated with waters of higher salinity, such as phosphorus, probably originate from marine waters.

Phytoplankton biomass is generally low in the river and the plume. During summer, phytoplankton concentrations are higher in the plume than in James Bay, due to increased mixing and nutrient regeneration in frontal regions of the plume (Messier 1985). Under ice cover during winter, the distribution of nutrients and phytoplankton is markedly different. Within the region of the plume, nutrient concentrations in under-ice waters are low; beyond the front of the plume, nutrient concentrations increase due to mixing with deep marine waters and this is associated with extensive algal growth on the underside of the ice (Freeman et al. 1982). The enormous technical difficulties associated with studies during the period of ice-melt have precluded a study of phytoplankton populations in spring, the time of peak production in many northern areas (Hood 1983). It is possible that conditions which promote rapid phytoplankton growth in spring in other areas (e.g., high nutrient concentrations) do not occur in the La Grande estuary (SEBJ 1990).

Many of the shallow, sheltered coastal embayments of eastern James Bay support extensive beds of eelgrass, *Zostera marina* (Stewart et al. 1993). Although eelgrass is restricted from large estuaries such as that of the La Grande because it requires a summer salinity of greater than 5‰, eelgrass is a major source of detritus and may contribute to the organic carbon present in the estuary of the La Grande River (SEBJ 1990). Studies have shown that the expansion of the plume of the La Grande during the winter has not caused a reduction in the eelgrass beds; apparently eelgrass can tolerate salinity as low as 2‰ during winter (SEBJ 1990).

3.3.3 Higher Trophic Levels - Invertebrates and Fish

Under natural conditions, the benthos in brackish waters beyond the mouth of the river was dominated by euryhaline species typical of boreal and subarctic regions while the river itself contained freshwater molluscs and chironomids (Table 10, Dadswell 1974). In a survey of the area, Wacasey et al. (1976) collected no organisms at stations with a salinity of less than 10‰, and recorded peak densities of 4492 m^{-2} 8 km from the mouth of the La Grande. Polychaetes were numerically dominant, but molluscs comprised a larger proportion of the biomass at stations where they were abundant. Benthic densities off the mouth of the La Grande were much higher than those recorded in the deep, marine waters of James Bay where maximum densities reached only 748 m^{-2}. Under the increased flow regime following hydroelectric development, the majority of the delta has been transformed to a freshwater environment, and brackish water species such as *Macoma balthica*, which were previously present in low densities, have probably disappeared (Messier 1985).

Fish distributions and use of the lower portions of the La Grande estuary and plume reflect salinity tolerances of individual species, the most abundant species tending to tolerate the greatest range of salinity (Fig. 13). Anadromous species, particularly lake cisco and lake whitefish, which feed in the estuary during the summer and return to the river in fall to spawn and overwinter, are the most abundant (Messier 1985). Using mercury as a marker, it has been demonstrated that migrants from the La Grande River use the freshwater plume during the summer, ranging approximately 15 km north and 10 km south of the mouth of the river (SEBJ 1990). During studies of fish movements in the La Grande River and estuary, most fish were recaptured near where they were marked, but one immature cisco was recaptured 66 km from its point of marking (Morin et al. 1981).

The diet of anadromous fish varies among fresh, brackish and coastal waters and between seasons. In fresh waters, insect larvae are usually the main dietary item, while molluscs, freshwater insects (presumably drifting from the river) and fish, including sand lance and capelin, comprise the diet in estuarine and marine waters (Greendale and Hunter 1978).

A significant fishery exists in the area: during the period 1975 to 1979, local fishermen captured 65,000 fish annually, of which 49% were coregonids, 25% were brook trout, and 13% were suckers (Messier 1985). During the period 1980 to 1984, fish yield from experimental gillnetting in the lower portion of the estuary and plume remained approximately constant, though yields increased in upstream areas due to the input (i.e., downstream transfer through turbines) of fish from upstream reservoirs (Messier 1985). During the same period, recruitment of all species except walleye and northern pike remained approximately the same. Pike and walleye may be adversely affected by cooler summer temperatures and appear to have shifted to the warmer waters of tributary streams (Messier 1985). Further studies have confirmed that fish populations were relatively unaffected by flow augmentation (SEBJ 1990).

3.4 Eastmain

3.4.1 The Physical Environment

The Eastmain estuary is shallow (average depth 3 m), and even 5 km offshore depths do not exceed 10 m (Fig. 14, Messier et al. 1986). The sediments are sandy with equal proportions of silt and clay. In 1980, freshwater flow into the estuary was reduced by 90%, due to diversions affecting the Eastmain, Opinaca, and Petite Opinaca rivers. Following this reduction in flow, the sedimentation regime in the estuary was changed from erosion to deposition. The previous sediments contained little organic carbon (less than 1%), but the newly deposited sediments are richer (1 to 2% organic carbon, Messier 1985).

Prior to diversion, the estuary consisted of a freshwater zone extending 27 km upstream from the mouth, a narrow mixed zone in which salinity ranged to 8‰, and a plume, 1 to 1.5 m thick, covering approximately 100 km^2 of James Bay (Fig. 14, Grenon 1982, Ingram 1982). Salinity intrusion rarely occurred upstream of the mouth. Under ice cover, the size and depth of the natural plume increased considerably due to the reduction in wind and tidal mixing (Ingram 1982).

Flow reduction caused large changes in the physical properties of the estuary. The tide now propagates more or less freely throughout the estuary, introducing saline water up to 10 km upstream of the river mouth, converting a large proportion of the estuary from a fresh water to a brackish water environment (Fig. 14, Messier 1985). A mixed zone has developed where saline water has intruded, and altered circulation has produced a turbidity maximum within the estuary (Messier et al. 1986). The plume in summer has decreased in size by an estimated 50% and circulation both within the river and offshore has changed (Messier et al. 1986).

3.4.2 Nutrients and Primary Producers

Prior to diversion, water entering the estuary from the Eastmain River was relatively nutrient poor. Diversion decreased the volume by 90%, but increased the concentration of organic and inorganic nutrients in the river water due to the increased residence time and predominance of the more nutrient rich coastal rivers in the reduced drainage basin (Messier et al. 1986). Chlorophyll *a* concentrations under natural conditions ranged from 1 to 2 mg m^{-3}, and increased following diversion due to nutrient enrichment, culminating in a brief bloom in late summer when concentrations reached 10 mg m^{-3} (Ingram et al. 1985). Chlorophyll concentrations in the portion of the estuary affected by saline intrusion have declined since the initial post-diversion period but are expected to remain slightly higher than pre-diversion values because the coastal rivers which now comprise the entire watershed of the Eastmain River contain more nutrients than the diverted waters of the upstream watershed (Table 11, Messier 1985).

3.4.3 Higher Trophic Levels - Invertebrates and Fish

Under pre-diversion conditions, the density of benthos was lowest in brackish waters at the river mouth and increased in both the riverine and marine environments (Grenon 1982). Diversity increased from the fresh water to marine environments (Table 12, Grenon 1982). In the marine zone, molluscs, dominated by the clam *Macoma balthica*, formed 70% of the fauna, polychaetes 25% and crustaceans (mainly cumaceans and amphipods) the remainder (Grenon 1982). The freshwater zone was dominated by chironomid larvae, which reached densities of 2500 m^{-2} (Grenon 1982). Four years after diversion, the distribution of the benthos had shifted in accordance with the intrusion of saline waters, with both fresh and marine species shifting 4 to 8 km upstream (Messier 1985). In the long-term, abundance of benthos is expected to increase due to organic enrichment of the sediments (Messier et al. 1986).

The fish community in the brackish waters at the mouth of the Eastmain River before diversion was dominated by lake cisco and fourhorned sculpin; ogac, shorthorned sculpin, brook trout, and capelin were abundant at certain seasons (Morin and Dodson 1986). The freshwater portions of the Eastmain estuary during summer were dominated by longnose suckers, with significant numbers of juvenile walleye occurring just upstream of the saline front, where they fed on two brackish water species, threespine and ninespine sticklebacks (Morin and Dodson 1986). During fall, spawning migrations of lake whitefish and lake cisco made these the most abundant species (Messier et al. 1986).

After diversion, freshwater species such as walleye and longnose sucker moved upstream while two marine species, fourhorned sculpin and capelin, became the most common species at the mouth (Messier et al. 1986). Regular surveys of the populations of lake whitefish and lake cisco, the most recent conducted 12 years after diversion, indicate that the population has remained constant, suggesting that sufficient overwintering and spawning habitat to support the existing populations were still available in the river despite lowered water levels (Messier et al. 1986, Groupe Environnement Shooner 1993). The reduced feeding area in the estuary does not appear to have affected long-term population levels.

3.5 Chesterfield Inlet

3.5.1 The Physical Environment

Chesterfield Inlet is a large, partially mixed arctic estuary (Fig. 15). The inlet is long (220 km), wide (4 to 6 km) and deep (7 m at the outlet of Baker Lake to 100 m at the mouth). Flows into the estuary are also large, ranging from 1600 $m^3 s^{-1}$ in September to more than 4300 $m^3 s^{-1}$ in spring. Tides are relatively high, ranging from 5 m at the mouth to 1.5 m at Baker Lake, and have a considerable effect on water level and circulation patterns in the inlet (Roff et al. 1980). The complex morphometry, high tides, and strong tidally driven currents (2.0 m s^{-1}) combine to create complicated and variable mixing patterns in the estuary. The inlet is vertically stratified, with salinity in surface waters (0 - 20 m) gradually increasing from 0 at the head at Baker Lake to 28‰ at the mouth. Cold and saline marine water lies below the brackish surface layer.

The extent of mixing and vertical stratification of the entire inlet is strongly influenced by differences in the spring-neap tide cycle (Budgell 1982). Vertical stratification is increased during neap tides, causing a decrease in vertical mixing and increased stability. Spring tides cause more vigorous mixing, and decreased vertical stratification and stability. These different mixing regimes can cause large changes in the concentration and distribution of nutrients and aquatic biota in the estuary.

3.5.2 Nutrients and Primary Producers

Concentrations of nutrients generally parallel salinity gradients in the estuary (Roff et al. 1980). Maximum concentrations of phosphorus (0.6 $\mu g\ l^{-1}$) and total nitrogen (13 $\mu g\ l^{-1}$) occur in the cold, marine water of the outer estuary, while highest levels of nitrate and nitrite (0.7 $\mu g\ l^{-1}$) are recorded in the warm, brackish water of the upper estuary. Peak phytoplankton biomass (1.9 $\mu g\ l^{-1}$ chlorophyll *a*) and particulate organic carbon occur in the upper estuary, and are lowest at the mouth (0.3 $\mu g\ l^{-1}$ chlorophyll *a*), and are strongly negatively correlated with salinity.

The maximum biomass of phytoplankton occurs 40 to 60 km downstream of Baker Lake in low salinity waters (3-4‰), where freshwater species characteristic of Baker Lake are dominant. In marine water near the mouth, phytoplankton is dominated by marine forms. The distribution and species composition of phytoplankters in northern Hudson Bay estuaries are poorly known. A 1978 study of the inlet documented at least 40 new diatom and 29 dinoflagellate species that were previously unrecorded in Hudson Bay (Roff and Legendre 1986).

3.5.3 Higher Trophic Levels - Invertebrates and Fish

Study of organisms at higher trophic levels in Chesterfield Inlet has been limited. Mainly freshwater zooplankters such as rotifers and diaptomid copepods occur well down the inlet (Rogers 1981). The abundance of tintinids (ciliated protozoan zooplankters) is similar to that of temperate waters, but production is at most one-third that of temperate areas (Rogers 1981).

Additional information can be derived from the nearby Saqvaqjuac region, which has been studied for many years by the Department of Fisheries and Oceans (Welch and Legault 1986, Welch et al. 1991), and is probably typical of the many small estuaries of the northwest coast of Hudson Bay. These estuaries are formed within convoluted bays that are deep, vertically stratified, and have high tides and strong currents. There are large seasonal differences in freshwater inflow. During spring, the input of freshwater and associated nutrients is high while, during winter, inputs are negligible. The subtidal and sheltered coastal region appears very productive with large kelp beds and other macrophytes, clams and crustacea evident (M. Bergman, DFO Winnpeg, pers. comm.). Large numbers of greenland cod (*Gadus ogac*), capelin, and arctic char are seasonally abundant in the Saqvaqjuac estuary (Mikhail and Welch 1989). Sculpin, prickleback, and American sand lance are also present.

3.6 Comparison between Estuaries in Hudson Bay

3.6.1 Lower Trophic Levels

The estuaries of Hudson Bay are formed at the intersection of nutrient poor river inflow and nutrient poor marine waters. Thus, the processes which produce nutrient rich environments in other estuaries, i.e., input of nutrients from river water and upwelling of deep marine water, do not produce similarly nutrient rich environments in the Hudson Bay area. However, these estuaries may receive significant amounts of detritus from river inflow or coastal waters, as well as resuspension of sediments within the estuaries themselves. McLusky (1981) noted that the concentrations of particulate and dissolved organic matter in estuaries are generally lower than in rivers and higher than in coastal seas, ranging between 1 to 5 mg l^{-1} for dissolved organic carbon and 0.5 to 5 mg l^{-1} for particulate organic carbon. Available information suggests that organic carbon concentrations within the estuaries examined in this study are slightly lower or within this range.

In large rivers under natural or enhanced flow conditions (due to hydroelectric development), there appears to be no deposition of material at the river mouths. The lack of deposition at river mouths, in conjunction with isostatic uplift of coastal areas, might have allowed erosion by river flow to produce the deep central channels seen in many of the estuaries along the western coast of Hudson Bay (e.g., Chesterfield Inlet, and the estuaries of the Saqvaqjuac, Churchill and Nelson rivers). No information is available for estuaries formed by smaller rivers, but flow reduction in the Eastmain estuary transformed it from an erosional to a depositional environment, suggesting that deposition may also occur in natural small estuaries where tidal currents are small (e.g., Knife River delta of western Hudson Bay).

Primary production by phytoplankton in the estuaries of Hudson Bay and the surrounding area appears to be limited by low nutrient concentrations and turbulent waters, which mix cells out of the photic zone. The zone of the estuary in which maximum densities of phytoplankton occur is closely related to circulation patterns. In estuaries where most phytoplankton are derived from freshwater sources, such as the Nelson and Chesterfield Inlet, maximum cell densities occur near the source, though water circulation may act to concentrate cells in a region further downstream. Increased concentrations of phytoplankton in offshore areas can be observed in estuaries such as the La Grande, with well-developed frontal zones along the margins of the plume where mixing increases nutrient concentrations.

Knowledge of the larger bottom-living plants of Hudson Bay is limited; however, the development of vegetation in shallow, nearshore areas does not appear to be extensive, probably because of ice scour in these areas (Stewart et al. 1991). James Bay is unusual among Canada's sub-arctic regions in having extensive beds of eelgrass in shallow, sheltered embayments along its east coast (Stewart et al. 1993). Eelgrass is restricted from estuaries formed by large rivers such as the La Grande because salinity is less than 5‰ during the summer (Messier 1985). Unlike southern areas, northern coastal areas and estuaries in the vicinity of Chesterfield Inlet are characterized by clear waters and a very deep photic zone, permitting extensive growth of attached algae (M. Bergman, pers. comm.).

The importance of detritus to food chains in the estuaries of the Hudson Bay area is difficult to determine because of limited data. Given the limited primary production, known inputs of detritus, and the ability of most estuarine benthic and planktonic invertebrates to use this food source, the detrital food chain is probably important. Available information does not allow the assessment of the relative importance of the detritus and phytoplankton-based food chains: though the abundance of detritus is greater, its nutritional value (reflected in the high carbon:nitrogen ratio) is low.

In each of the estuaries examined, there was an increase in the number and diversity of invertebrate species from fresh to marine waters but relative abundances between fresh, brackish and marine waters varied. The distribution of benthic invertebrates is strongly affected by water depth and currents, substrate type, and the presence of detritus in the water and sediments.

Under pre-development conditions in estuaries such as the La Grande and Eastmain, the river fauna was dominated by large numbers of chironomid larvae; few organisms occurred in the transitional zone of brackish water, and marine waters were dominated by molluscs, crustaceans, and polychaetes (Grenon 1982, Dadswell 1974). In contrast, in the Churchill estuary, peak benthos densities occurred in the brackish transition between fresh and marine waters, in an area where there is a large flux of detritus (Lawrence and Baker 1994). Comparison of the benthic species composition among the La Grande, Eastmain and Nelson estuaries reveals surprisingly few species occurring in all areas (Tables 4, 10, and 12); these differences may reflect isolated populations (Stewart et al. 1993) or the need for more taxonomic verification.

Comparisons of zooplankton among estuaries is difficult because studies have been limited and sampling techniques vary. In the Nelson estuary, densities of zooplankton were higher than have been reported for the marine waters of Hudson Bay (Baker et al. 1993).

Most studies of arctic and sub-arctic estuarine biology have been conducted during the summer months; however, in northern waters a significant portion of annual phytoplankton production occurs during the late winter and early spring (Roff and Legendre 1986, Hood 1983, Welch et al. 1991). Significant quantities of ice algae have been reported in the areas of the La Grande and Grande Baleine plumes. These algal populations can have important effects on other organisms in the food chain. For example, in Manitounuk Sound and the Grande Baleine River plume the pre-breakup bloom of ice algae triggers the reproduction of copepods (Hirche and Bohrer 1987, Tourangeau and Runge 1991), the eggs and young of which are consumed by newly hatched fish larvae (Drolet et al. 1991). The abundance and relative condition of larval sand lance appear to be closely tied to the production of ice algae (Drolet et al. 1991, Ponton and Fortier 1992, Gilbert et al. 1992).

A complete understanding of the seasonal cycle of productivity in northern waters involves tremendous logistical problems due to the difficulty of sampling at and just after ice-out. However, studies in temperate areas have suggested that the seasonal cycle of freshwater flow to coastal areas (e.g., Texas, Armstrong 1982, Gulf of St. Lawrence, Dickie and Trites 1983) may be of critical importance in determining year-class strength and thus future yields of commercial fish species.

3.6.2 Fish

The fish communities of the estuaries of Hudson Bay are dominated by salmonidae, catostomidae, and cottidae (Table 13). Within an estuary, the distributional limit of a species is largely determined by its salinity tolerance. The chief freshwater fish is longnose sucker with the addition of warm water species such as walleye in southern areas. Brackish estuarine areas are dominated by anadromous fish, primarily coregonids, which also may move into coastal waters. Least is known about marine species, but fourhorned sculpin, sand lance and capelin occur in most areas. The freshwater and semi-anadromous species appear to use estuaries and coastal waters for summer feeding, moving into the rivers to spawn. Overwintering sites vary between species and estuary, but include river mouths, select sites upstream in the mainstem or tributaries, and possibly within the estuary itself (MacDonell et al. 1992).

Quantitative comparisons of fish populations among estuaries are difficult because sampling within estuaries is limited and techniques vary between studies. Lake cisco and lake whitefish have been the most closely measured because they are often caught for local consumption. Roy (1989) concluded that the fish population of James Bay was low based on the comparison of the annual yield of fish returning to the La Grande (50 t) to that of the Fraser River, which has a flow rate 5 to 6 times as large, but a return rate of thousands of tonnes. It was postulated that the number of anadromous fish in an estuary depends on the number of young fish generated in freshwater environments, the length of the river outflow zone and on food abundance. The generally low abundance of fish in the James Bay area was attributed to the paucity of food organisms.

Less is known about the marine fish, such as capelin and sand lance, which seasonally use estuaries. These fish provide food for both anadromous fish within the estuaries as well as marine mammals and fish in the bay as a whole.

3.6.3 Marine Mammals

Five species of seal have been reported in Hudson Bay - bearded (*Erignathus barbatus*), harbour (*Phoca vitulina*), ringed (*P. hispida*), harp (*P.groenlandica*), and hooded (*Cystophora cristata*) and six whale species are known from northern Hudson Bay waters - beluga (*Delphinapterus leucas*), narwhal (*Monodon monoceros*), bowhead (*Balaena mysticetus*), minke

(*Balaenoptera acurostrata*), and killer whale (*Orcinus orca*)(Sergeant 1986). Among the seals, only harbour seals are commonly seen in estuaries and have been observed well upstream in rivers such as the Thlewiaza (Beck et al. 1970), Seal, and Nelson (Baker 1989). Bearded seals have also been observed in the Nelson and Churchill estuaries (Baker 1989, Lawrence and Baker 1994). Among the whale species, only the beluga is common in Hudson Bay and the estuarine environment is important in its life cycle.

Beluga whales are widely distributed along the coast of Hudson and James Bay during summer, with large concentrations in estuaries, especially those of the Nelson, Churchill, and Seal rivers. Hudson and James bay beluga are commonly divided into three "stocks" or populations for management purposes based on their summer distribution (Fig. 16). These are: the Western Hudson Bay (WHB) stock that includes all beluga inhabiting the area from James Bay north to Rankin Inlet (at least 23,000 whales, Richard et al. 1990); the Northern Hudson Bay (NHB) stock that includes a small population (1,000 individuals, Smith and Hammill 1986) that summers around Southampton Island; and an Eastern Hudson Bay (EHB) stock that ranges from Ivujivik south into James Bay (2,700 whales, Smith and Hammill 1986). During winter, the majority of Hudson and James bay beluga migrate northward along the eastern and western coast of Hudson Bay to common wintering areas in Hudson Strait (Fig. 17, Finley et al. 1982), casting some doubt on the distinctiveness of the beluga stocks.

The largest summer concentration of whales in Hudson Bay occurs in the Nelson River estuary. Beluga whales first arrive in the Nelson River estuary during late May and persist in large numbers through July. Most whales have left the estuary by mid-August. Of the estimated 23,000 WHB beluga stock, up to 19,500 are present within 145 km of the estuary (Richard et al. 1990). Beluga are highly mobile, moving on- and offshore large distances, often with the tides (Baker 1989) or along the coast (e.g., between the Nelson and Churchill estuaries, P. Weaver, DFO Winnipeg, pers. comm.).

Although it is not clear why so many beluga whales inhabit the Nelson River estuary, potential reasons include temperature (estuaries are warmer than the open ocean), and habitat for nursery grounds for calves, moulting of old skin, social functions, and feeding (Lawrence et al. 1992). It is most likely that the large volume of freshwater and shallow, gravel bottom of the river and extensive mudflats provide ideal habitat for the moulting of old skin (St. Aubin et al. 1990). In addition, this population has never been depleted by hunting as has occurred in other estuaries (Baker et al. 1992, Reeves and Mitchell 1987, 1989).

The Churchill and Seal estuaries also contain at least 5,600 beluga during summer (Richard et al. 1990). Likely, the Churchill beluga population was historically much larger, given that beluga were commercially harvested in this estuary as recently as 1968 (Baker et al. 1992). Beluga whales arrive at the Churchill and Seal estuaries in early June, somewhat later than their arrival in the Nelson estuary, and may leave one to two weeks later when they are joined by Nelson River beluga to begin their northward migration to overwintering grounds in Hudson Strait.

Smaller numbers of beluga whales (hundreds) also occur in many other western Hudson Bay estuaries in Ontario (the Winisk and Severn rivers), and in the Keewatin including the Tha-anne, Thlewiaza, Maguse, and McConnell rivers.

Along the eastern Hudson Bay coast, beluga leave overwintering areas in Hudson Strait and move south along the eastern Hudson Bay coast during April to June (Reeves and Mitchell 1987). Beluga do not enter river estuaries between Ivujivik and Inukjuak, but tend to concentrate in the southeastern portion of the bay (Stewart et al. 1991). During summer, belugas are widespread throughout the east Hudson Bay coast, James Bay, and the Belcher Islands (Smith and Hammill 1986) and are most abundant offshore, but also occur in small numbers (<100) in the Petite Baleine and Nastapoka rivers and in Lac Guillaume-Delisle (Richmond Gulf) (Fig. 16). Estuaries in James Bay do not support large summer concentrations of whales (Smith and Hammill 1986), but whales are distributed throughout the bay, with reports of whales occurring in small numbers in most of the larger rivers along the coast such as the Attawapiskat, Moose, Albany, Hurricana, Eastmain, and La Grande rivers. In September and October, beluga undertake a northward migration along the coast, back toward Hudson Strait (Finley et al. 1982).

Because beluga whales exhibit very strong fidelity to particular estuaries during summer (Smith and Hammill 1986, Caron and Smith 1990), they are very vulnerable to hunting. For example, the earliest population estimate of the Grande Baleine and Petite Baleine rivers in 1854 was at least 6600 whales (Reeves and Mitchell 1987). However, the commercial net fishery operated by the Hudson's Bay Company (H.B.C.) between the 1850's and 1870's, and persistent harvesting of beluga for domestic purposes by native people (at least some of the domestic harvest was sold to the H.B.C. for oil and hides) until the 1970's, considerably reduced their numbers (Reeves and Mitchell 1989).

4. Estuaries and Anthropogenic Development

Hydroelectric development is the most important anthropogenic influence on the physical nature of estuaries of Hudson Bay and surrounding area. Many pulp mills and other industrial developments exist in upstream reaches of rivers draining the Hudson Bay lowlands in Ontario; though low concentrations of a range of pollutants are detectable near the river mouths, no major problems with water quality have been found (McCrea et al. 1984). Although many of the rivers entering Hudson Bay have hydroelectric developments in upstream reaches, only two developments, the Nelson/Churchill in Manitoba, and the La Grande complex (affecting the estuaries of the La Grande, Eastmain and Koksoak rivers) in Québec have sufficient storage capacities or involve diversions large enough to cause major differences in the flows of rivers entering Hudson Bay. Further developments planned in Québec are the Grande Baleine complex (affecting the Grande and Petite Baleine rivers) and the NBR complex (affecting the Rupert, Nottaway, and Broadback rivers). Further developments are possible along the Moose and Nelson rivers.

The La Grande development in Québec was the subject of extensive pre- and post-development studies, providing a valuable basis for assessing the effect of development in northern waters. Augmentation and regulation of the La Grande had relatively little effect on the quality of water entering the estuary. On the other hand, diversion of the upper reaches of the Eastmain caused relative enrichment of the remaining flow. However, because the flow into the Eastmain estuary was reduced by 90%, total input of nutrients to the estuary has not been increased by this enrichment. In the coastal waters of James Bay, increased winter flows considerably increased the size of the La Grande plume and decreased flow reduced the Eastmain plume and permitted intrusion of saline water upstream into previously freshwater areas. The relationship between flow and extent of the estuary is complex and depends on the interaction of local topography with the relative freshwater and marine (tidal and wind-driven) flows.

Therefore, large flow reductions may cause either major or minor changes in the extent of the freshwater and marine portions of the estuary.

In the Eastmain and La Grande estuaries, changes in freshwater input and thus estuarine circulation and upwelling of deep marine waters did not cause large changes in either nutrients or phytoplankton, presumably because neither the river nor deep marine waters provided a major source of nutrients (Messier 1985). Studies in other areas have demonstrated that peak productivity in northern areas occurs in spring just after ice-out (Hood 1983); the effect of seasonal alterations in flow on primary productivity has not been directly assessed due to the tremendous technical difficulties associated with such a project.

Available information on the fish populations of the La Grande and the Eastmain suggest that no major changes in the fish populations of brackish waters occurred, though species distribution shifted in response to changing salinity. The maintenance of lake whitefish and cisco populations following flow alteration was attributed to the preservation of suitable spawning and overwintering habitat in freshwaters (Messier et al. 1986, SEBJ 1990, Groupe Environnement Shooner 1993). Subtle changes in the productivity and extent of feeding areas in estuarine regions were expected to have a long-term effect, but research to date has not demonstrated a change in the coregonid populations of either river (SEBJ 1990, Groupe Environnememt Shooner 1993). This suggests that the food web upon which these fish species depend has not been altered sufficiently to affect the fish populations (Roy and Messier 1989, SEBJ 1990).

Although the biota of selected estuaries in Hudson Bay have been relatively well-studied, it is not possible to assess the significance of these areas in the context of the bay as a whole because very little is known about either the coastal or marine waters of Hudson Bay. Therefore, it is not possible to clearly establish whether these estuaries are more or less productive than surrounding areas or assess the effect of upstream development on the area as a whole. The combined input of the several large and many small rivers entering Hudson Bay may produce an almost continuous band of coastal estuarine habitat. Little information exists concerning either the estuaries created by small rivers or the brackish coastal zone. Besides providing extensive estuarine habitat for foraging, this coastal strip of brackish water may serve as a corridor between estuaries for less salinity-tolerant species. To assess the cumulative impact of the construction of many hydroelectric facilities, it is imperative to know the significance of this brackish zone, interconnections between estuaries, and the effect of flow alterations on the spatial extent and continuity of this area.

Very little information exists pertaining to the seasonality of processes in the estuaries. In both the Nelson and La Grande estuaries, hydroelectric development has caused large increases in winter flows. In the La Grande, the substantial spring freshet was also eliminated. The early spring is generally the time of peak phytoplankton production and the time of hatching of many fish species, including both marine (sand lance) and anadromous (coregonids) species. Recent research has demonstrated that the abundance and relative condition of larval sand lance appears to be closely tied to the production of zooplankton (copepods) which in turn depends upon ice algal production (Drolet et al. 1991, Ponton and Fortier 1992, Gilbert et al. 1992). The spring freshet of rivers draining southern areas, such as the Moose, brings water that is considerably warmer than the surrounding area into the bay (McCrea et al. 1984), but whether this affects the estuarine biota is not known.

Finally, most estuarine research to date has focused on inshore areas, principally on populations of anadromous fish. Typically marine organisms, including both fish (e.g., capelin) and whales (beluga) seasonally occupy estuaries, but the extent and purpose of use has not been well documented. The role of fresh or brackish waters in the ecology of beluga is also not well understood. Marine species are vulnerable to changes on the fringes of the estuaries. For example, in the Beaufort Sea, bowhead whales tend to congregate in frontal regions, where there is a large concentration of food organisms (Borstad 1985, Richardson 1987). Neither the significance of such regions nor the changes induced by hydroelectric development are well known in Hudson Bay.

5. Summary and Conclusions

The estuaries of Hudson Bay and the surrounding area are nutrient poor with low productivity. Inputs of organic carbon from rivers may be an important energy source for estuarine biota, but the relative importance of food chains based on phytoplankton versus detritus is not known. Based on available data, no clear difference in primary production as indicated by chlorophyll *a* concentrations is apparent between stratified and well-mixed estuaries, but further investigation may reveal previously undetected differences. There may be a difference in the distribution of particles: highest particle concentrations occur in frontal regions of stratified areas and the middle regions of mixed areas. Well-mixed estuaries also tend to have a larger region of brackish water compared to stratified estuaries, which affects the amount of area available for species (particularly benthos) to inhabit.

The brackish waters of estuaries are extensively used as feeding and nursery areas by semi-anadromous fish, principally lake cisco and whitefish, though typically freshwater species such as longnose sucker also occur in waters with low salinity. For species tolerant of higher salinity, such as lake cisco, much of the coastal region of Hudson and James bays provides suitable habitat, with the potential to move between estuaries. Marine species, such as sand lance and capelin, occur in the more saline portions of estuaries, but little is known about their distribution or abundance. The relationship between productivity at lower trophic levels in the estuaries and fish populations has not been examined.

Studies before and after extensive hydroelectric development on the Eastmain and La Grande rivers showed that changes in river flow have had a large effect on salinity distribution. However, overall production and populations of lake cisco and whitefish appear unchanged. The maintenance of suitable spawning and overwintering habitats was considered key to the observed stability of these fish populations.

Less is known about changes caused by hydroelectric development in the more marine areas of estuaries. Changes in the extent of brackish waters or frontal regions could have large effects on marine species.

Many questions remain unanswered about the estuaries of this region, but the following are some of the most important to better evaluate the effect of anthropogenic development (chiefly hydroelectric): What is the importance of late winter and early spring phytoplankton production to organisms at higher trophic levels (particularly larval fish)?; What effect do increased or decreased winter and spring flows have on early spring phytoplankton production?; What processes occur on the marine margins of estuaries and of what significance are these regions to marine animals, particularly whales?; How do estuaries compare to adjacent coastal and marine regions in terms of species distribution and abundance and productivity (i.e., how significant is the change in area of estuarine habitat)?; and What is the cumulative effect of flow regulation and other upstream developments (e.g., pulp mills) on estuaries?

6. Acknowledgments

We gratefully acknowledge Danielle Messier and Peter Sly for their extensive comments which substantially improved the quality of this paper. Sheila McRae assisted in literature searches.

7. References

ANDERSON, J.T., and J.C. ROFF. 1980a. Seston ecology of the surface waters of Hudson Bay. Can. J. Fish. Aquat. Sci. 37: 2242-2253.

ANDERSON, J.T., and J.C. ROFF. 1980b. Subsurface chlorophyll *a* maximum in Hudson Bay. Nat. Can. 107: 207-213.

ANEMA, C., R.E. HECKY, S. HIMMER, and S.J. GUILDFORD. 1990. Water chemistry of some lakes and channels in the Mackenzie Delta and on the Tuktoyaktuk Peninsula, N.W.T., 1986. Can. Data Rep. Fish. Aquat. Sci. 729: vi + 63 p.

ARMSTRONG, N.E. 1982. Responses of Texas estuaries to freshwater inflows. p. 103-120 In V.S. Kennedy (ed.) Estuarine comparisons. Academic Press, N.Y.

BAKER, R.F. 1989. An environmental assessment and biological investigation of the Nelson River estuary. A report prepared for Manitoba Hydro by North/South Consultants Inc. 179 pp.

BAKER, R.F. 1990. A fisheries survey of the Nelson River estuary, August, 1989. A report prepared for Manitoba Hydro by North/South Consultants Inc. 27 pp.

BAKER, R.F., R.A. REMNANT, and B.D. HORNE. 1992. Harvest statistics of beluga whale (*Delphinapterus leucas*) and relationship to exploitation in Hudson Bay, 1930-1990. A report prepared by North/South Consultants Inc. for CSSA Consultants Ltd.

BAKER, R.F., M.J LAWRENCE, AND F. SCHNEIDER. 1993. Oceanography and mid-summer distribution and abundance of plankton and fish in the Nelson River estuary, Hudson Bay. A report prepared for Manitoba Hydro by North/South Consultants Inc. 67 pp.

BECK, B., T.G. SMITH, and A.W. MANSFIELD. 1970. Occurrence of the harbour seal, *Phoca vitulina* Linnaeus, in the Thlewiaza River, N.W.T. Can. Field Nat. 84: 297-300.

BORSTAD, G.A. 1985. Water colour and temperature in the southern Beaufort Sea: remote sensing in support of ecological studies of the bowhead whale. Can. Tech. Rep. Fish. Aquat. Sci. 1350. 68 pp.

BUDGELL, W.P. 1982. Spring-neap variation in the vertical stratification of Chesterfield Inlet, Hudson Bay. Nat. Can. 109(4): 709-718.

CANADA, DEPARTMENT OF ENERGY, MINES, AND RESOURCES, SURVEYS AND MAPPING BRANCH. 1974. National Atlas of Canada, Fourth Edition. The Macmillan Co. of Canada Ltd. in conjunction with the Department of Energy, Mines, and Resources and Information Canada.

CANADA, DEPARTMENT OF ENERGY, MINES, AND RESOURCES, SURVEYS AND MAPPING BRANCH. 1978. Hydrologic Atlas of Canada. Department of Energy, Mines, and Resources and Information Canada.

CANADA, DEPARTMENT OF ENERGY, MINES, AND RESOURCES, SURVEYS AND MAPPING BRANCH. 1985. National Atlas of Canada, Fifth Edition. Department of Energy, Mines, and Resources and Information Canada.

CANADA, INLAND WATERS DIRECTORATE, WATER RESOURCES BRANCH. 1991. Historical streamflow summary, Manitoba, to 1990. Environment Canada. 301 pp.

CARON, L.J.J., and T.G. SMITH. 1990. Philopatry and site tenacity of belugas, *Delphinapterus leucas*, hunted by the Inuit at the Nastapoka estuary, eastern Hudson Bay. p. 69-79. In T.G. Smith, D.J. St. Aubin, and J.R. Geraci (eds.) Advances in research on the beluga whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224.

DADSWELL, M.J. 1974. A physical and biological survey of La Grande River estuary, James Bay, Québec. Can. Field Nat. 88:477-480.

DICKIE, L.M. and R.W. TRITES. 1983. The Gulf of St. Lawrence. p. 403-425. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

DROLET, R., L. FORTIER, D. PONTON, and M. GILBERT. 1991. Production of fish larvae and their prey in subarctic southeastern Hudson Bay. Mar. Ecol. Prog. Ser. 77 105-118.

EDWARDS, C.J., P.L. HUDSON, W.G. DUFFY, S.J. NEPSZY, C.D. MCNABB, R.C. HAAS, C.R. LISTON, B. MANNY, and W.N. BUSCH. 1989. Hydrological, morphometrical, and biological characteristics of the connecting rivers of the international Great Lakes: a review. p. 240-264. In D.P. Dodge (ed.) Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

FINLEY, K.J., G.W. MILLER, M. ALLARD, R.A. DAVIS and C.R. EVANS. 1982. The belugas *Delphinapterus leucas* of northern Québec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Aquat. Sci. 1123: vii + 63 pp.

FREEMAN, N.G., J.C. ROFF, and R.J. PETT. 1982. Physical, chemical, and biological features of river plumes under an ice cover in James and Hudson bays. Nat. Can. 109(4): 745-764.

GILBERT, M., L. FORTIER, D. PONTON, and R. DROLET. 1992. Feeding ecology of marine fish larvae across the Great Whale River plume in seasonally ice-covered southeastern Hudson Bay. Mar. Ecol. Prog. Ser. 84: 19-30.

GRAINGER, E.H., and S. McSWEEN. 1976. Marine zooplankton and some physical-chemical features of James Bay related to La Grande hydro-electric development. Can. Fish. Tech. Rep. 650. 94 pp.

GREENDALE, R.G. and J.G. HUNTER. 1978. Feeding of freshwater fishes in estuarine and coastal waters. Fish. Mar. Serv. Tech. Rep. 777: 11 pp.

GRENON, J.F. 1982. The macrobenthic fauna of the Eastmain estuary (James Bay, Québec), before the diversion. Nat. Can. 109: 793-802.

GROUPE ENVIRONNEMENT SHOONER INC. 1993. Étude de la communauté de possions de l'estuaire de la rivière Eastmain, 12 ans après la reduction du débit fluvial. Report prepared for the vice-president of Hydro Québec, 100 pp. and appendices.

HAEDRICH, R.L. 1983. Estuarine fishes. p. 183-207. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

HIRCHE, H., and J. BOHRER. 1987. Reproduction of the arctic copepod *Calanus glacialis* in Farm Strait. Mar. Biol. 94: 11-17.

HOOD, D.W. 1983. The Bering Sea, p. 337-373. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

INGRAM, R.G. 1982. Mean and tidal circulation of the Eastmain River (James Bay). Nat. Can. 109: 733-743.

INGRAM, G.R., L. LEGENDRE, Y. SIMARD, and S. LEPAGE. 1985. Phytoplankton response to freshwater runoff: The diversion of the Eastmain River, James Bay. Can. J. Fish. Aquat. Sci. 42: 1216-1221.

JANUSZ, L. 1990. Summary of phytoplankton data for the Nelson River and Rat-Burntwood lakes, 1989. Man. Dept. Nat. Res. Fish. Br. MS report No. 90-12. 79 pp.

KELEHER, J.J. 1953. Report on field work at Churchill, Manitoba, and growth of ciscoes in the Churchill River. Fish. Res. Bd Can. Man. Rep. Biol. St. 555. 19 pp.

KEMP, A., L. BERNATCHEZ, and J.J. DODSON. 1989. A revision of coregonine fish distribution and abundance in eastern James-Hudson Bay. Envir. Biol. Fish. 26: 247-255.

KETCHUM, B.H. 1983. Estuarine characteristics. p. 1-14. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

LAKE WINNIPEG, CHURCHILL & NELSON RIVERS STUDY BOARD. 1971-75. Technical report. Canada Manitoba.

LAWRENCE, M.J., and R. BAKER. 1994. Churchill River estuary biological and oceanographic survey. In prep.

LAWRENCE, M.J., M. PATERSON, R.F. BAKER, and R. SCHMIDT. 1992. Report on the workshop examining the potential effects of hydroelectric development on beluga of the Nelson River Estuary, Winnipeg, Manitoba, November 6 and 7, 1990. Can. Tech. Rep. Fish. Aquat. Sci. 1838: iv + 39 pp.

LIVINGSTON, L. 1989. Summary of phytoplankton data for the Nelson River and Rat-Burntwood lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS Report 89-07, 81 pp.

MACDONELL, D.S. and W.J. BERNHARDT. 1992. A synthesis of fisheries studies conducted between 1915 and 1992 and general life history descriptions of fish species of the lower Nelson River. A report prepared for Manitoba Hydro by North/South Consultants Inc. 120 pp.

MACDONELL, D.S., R.L. BRETCHER, AND R.A. REMNANT. 1992. Lower Nelson River tributary fish utilization studies: Limestone River and Moondance Creek Year II 1991. A report prepared for Manitoba Hydro by North/South Consultants Inc. 151 pp.

MCLUSKY, D. 1981. The estuarine ecosystem. John Wiley and Sons, New York. 143 pp.

MCCREA, R.C., R.E. KWIATKOWSKI, D.E. CAMPBELL, P.P. McCARTHY, and T.A. NORRIS. 1984. An investigation of contaminants and benthic communities in the major rivers of the Hudson Bay Lowland, Ontario. Environ. Can. Tech. Bull. 131. 47 pp.

MESSIER, D. 1985. Modifications oceanographiques physiques et biologiques a la suite de l'amenagement du Complexe La Grande. Société d'énergie de la Baie James, Montreal. 127 pp.

MESSIER, D., R.G. INGRAM, and D. ROY. 1986. Physical and biological modifications in response to La Grande hydroelectric complex. p. 403-424. In I.P. Martini (ed.) Canadian Inland Seas. 494 pp.

MESSIER, D.S., S. LEPAGE, AND S. DE MARGERIE. 1989. Influence du couvert de glace sur l'étendue La Grande Rivière (baie James). Arctic 42: 278-284.

MIKHAIL, M.Y. and H.E. WELCH. 1989. Biology of Greenland cod, *Gadus ogac*, at Saqvaqjuac, northwest coast of Hudson Bay. Environ. Biol. Fish. 26: 49-62.

MORIN, R., and J.J. DODSON. 1986. The ecology of fishes in James Bay, Hudson Bay and Hudson Strait. p. 293-325. In I.P. Martini (ed.). Canadian inland seas. 494 pp.

MORIN, R., J.J. DODSON, and G. POWER. 1980. Estuarine fish communities of the eastern James-Hudson Bay coast. Env. Biol. Fish. 5:135-141.

MORIN, R., J.J. DODSON, and G. POWER. 1981. The migrations of anadromous cisco (*Coregonus artedii*) and lake whitefish (*C. clupeaformis*) in estuaries of eastern James Bay. Can. J. Zool. 59:1600-1607.

MOULTON, L.L. 1989. Recruitment of arctic cisco (*Coregonus autumnalis*) into the Colville Delta, Alaska, in 1985. Biol. Pap. Univ. Alaska 24: 107-111.

NORTHCOTE, T.G. and P.A. LARKIN. 1989. The Fraser: a major salmonine production system. p. 172-204. In D.P. Dodge (ed.) Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

OFFICER, C.B. 1983. Physics of estuarine circulation, p. 15-41. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

PARSONS, T.R., D.G. WEBB, B.E. ROKEBY, M. LAWRENCE, G.E. HOPKY, and D.B. CHIPERZAK. 1989. Autotrophic and heterotrophic production in the Mackenzie River/Beaufort Sea estuary. Polar Biology 9: 261-266.

PONTON, D., and L. FORTIER. 1992. Vertical distribution and foraging of marine fish larvae under the ice cover of southeastern Hudson Bay. Mar. Ecol. Prog. Ser. 81:215-227.

REEVES, R.R. and E. MITCHELL. 1987. Distribution and migration, exploitation, and former abundance of white whales (*Delphinapterus leucas*) in Baffin Bay and adjacent water. Can. Spec. Publ. Fish. Aquat. Sci. 99: 34 p.

REEVES, R.R. and E. MITCHELL. 1989. Status of white whales (*Delphinapterus leucas*) in Ungava Bay and eastern Hudson Bay. Can. Field Nat. 103 (2): 220-239.

REMNANT, R.A. and W.J. BERNHARDT. 1994. Spring and fall fish movements in Goose Creek, a tributary of the lower Churchill River, Manitoba. A report prepared for Manitoba Hydro by North/South Consultants Inc., in prep.

RICHARD, P.R., J.R. ORR, and D.G. BARBER. 1990. The distribution and abundance of belugas, *Delphinapterus leucas*, in eastern Canadian subarctic waters: a review and update, p. 23-38. In T.G. Smith, D.J. St. Aubin, and J.R. Geraci (eds.) Advances in research on the beluga whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224.

RICHARDSON, W.J. 1987. Importance of the eastern Alaskan Beaufort Sea to feeding bowhead whales, 1985-86. A report prepared for U.S. Mineral Management Service by LGL Ecological Research Associates, Inc. 547 pp.

ROFF, J.C., and L. LEGENDRE. 1986. Physio-chemical and biological oceanography of Hudson Bay, p. 265-291. In I.P. Martini (ed.). Canadian inland seas. 494 pp.

ROFF, J.C., R.J. PETT, G.F. ROGERS, and W.P. BUDGELL. 1980. A study of plankton ecology in Chesterfield Inlet, Northwest Territories, an arctic estuary, p. 185-197. In V. Kennedy (ed.) Estuarine perspectives. Academic Press, New York.

ROGERS, G.F. 1981. Biological oceanography of Chesterfield Inlet, N.W.T., Summer 1978 - Phytoplankton and zooplankton. M.Sc. Thesis, Univ. Guelph. 185 pp.

ROY, D. 1989. Physical and biological factors affecting the distribution and abundance of fishes in rivers flowing into James Bay and Hudson Bay. p. 159-171. In D.P. Dodge (ed.) Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

ROY, D. and D. MESSIER. 1989. A review of the effects of water transfers in the La Grande hydroelectric complex (Québec, Canada). Reg. Rivers 4: 299-316.

SCHNEIDER, F. and R. BAKER. 1993. Summary of lower trophic level studies in the lower Nelson River, 1988 to 1992. A report prepared for Manitoba Hydro by North/South Consultants Inc. 48 pp.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE JAME (SEBJ). 1990. Suivi environmental du projet de La Grande 2A. Volume 1. 243 pp.

SERGEANT, D.E. 1986. Sea mammals. p. 327-340. In I.P. Martini (ed.). Canadian inland seas. 494 pp.

SMAYDER, T.J. 1983. The phytoplankton of estuaries. In B.S. Ketchum (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co., Amsterdam.

SMITH, T.G. and M.O. HAMMILL. 1986. Population estimates of white whale, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay, and Ungava Bay. Can. J. Fish. Aquat. Sci. 43: 1982-1987.

ST. AUBIN, D.J., T.G. SMITH, and J.R. GERACI. 1990. Seasonal epidermal molt in beluga whales, *Delphinapterus leucas*. Can. J. Zool. 68: 359-367.

STEWART, D.B., L.M.J. BERNIER, and M.J. DUNBAR. 1991. Marine natural areas of Canadian significance in the Hudson Bay marine region. A report prepared by Arctic Biological Consultants for the Canadian Parks Service, Ottawa. vii + 241 pp.

STEWART, D.B., M.J. DUNBAR, and L.M.J. BERNIER. 1993. Marine natural areas of Canadian significance in the James Bay marine region. A report prepared by Arctic Biological Consultants for the Canadian Parks Service, Ottawa. ix + 294 pp.

TOURANGEAU, S., and J.A. RUNGE. 1991. Reproduction of *Calanus glacialis* under ice in spring in southeastern Hudson Bay. Mar. Biol. 108: 227-233.

WACASEY, J.W., E.G. ATKINSON, and L. KINLOUGH. 1976. Zoobenthos data from James Bay, 1959, 1974. Fish. Mar. Serv. Res. Dev. Tech. Rep. 661: 62 pp.

WELCH, H.E. and J.A. LEGAULT. 1986. Precipitation chemistry and chemical limnology of fertilized and natural lakes at Saqvaqjuac, N.W.T. Can. J. Fish. Aquat. Sci. 43: 1104-1134.

WELCH, H.E., M.A. BERGMANN, T.D. SIFERD, and P.S. AMARUALIK. 1991. Seasonal development of ice algae near Chesterfield Inlet, N.W.T., Canada. 48: 2395-2402.

WETZEL, R.G. 1983. Limnology. Saunders College Publishing, Philadelphia, 767 pp.

LIST OF TABLES

Table 1. Selected characteristics of rivers and their watersheds in the study area.

Location [1]	Drainage [2] (km^2)	Discharge [1] (m^3s^{-1})	Landform [3]	Vegetation [3]
North West Hudson Bay				
Thelon	142400	804	Shield	tundra
Kazan	71500	566		
25 rivers	397129	nd	Shield	tundra
South West Hudson Bay				
Seal	50000	nd	Shield	tundra, woodlands, bog
Churchill [4]	281300	1270	Coastal Lowlands, Shield	tundra, woodlands, bog
Nelson [4]	1072300	2830	Coastal Lowlands, Shield, Interior Plain	bog, boreal forest, grasslands
Hayes	108000	694	Coastal Lowlands, Shield	bog, boreal forest
Severn	102800	722	Coastal Lowlands, Shield	bog, boreal forest
Winisk	67300	694	Coastal Lowlands, Shield	bog, boreal forest
10 rivers	79849	nd	Coastal Lowlands, Shield	bog, boreal forest
Western James Bay				
Attawapiskat	50500	626	Coastal Lowlands, Shield	bog, boreal forest
Albany [4]	135200	1420	Coastal Lowlands, Shield	bog, boreal forest
Moose	108500	1440	Coastal Lowlands, Shield	bog, boreal forest
6 rivers	63622	nd	Coastal Lowlands, Shield	bog, boreal forest
Eastern James Bay				
Harricanaw	29300	473	Coastal Lowlands, Shield	bog, boreal forest
Nottaway	65800	1130	Coastal Lowlands, Shield	bog, boreal forest
Broadback	20800	nd	Coastal Lowlands, Shield	bog, boreal forest

Table 1. (continued)

Location [1]	Drainage [2] (km^2)	Discharge [1] (m^3s^{-1})	Landform [3]	Vegetation [3]
Rupert	43300	878	Coastal Lowlands, Shield	bog, boreal forest
Eastmain [4]	46400	909	Coastal Lowlands, Shield	boreal forest
La Grande [4]	97600	1720	Shield	woodland
7 rivers	63195	nd	Coastal Lowlands, Sheild	boreal forest, woodland
South East Hudson Bay				
Baleine, Grande	42700	665	Shield	woodland
8 rivers	61490	nd	Shield	woodland, tundra
North East Hudson Bay				
Povungnituk	28500	nd	Shield	tundra
6 rivers	78570	nd	Shield	tundra
Ungava Bay				
Arnaud	49500	654	Shield	tundra
Feuilles	42500	575	Shield	tundra
Koksoak [4]	133400	2420	Shield	tundra, woodland
Baleine	31900	581	Shield, Lowland	tundra, woodland
George	41700	881	Shield	tundra
10 rivers	54228	nd	Shield	tundra
Hudson Strait (north shore)				
5 rivers	51666	nd	Shield, Coastal Plain	tundra

Table 1. (continued)

Location [1]	Drainage [2] (km^2)	Discharge [1] (m^3s^{-1})	Landform [3]	Vegetation [3]
Hudson Strait (south shore)				
2 rivers	32876	nd	Shield	tundra
Foxe Basin				
24 rivers	290375	nd	Arctic Lowlands, Shield	tundra
Total	4010000	30900		
Total other rivers	1173000	8950		

[1] Data from Canada, Department of Energy, Mines and Resources 1978 using pre-1976 data. Named rivers have a discharge greater than 283m^3s^{-1}. "Other" rivers are shown on a 1:7,500,000 map.
[2] Data from Canada, Department of Energy, Mines and Resources 1985.
[3] Data from Canada, Department of Energy, Mines and Resources 1974.
[4] Affected by major diversion. Discharges and drainage basins are from the early 1970's, before most major diversions.

Table 2. Summary of organic and inorganic nutrients in the Nelson, La Grande and Eastmain rivers. Data for the Nelson River are taken from Schneider and Baker (1993) and measurements from the La Grande and Eastmain rivers are from Messier (1985). All measurements were standardized to the same units.

	Nelson			La Grande						Eastmain					
	Post-development			Pre-development			Post-development			Pre-development			Post-development		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Total Nitrogen (g m^{-3})	0.41	0.24	0.57	0.27	0.26	0.59	0.21	0.14	0.29	0.27	0.21	0.43	0.32	0.22	0.47
Total Phosphorus (g m^{-3})	0.034	0.02	0.10	0.014	0.005	0.030	0.014	0.007	0.033	0.022	0.009	0.066	0.038	0.017	0.092
Total Oraganic Carbon (g m^{-3})	9.14	7.17	19.00	6.20	5.30	7.00	5.30	4.00	6.50	8.00	6.20	9.50	13.90	6.00	19.10
Conductivity (μs)	230	202	287	16	13	21	15	13	18	14	11	16	29	13	40

Table 3. Surface water chemistry data for the Nelson estuary at low and high tides. Data from Baker et al. (1993).

Distance from Port Nelson	Total Dissolved Nitrogen (mg m^{-3})	Total Dissolved Phosphorus (mg m^{-3})	Dissolved Organic Carbon (mmol l^{-1})	Suspended Carbon (mg m^{-3})
Low Tide				
0.00	340	11	570	890
6.75	360	11	580	1240
16.50	190	12	570	810
23.75	300	13	320	700
27.25	520	40	120	570
High Tide				
1.25	350	12	570	820
8.00	190	11	490	1920
13.75	310	19	170	1660
18.50	390	20	140	1150
24.00	520	29	70	470
26.00	510	30	50	370
31.20	520	33	40	250

Table 4. Composition of the benthos in summer and fall from the Nelson estuary in the riverine and estuarine zones. Percent composition by major group and the % contribution of the major species within a group are shown. + = present, - = absent. Data from Baker (1989).

	Riverine		Estuarine	
	Summer	Fall	Summer	Fall
Polychaeta	0	0	52	96
Eteone sp.	-	-	-	+
Manayunkia aestuarina	-	-	100	100
Oligochaeta	2	52	12	<1
Amphichaeta leydigi	-	-	-	-
Limnodrilus sp.	48	-	91	93
Limnodrilus hoffmeisteri	-	39	-	-
Limnodrilus profundicola	-	-	-	-
Limnodrilus udekemaianus	-	+	-	-
Nais sp.	-	-	+	+
Nais variabilis	+	-	-	-
Paranais litoralis	-	-	-	-
Tubifex tubifex	-	56	-	-
Tubifex sp.	50	-	+	+
Acarina	<1	0	0	0
Spechon pseudoplumifera	+	-	-	-
Branchipoda	<1	1	<1	0
Cladocera	-	+	+	-
Daphnia sp.	+	+	-	-
Eurycercus sp.	+	+	-	-
Copepoda	<1	<1	<1	<1
Cyclops vernalis	-	+	-	+
Eurytemora affinis	+	-	+	+
Harpacticoida	-	-	+	+

Table 4. (continued)

	Riverine		Estuarine	
	Summer	Fall	Summer	Fall
Limnocalanus macrurus	+	-	-	+
Amphipoda	0	0	<1	<1
Gammaracanthus loricatus	-	-	+	+
Gammarus oceanicus	-	-	+	-
Monoculodes borealis	-	-	+	+
Onisimus litoralis	-	-	+	+
Mysidacea	78	0	25	1
Mysis litoralis	100	-	100	100
Ostracoda	<1	0	<1	<1
Insecta	19	45	6	<1
Diptera				
Chironomidae	79	100	100	+
Ephemeroptera	+	-	-	-
Thysanoptera	+	-	-	-
Tricoptera	17	-	-	+
Hydrozoa	+	+	+	+
Diphasia pulchra	+	+	+	-
Hartlaubella sp.	+	-	+	-
Hartlaubella gelatinosa	-	+	+	+
Sertularia schmidti	+	-	+	-
Sertularia tenera	+	+	+	+
Ectoprocta	+	+	+	+
Celleporella hyalina	+	-	+	-
Cristatella mucedo	+	+	+	+
Eucratea loricata	+	+	+	+

Table 4. (continued)

	Riverine		Estuarine	
	Summer	Fall	Summer	Fall
Bivalvia	<1	<1	5	<1
Cyrtodaria kurriana	-	-	-	+
Macoma balthica	+	+	99	+
Mytilus edulis	-	-	+	-
Sphaerium rhomboideum	+	-	-	-
Sphaerum	+	-	-	-
Pelecypoda	+	-	-	-
Gastropoda	<1	<1	<1	<1
Ferrissia rivularis	-	+	-	-
Gyraulus parvus	-	+	-	+
Littorina obtusata	-	-	+	-
Lymnaea parva	-	+	+	-
Margarites olivaceus	+	-	-	-
Physa jennessi	+	-	-	-
Physa sp.	-	+	-	-
Probythinella lacustris	-	+	-	-
Stobilops labyrinthica	-	+	-	-
Vallonia gracilicosta	-	+	-	-
Valvata sincera	+	-	-	-
Valvata tricaranata	-	+	-	-
Nematoda	<1	<1	<1	<1
Foraminiferans	-	+	+	+

Table 5. Fish fauna occurring in the Nelson River and estuary indicating relative abundance in gillnet catches or presence (+) and absence (-).

Family Species	Common Name	Lower Nelson River [1]	Estuary 1988 [1]	Estuary 1989 [1]	Estuary 1992 [2]
Acipenceridae					
Acipencer fulvescens	Lake sturgeon	4.1	1	-	-
Hiodontidae					
Hiodon alosoides	Goldeye	0.4	1	-	-
Hiodon tergisus	Mooneye	0.5	-	-	-
Esocidae					
Esox lucius	Northern pike	6.8	1	0.3	-
Salmonidae					
Salevelinus fontinalis	Brook trout	-	-	0.3	-
Coregonus artedii	Lake cisco	4.5	17	0.5	+
Coregonus clupeaformis	Lake whitefish	8.3	24	43.9	-
Osmeridae					
Mallotus villosus	Capelin	-	-	-	+
Cyprinidae					
Couesius plumbeus	Lake chub	3.4	-	-	-
Catostomidae					
Catostomus catostomus	Longnose sucker	57.6	52	55	-
Catostomus commersoni	White sucker	8.9	2	-	-
Gadidae					

Table 5. (continued)

Family Species	Common Name	Lower Nelson River [1]	Estuary 1988 [1]	Estuary 1989 [1]	Estuary 1992 [2]
Lota lota	Burbot	2.6	-	-	-
Gasterosteidae					
Pungitius pungitius	Ninespine stickleback	-	-	-	+
Gasterosteus aculeatus	Threespine stickleback	-	-	-	+
Percidae					
Stizostedion vitreum	Walleye	1.9	-	-	-
Stizostedion canadense	Sauger	0.7	-	-	-
Perca fluviatilis flavescens	Yellow perch	0.1	-	-	-
Stichaeidae					
Stichaeus punctatus	Arctic shanny	-	-	-	-
Lumpenus fabricii	Slender eelblenny	-	-	-	+
Ammodytidae					
Ammodytes americanus	American sand lance	-	-	-	+
Cottidae					
Myoxocephalus quadricornis	Fourhorned sculpin	-	1	-	+

[1] MacDonell and Bernhardt (1992)

[2] Baker et al. (1993)

Table 6. Water chemistry for the Churchill estuary. Data from Lawrence and Baker (1994).

Distance from Mosquito Point (km)	Depth (m) of sample	Total Dissoved Nitrogen (mg m^{-3})	Total Dissolved Phosphorus (mg m^{-3})
3.7	0	415	8
3.7	1.5	320	9
7.7	0	470	14
7.7	2	510	29
7.7	3.5	460	27
11.4	0	450	25
11.4	2	440	25
11.4	5	415	25
11.4	11	410	25
13.5	0	405	25
13.5	2	400	26
13.5	5	370	23
13.5	13	390	23
18.5	0	405	23
18.5	2	380	25
18.5	5	375	24
18.5	10	370	24
18.5	bottom	370	25
25	0	390	26
25	2	380	27
25	5	385	26
25	10	380	27
25	25	370	28

Table 7. Percent composition (%) and total density animals of major taxonomic groups in benthic samples from the inner and outer Churchill estuary and Hudson Bay. Data from Lawrence and Baker (1994).

	Inner Estuary	Outer Estuary	Hudson Bay
Polychaeta	7.3	40.6	29.4
Oligochaeta	55.1	10.0	50.8
Copepoda	0	0.3	<0.1
Amphipoda	26.2	1.7	4.9
Cumacea	0	0.3	0.7
Ostracoda	0	<0.1	<0.1
Insecta	0.2	0.2	<0.1
Anenome	0	0.7	<0.1
Cnidaria	0.6	0	0
Bryozoa	0.4	<0.4	0
Ascidia	1.7	0.3	<0.1
Bivalvia	6.2	38.7	5.3
Gastropoda	0.6	<0.1	0.1
Nematoda	1.7	6.8	8.1
Total density (animals m^{-2})	2256	7166	2674

Table 8. Fish fauna occurring in the lower Churchill River including fish captured moving up Goose Creek, a tributary stream, and the estuary. Sampling in the Churchill River mainstem and the estuary is limited so species lists are not complete. Numbers under Goose Creek indicate orders of abundance in spring hoopnet catches. Present (+), absent (-), anecdotal report (*).

Family Species	Common Name	Churchill River [1]	Goose Creek [1]	Estuary [2]	Estuary [3]
Acipenceridae					
Acipencer fulvescens	Lake sturgeon	*	-	-	-
Esocidae					
Esox lucius	Northern pike	+	2	-	+
Salmonidae					
Salvelinus alpinus	Arctic char	*	-	-	+
Salvelinus fontinalis	Brook trout	*	7	-	-
Coregonus artedii	Lake cisco	+	8	-	+
Coregonus clupeaformis	Lake whitefish	+	3	+	+
Prosopium cylindraceum	Round whitefish	+	9	-	+
Thymallus arcticus	Arctic grayling	*	5	-	-
Osmeridae					
Mallotus villosus	Capelin	-	-	*	+
Catostomidae					
Catostomus catostomus	Longnose sucker	*	1	-	+
Catostomus commersoni	White sucker	+	4	-	-

Table 8. (continued)

Family Species	Common Name	Churchill River [1]	Goose Creek [1]	Estuary [2]	Estuary [3]
Gadidae					
Lota lota	Burbot	+	6	-	-
Gasterosteidae					
Pungitius pungitius	Ninespine stickleback	-	+	-	+
Percidae					
Stizostedion vitreum	Walleye	*	-	-	-
Stichaeidae					
Stichaeus punctatus	Arctic shanny	-	-	+	-
Lumpenus fabricii	Slender eelblenny	-	-	+	+
Ammodytidae					
Ammodytes americanus	American sand lance	-	-	+	-
Cottidae					
Cottus cognatus	Slimy sculpin	-	+	-	-
Myoxocephalus quadricornis	Fourhorned sculpin	-	+	+	+

[1] Remnant and Bernhardt 1994
[2] Lawrence and Baker 1994
[3] Keleher 1953

Table 9. Chemical characteristics of coastal waters of northeastern James Bay along a salinity gradient in the plume of the La Grande River (SEBJ 1990).

A. Summer 1983	Suspended Solids (mg/L)	Suspended Organic Carbon (mg/L)	Suspended Organic Nitrogen (mg/L)	Orthophosphates (mg/L)	Total Phosphorus (mg/L)	Chl a (µg/L)
Surface 0 - 5‰	8.02	.4460	.0524	.006	.019	3.37
Surface 5 - 18‰	3.14	.3149	.0431	.007	.019	1.72
Surface 18 - 24‰	2.68	.2164	.0315	.012	.020	1.57
18 metres 20 - 25‰	1.57	.1570	.0180	.016	.022	.26

B. Winter 1987	Suspended Solids (mg/L)	Suspended Organic Carbon (mg/L)	Suspended Organic Nitrogen (mg/L)	Orthophosphates (µmol/L)	Total Nitrogen (µmol/L)	Chl a (µg/L)
Surface 0 - 5‰	1.52	.1741	.0152	.11	3.7	.10
Surface 5 - 15‰	1.37	.1293	.0106	.27	2.3	.05
Surface 15 - 24‰	.90	.1468	.0142	.55	2.4	.03
6 - 20 metres 20 - 26‰	.90	.0470	.0053	.69	2.2	.02

Table 10. Benthos at various sites in the La Grande estuary. Dash indicates species not found at locality, x indicates was found (Dadswell 1974).

	Riverine	Brackish	Plume	Plume	Intertidal	Intertidal	James Bay
Polychaeta							
Cistenides hyperborea	-	-	x	x	-	-	-
C. granulata	-	-	-	x	-	-	-
Antinoella sarsi	-	-	-	x	-	-	x
Scolelepis sp.	-	-	-	x	-	-	-
Aglaophamus malmgreni	-	-	-	-	-	-	x
Crustacea							
Mysis oculata	-	-	x	x	-	-	x
Atylus carinctus	-	-	-	x	-	-	-
Pontoporeia femorata	-	-	-	x	-	-	x
Aceropsis latipes	-	-	-	-	-	-	x
Monoculodes edwardsi	-	-	-	-	-	-	x
Gammarus setosus	-	-	-	-	-	x	x
G. oceanicus	-	-	-	-	-	x	-
Mollusca							
Macoma baltica	-	-	-	-	-	-	x
Mytilus edulis	-	-	-	-	-	-	x
Buccinium tenue	-	-	-	x	-	-	-
Admete couthouyi	-	-	-	x	-	-	-
Echinodermata							
Urasterias linki	-	-	-	x	-	-	-

Table 11. Water chemistry in the Eastmain estuary before and after diversion and resulting salinity intrusion (Messier 1985).

	1979-1980	1984
Nitrates-nitrites (mg l^{-1} N)	0.003	0.01-0.02
Phosphates (mg l^{-1} P)	0.01	0.01-0.02
Chlorophyll (μg l^{-1})	0.50-1.5	0.60-2.74
Salinity (‰)	0	0-15

Table 12. Benthic fauna of the Eastmain estuary showing the percent composition by major groups and the percent contribution of major species within a group (Grenon 1982).

	% Total	%Group
Polychetes	11.8	
Terebellides stroemi		54.0
Aglaophamus neotenus		25.4
Praxillella praetermissa		12.8
Aglaophamus rubella		<7.6
Exogone verugera		<7.6
Scoloplos armiger		<7.6
Harmothoe extenuata		<7.6
Eteone longa		<7.6
Crustacea	1.9	
Diastylis rathkei		47.2
Atylus carinatus		24.0
Onisimus littoralis		19.7
Corophium crassicorne		<9.0
Pontoporeia femorata		<9.0
Mysis mixta		<9.0
Balanus crenatus		<9.0
Insecta	51.9	
Stictochironomus		100
Ectoprocta	<0.6	
Alcyonidium gelatinosum		
Electra crustulenta var. arctica		
Gemmellaria loricata		
Scrupocellaria scabra		
Mollusca	33.8	
Bivalvia		

Table 12. (continued)

	% Total	%Group
Macoma balthica		81.7
Mytilus edulis		14.7
Nucula belloti		<3.6
Nuculana pernula		<3.6
Pisidium casertaneum		<3.6
Entodesma sp.		<3.6
Gastropoda		
Cylichna alba		80.5
Margarites olivaceus		19.5

Table 13. A comparison of fish species abundance in nine rivers and estuaries of Hudson and James bays. Relative abundance is indicated as % of total catch or as incidental (*), common (**), or abundant (***). Eastern Hudson/James Bay estuaries are from Morin et al. (1980), Morin and Dodson (1986), and Kemp et al. (1989). Western Hudson Bay estuaries are from Baker et al. (1993) and Lawrence and Baker (1994).

Family Species	Rupert Bay	Eastmain	La Grande	Grande Baleine	Petite Baleine	Innuksuak	Povungnituk	Nelson	Churchill
Petromyzontidae									
Ichthyomyzon unicuspis								*	
Acipenceridae									
Acipencer fulvescens	*	*	*					*	*
Hiodontidae									
Hiodon alosoides								*	
Hiodon tergisus	*							*	
Esocidae									
Esox lucius	*	*	*	*	*			*	*
Salmonidae									
Salvelinus fontinalis	*	5	*	11	28	27	8	*	*
S. alpinus						6	14		*
S. namaycush				1	*	2	3		
Coregonus artedii	6.3	43	48	2	4	2	14	**	**
C. clupeaformis	7.1	47	11	5	16	42	27	**	**
Prosopium cylindraceum		*	1	13	3	7	31		**
Thymallus arcticus									*
Salmo salar						*			
Osmeridae									
Mallotus villosus	*	*	**	1	20	3		*	***
Cyprinidae									
Rhinichthys cataractae		*	*					*	
R. atratulus								*	

Table 13. (continued)

Family Species	Rupert Bay	Eastmain	La Grande	Grande Baleine	Petite Baleine	Innuksuak	Povungnituk	Nelson	Churchill
Petromyzontidae									
Phoxinus neogaeus								*	
P. eos								*	
Semotilus margarita			*					*	
S. corporalis		*							
Notropis hudsonius	*	*	*					*	
N. atherinoides			*					***	*
Couesius plumbeus	*	*		3	1			*	
Cyprinus carpio								*	
Pimephales promelas								*	
Catostomidae									
Catostomus catostomus	52.6	**	**	30	15			***	**
Catostomus commersoni	6.0	*	1	*		2		**	**
Moxostoma macrolepidotum								*	
Gadidae									
Lota lota	*	*	*	*	*	1		**	*
Gadus ogac		*	*	5	1	**			
Gasterosteidae									
Culea inconstans			*					*	
Pungitius pungitius		*	*					**	*
Gasterosteus aculeatus	*	*	*	*	*	*		*	*
Percopsidae									
Persopsis omiscomaycus	*	*	*	*	*	*		*	
Percidae									

Table 13. (continued)

Family Species	Rupert Bay	Eastmain	La Grande	Grande Baleine	Petite Baleine	Innuksuak	Povungnituk	Nelson	Churchill
Petromyzontidae									
Etheostoma nigrum								*	
P. shumardi								*	
P. caprodes								*	
Stizostedion vitreum	24.8	**	*					*	*
S. canadense	*							*	
Perca fluviatilis flavescens		*						*	
Sciaenidae									
Aplodinotus grunniens								*	
Stichaeidae									
Stichaeus punctatus								*	*
Lumpenus fabricii			*	*	*			*	*
Ammodytidae									
Ammodytes americanus	*	*	*	*	*	*		***	**
A. dubius				*	*				
Cottidae									
Cottus ricei	*							*	
C. cognatus		*	*			*		*	*
C. bairdi		*							
Myoxocephalus quadricornis		**	**	18	3	11		**	**
M. scorpioides		*	*		*	4			
M. scorpius		*	2	3	6				

LIST OF FIGURE CAPTIONS

Figure 1. The Hudson Bay bioregion.

Figure 2. Monthly flow of the Seal River, an unregulated river. Data from Canada (1991).

Figure 3. Monthly flow of the Nelson River before and after flow regulation and augmentation in 1976. Data provided by Manitoba Hydro.

Figure 4. Monthly flow of the Churchill River before and after diversion (CRD) in 1976. Data from Canada (1991) and the Lake Winnipeg, Churchill & Nelson Rivers Study Board (1971-75).

Figure 5. Flow of the La Grande River on the eastern shore of James Bay since regulation. Heavy lines show minimum and maximum flows under natural conditions (SEBJ, unpublished data).

Figure 6. Monthly flow of the Eastmain River before and after diversion (Messier et al. 1986).

Figure 7. The lower Nelson River and estuary (Baker 1989).

Figure 8. Salinity in the Nelson estuary at high tide (Baker 1989).

Figure 9. The Churchill estuary (Lawrence and Baker 1994).

Figure 10. Salinity in the Churchill estuary and offshore. The mouth of the estuary is at km 13.5. Data from Lawrence and Baker (1994).

Figure 11. The La Grande estuary (Messier 1985).

Figure 12. Schematic evolution of the La Grande plume from 1976 (pre-development) to 1984 (post-development) (Messier et al. 1986).

Figure 13. Relative importance and salinity tolerance of fish caught in James Bay (after Messier 1985). Relative abundance indicated as follows: >30% ***; 10-30% **; 5-10% *; present +.

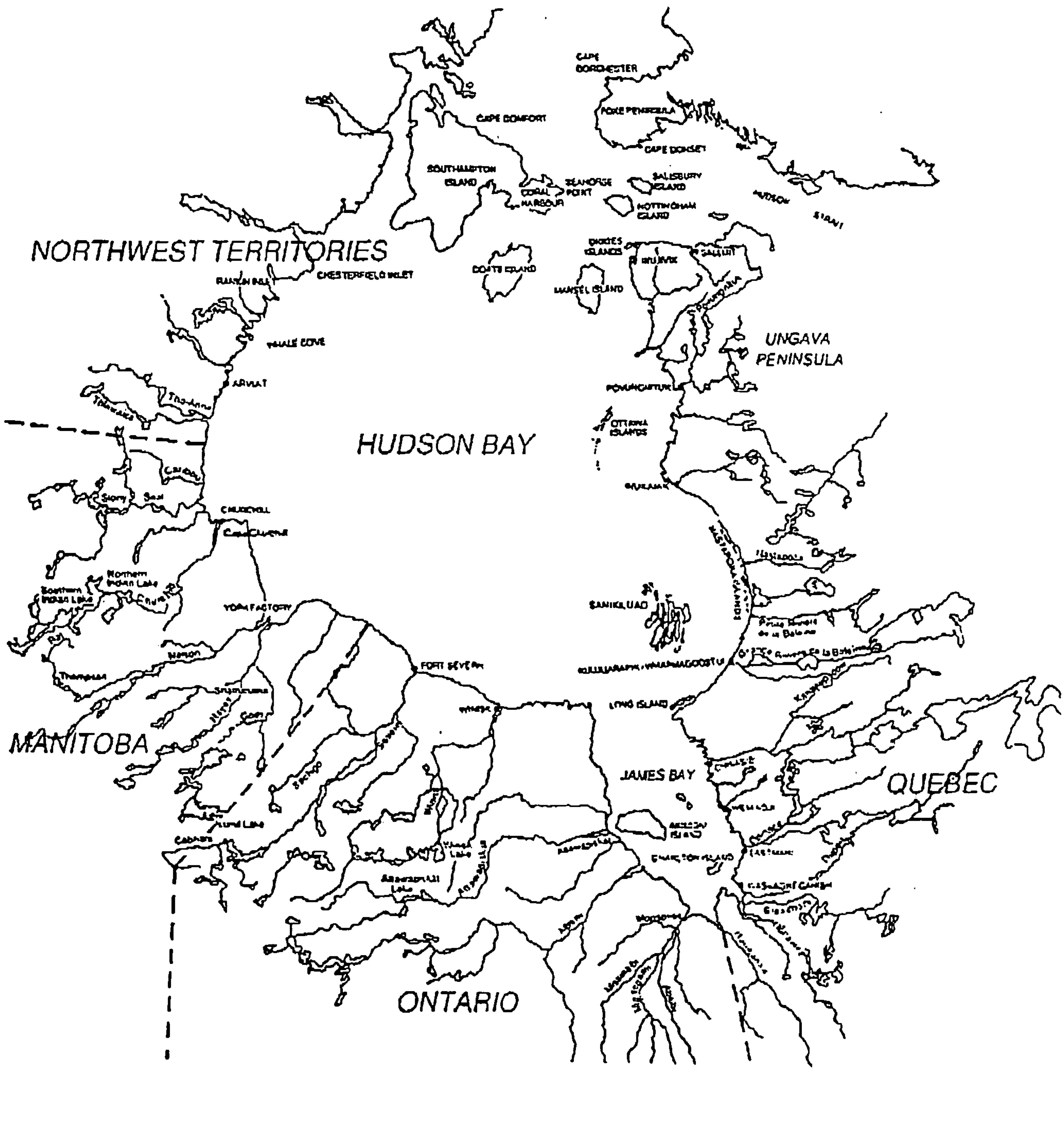
Figure 14. The Eastmain estuary showing salinity before and after diversion (Messier et al. 1986).

Figure 15. Map of Chesterfield Inlet between Baker Lake and Hudson Bay.

Figure 16. Beluga stocks in the Hudson Bay region during the summer (Baker et al. 1992).

Figure 17. Beluga stocks in the Hudson Bay region during the winter (Baker et al. 1992).

FIGURE 1: THE HUDSON BAY BIOREGION



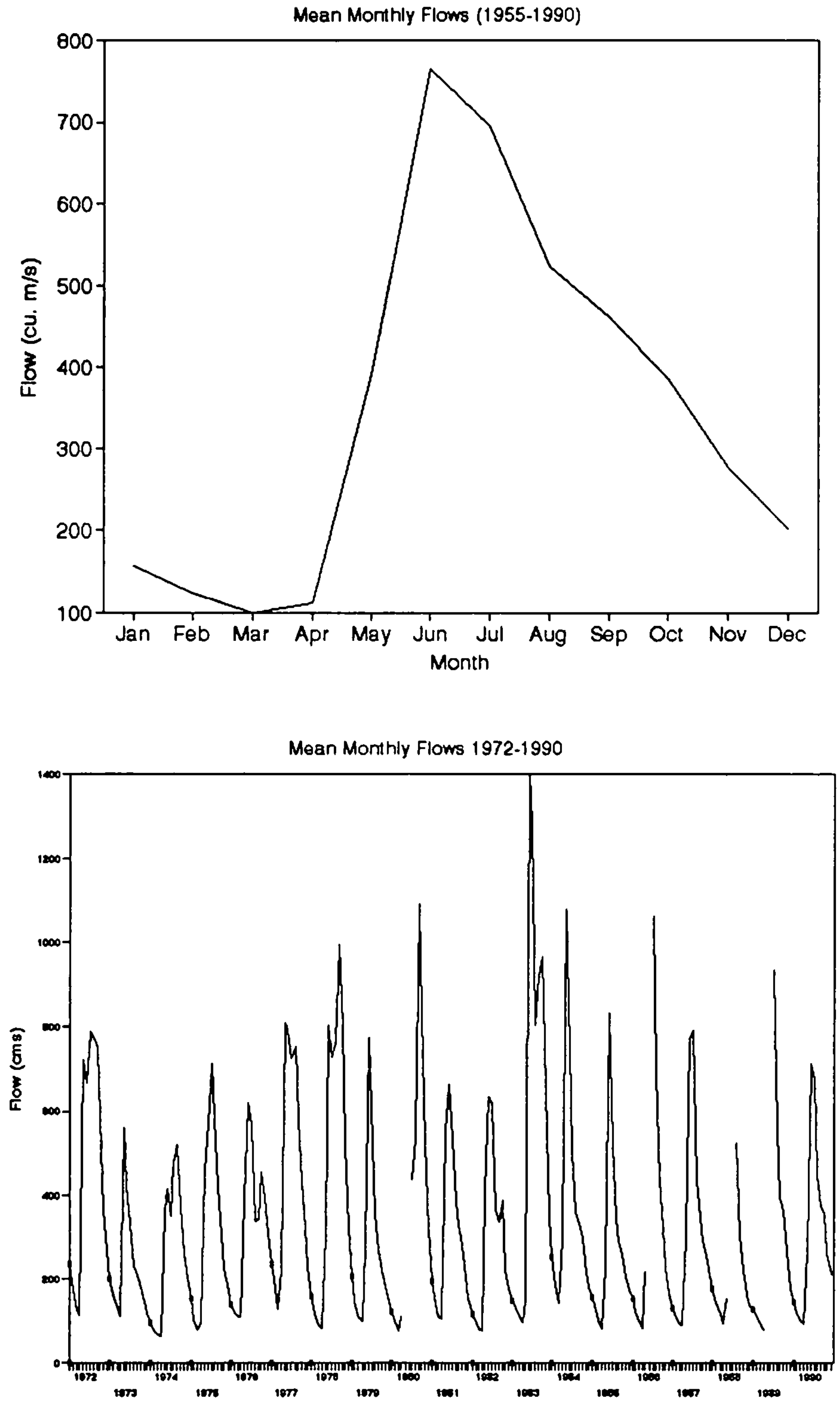


Figure 2. Monthly flow of the Seal River, an unregulated river. Data from Canada (1991).

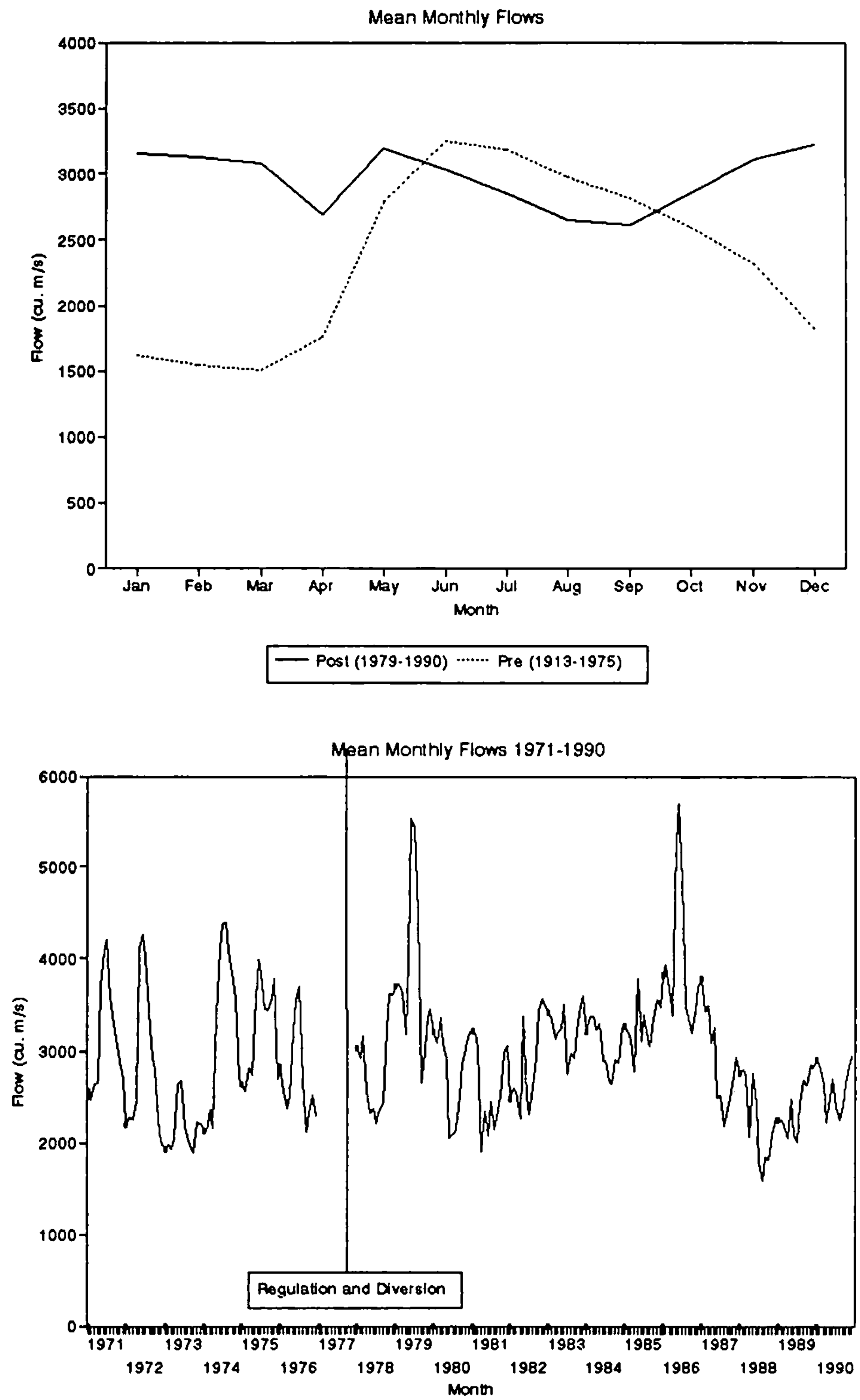


Figure 3. Monthly flow of the Nelson River before and after flow regulation and augmentation in 1976. Data provided by Manitoba Hydro.

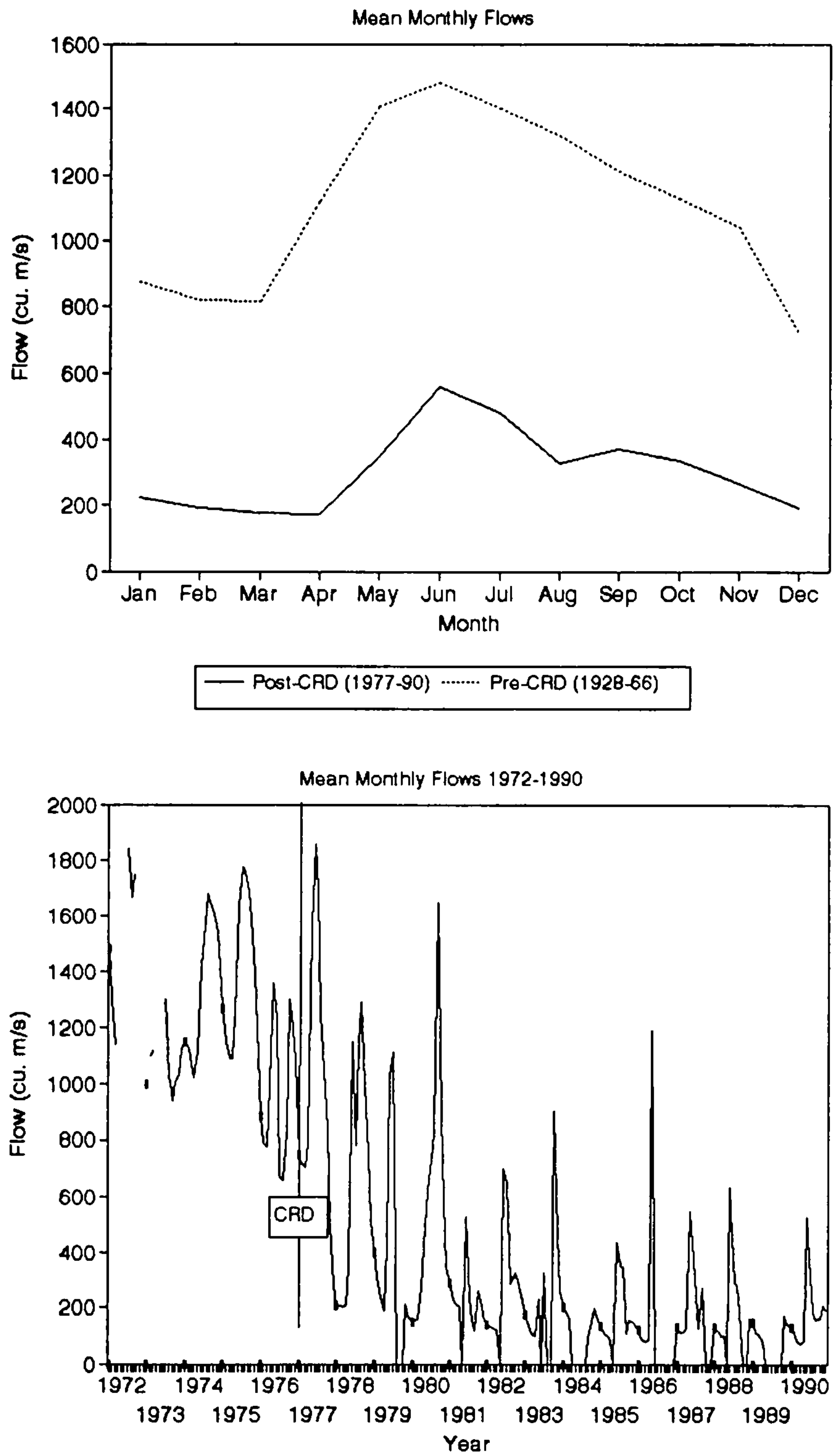


Figure 4. Monthly flow of the Churchill River before and after diversion (CRD) in 1976. Data from Canada (1991) and the Lake Winnipeg, Churchill & Nelson Rivers Study Board (1971-75).

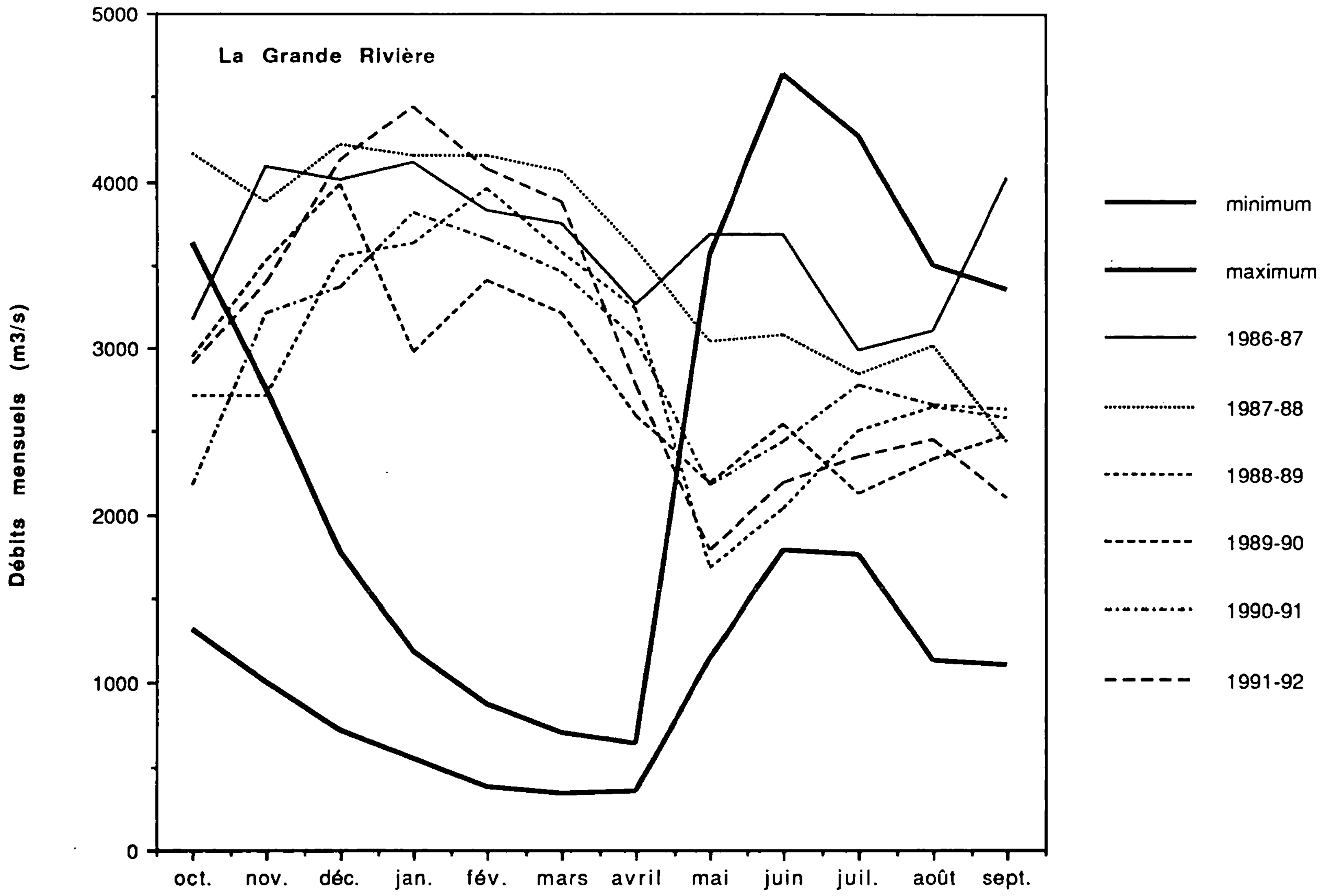


Figure 5. Flow of the La Grande River on the eastern shore of James Bay since regulation. Heavy lines show minimum and maximum flows under natural conditions (SEBJ, unpublished data).

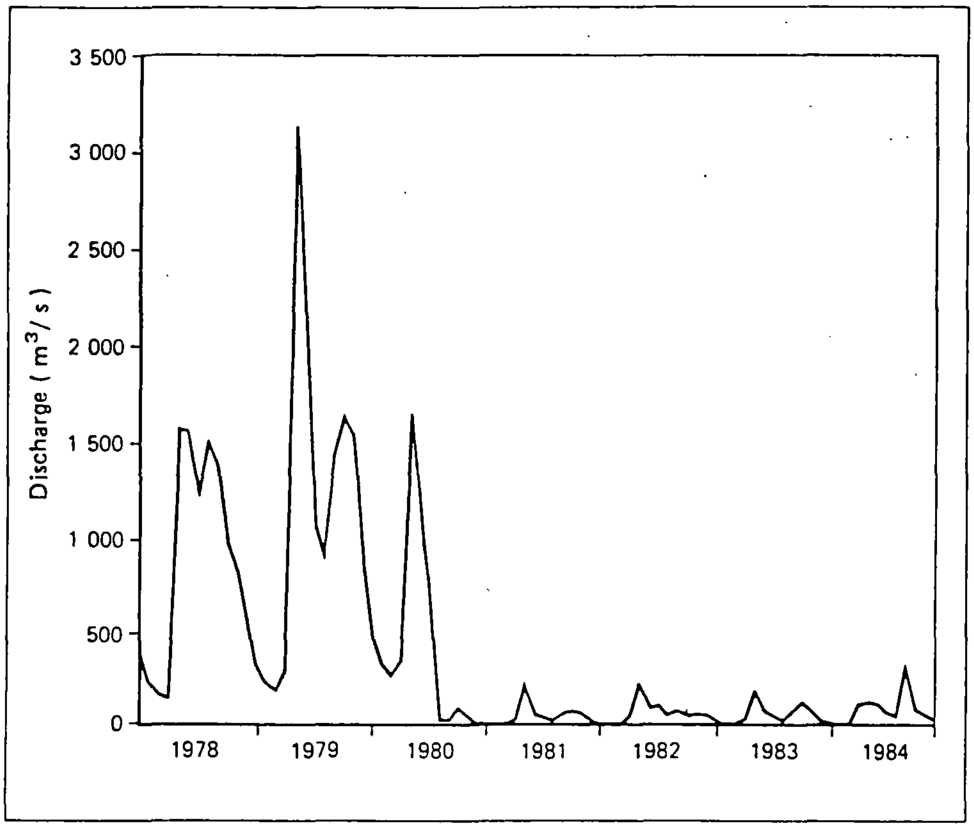


Figure 6. Monthly flow of the Eastmain River before and after diversion (Messier et al. 1986).

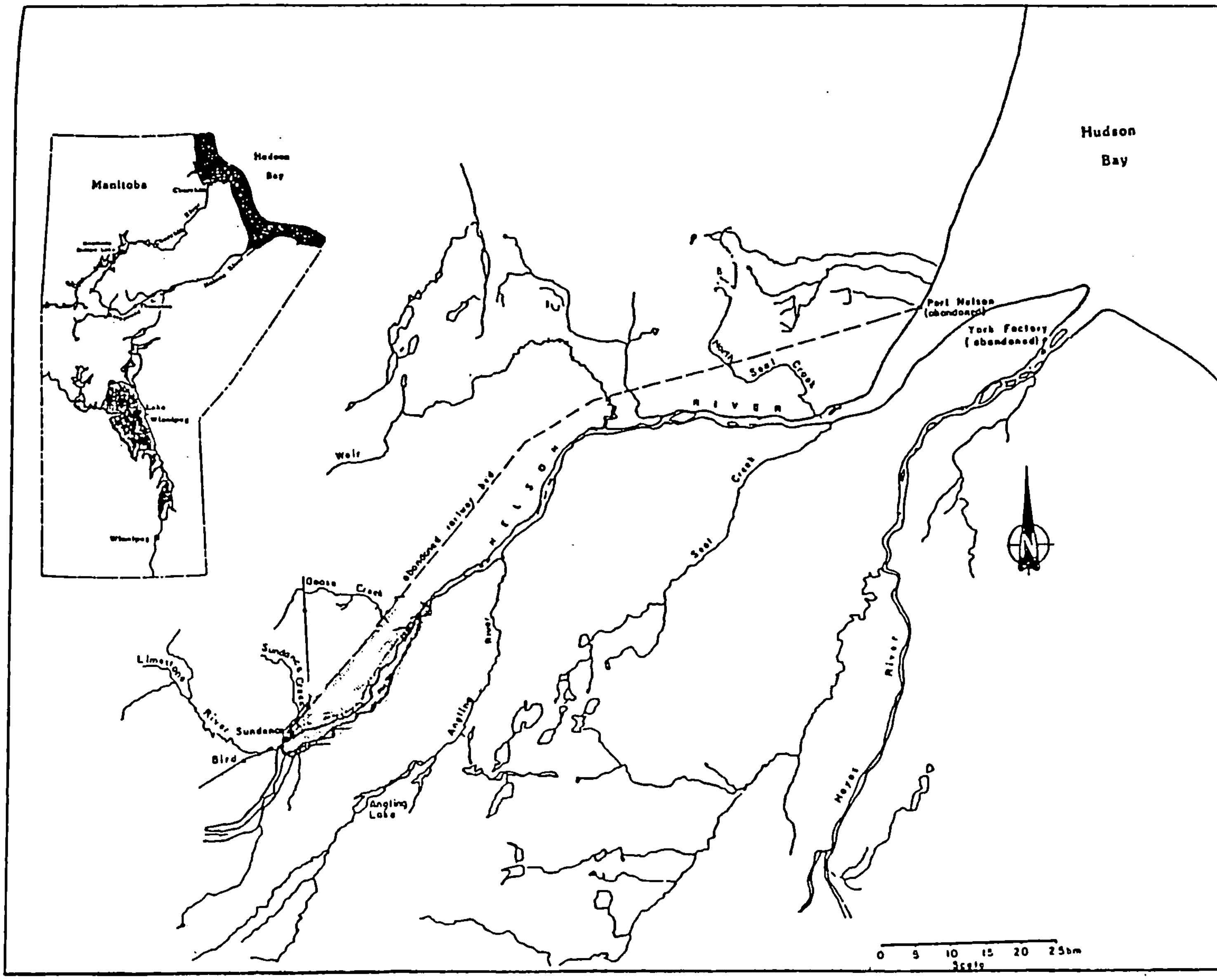


Figure 7. The lower Nelson River and estuary (Baker 1989).

Figure 8. Salinity in the Nelson estuary at high tide (Baker 1989).

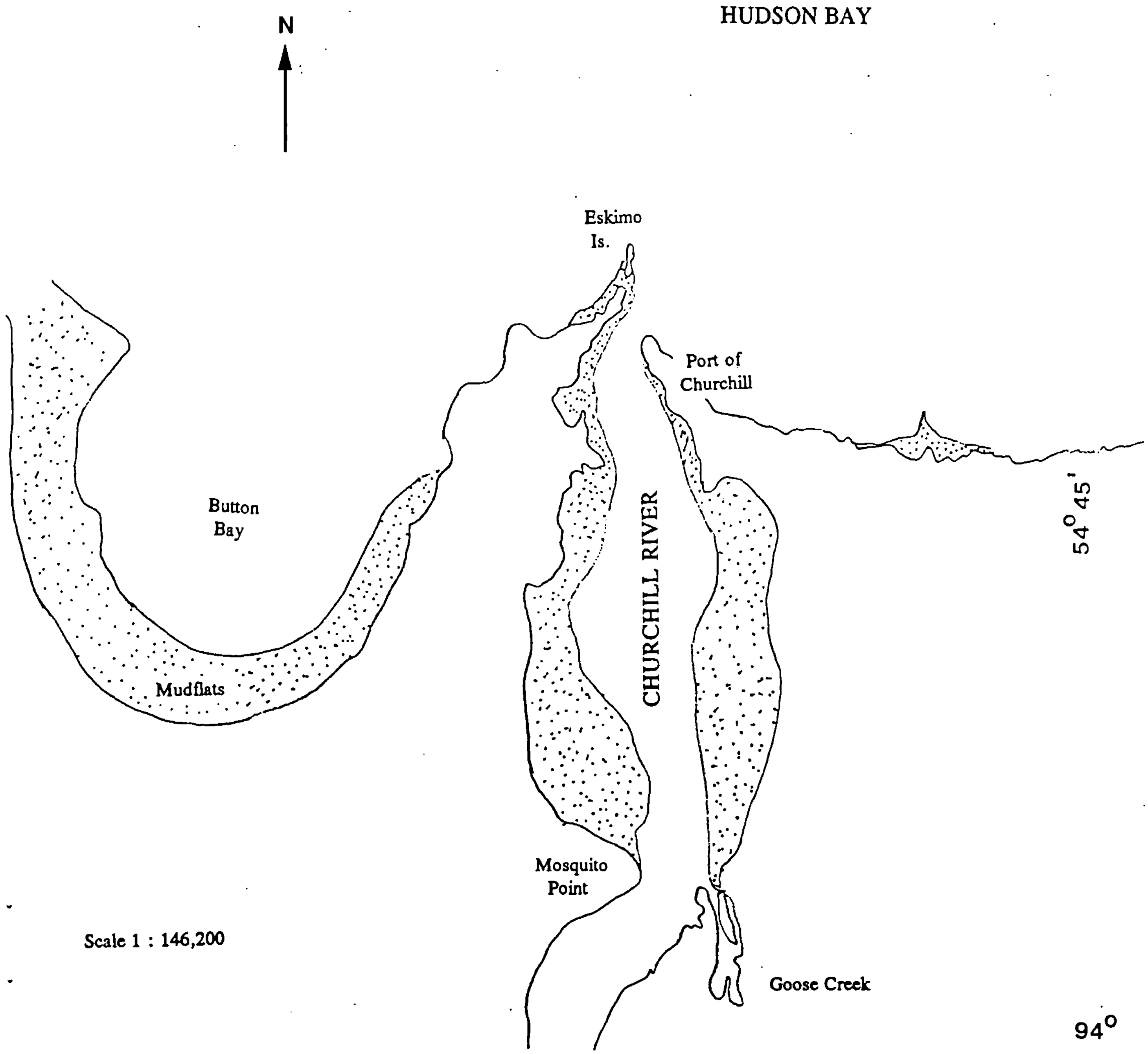


Figure 9. The Churchill estuary (Lawrence and Baker 1994).

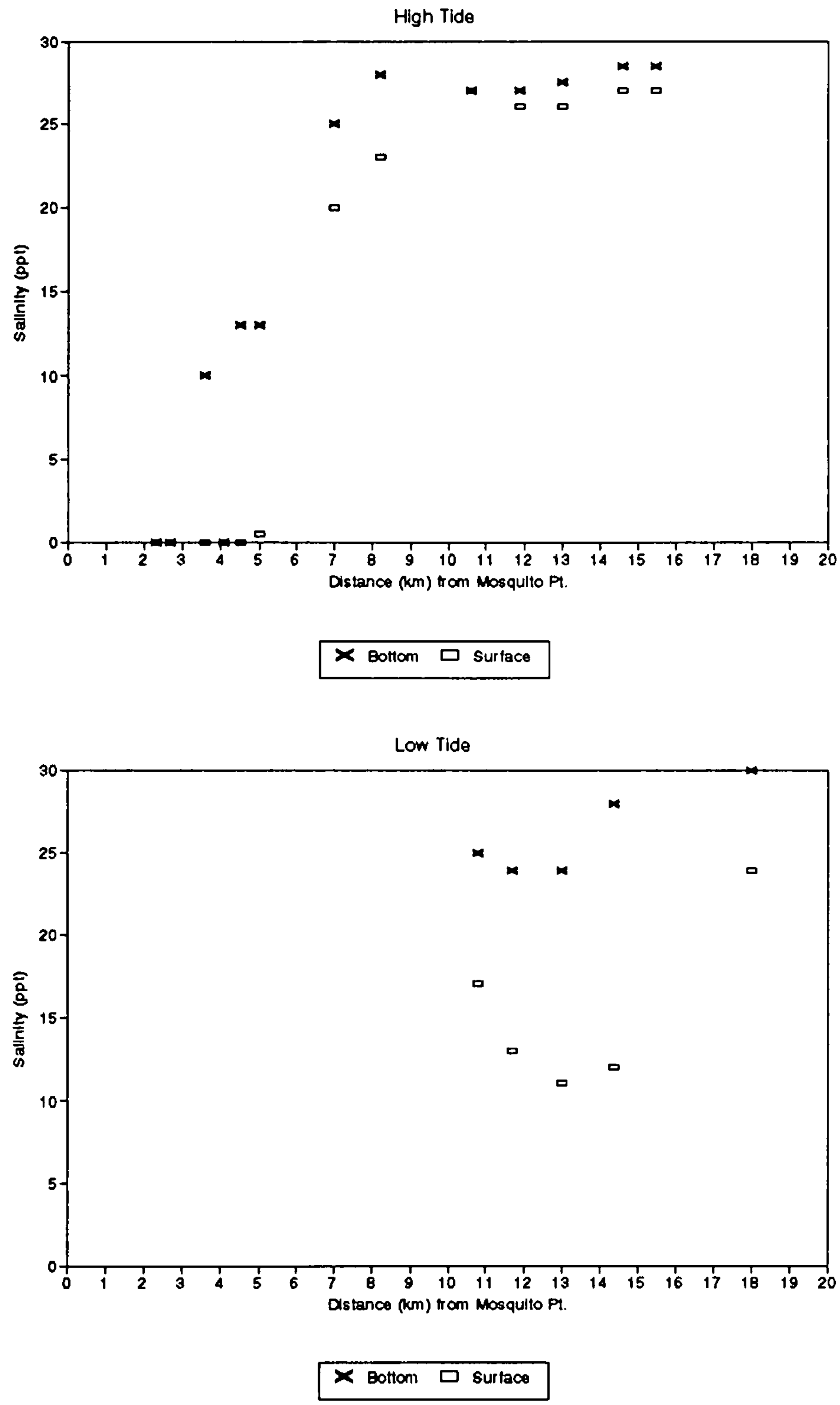


Figure 10. Salinity in the Churchill estuary and offshore. The mouth of the estuary is at km 13.5. Data from Lawrence and Baker (1994).

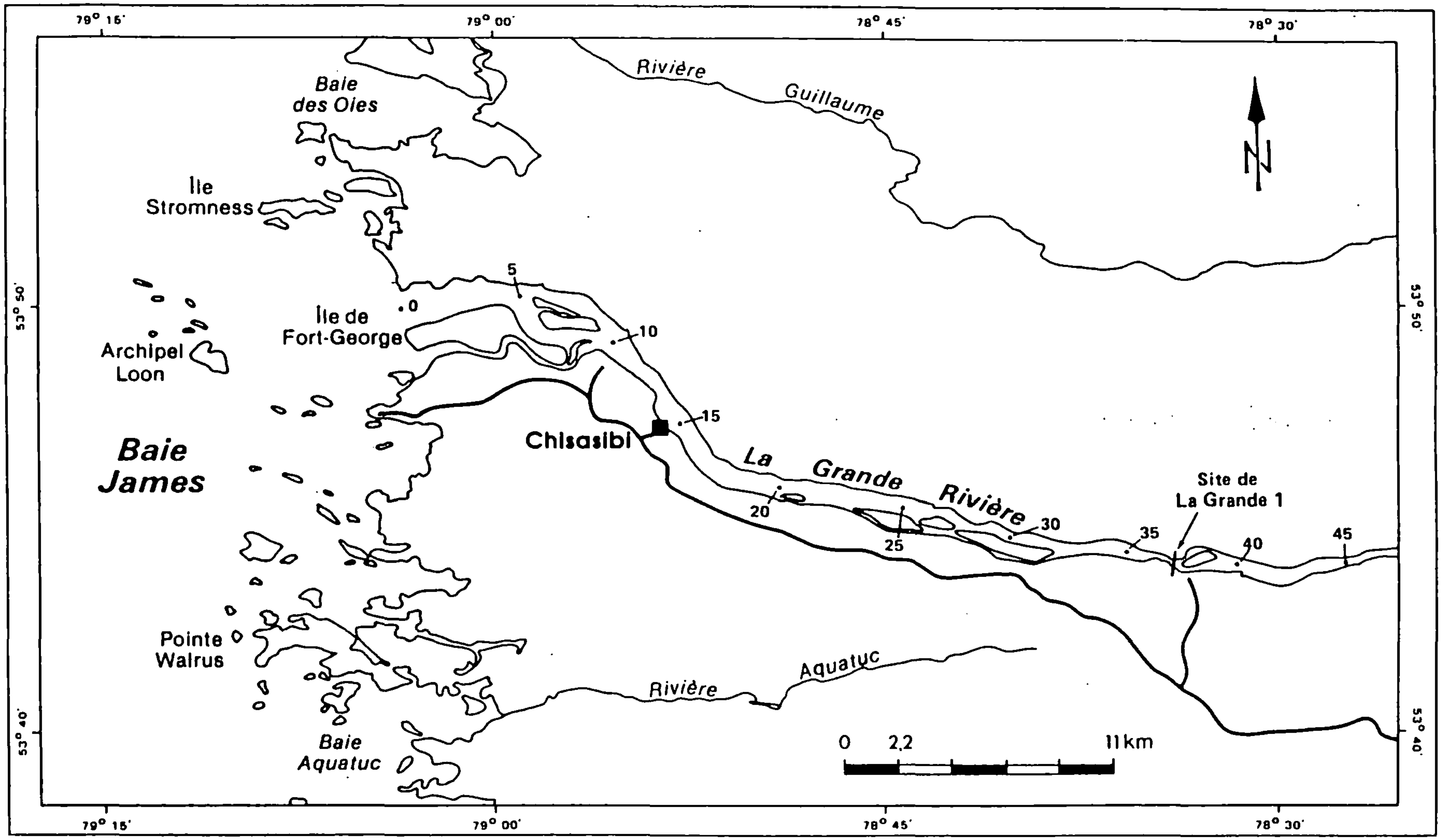


Figure 11. The La Grande estuary (Messier 1985).

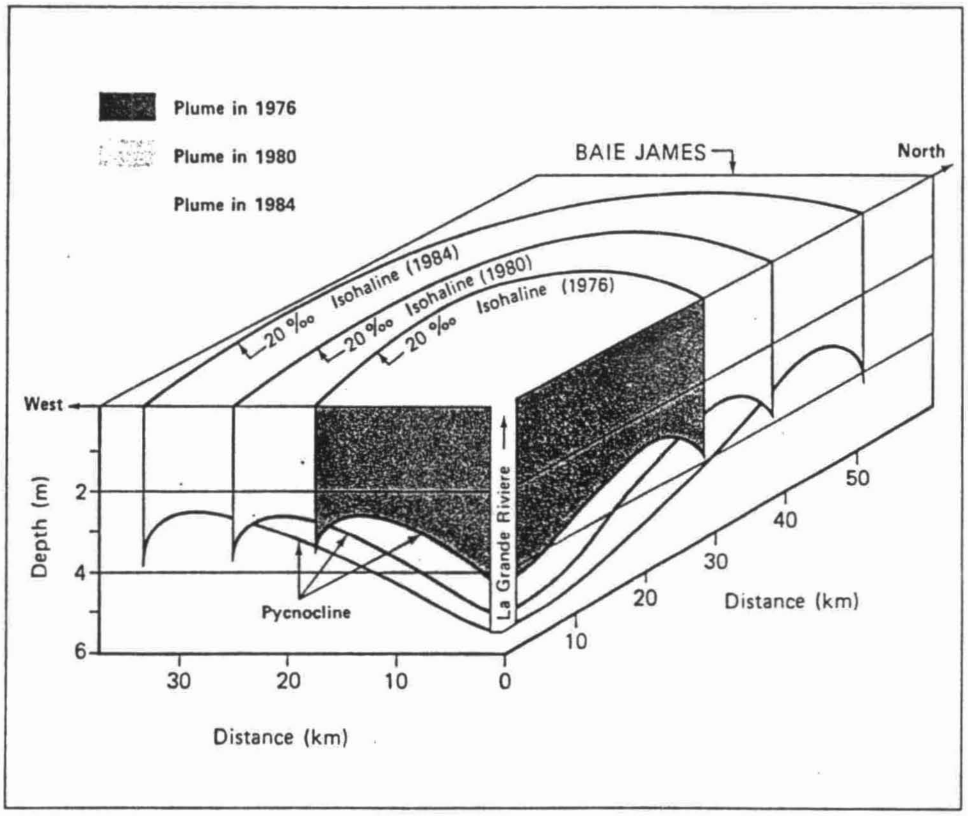


Figure 12. Schematic evolution of the La Grande plume from 1976 (pre-development) to 1984 (post-development) (Messier et al. 1986).

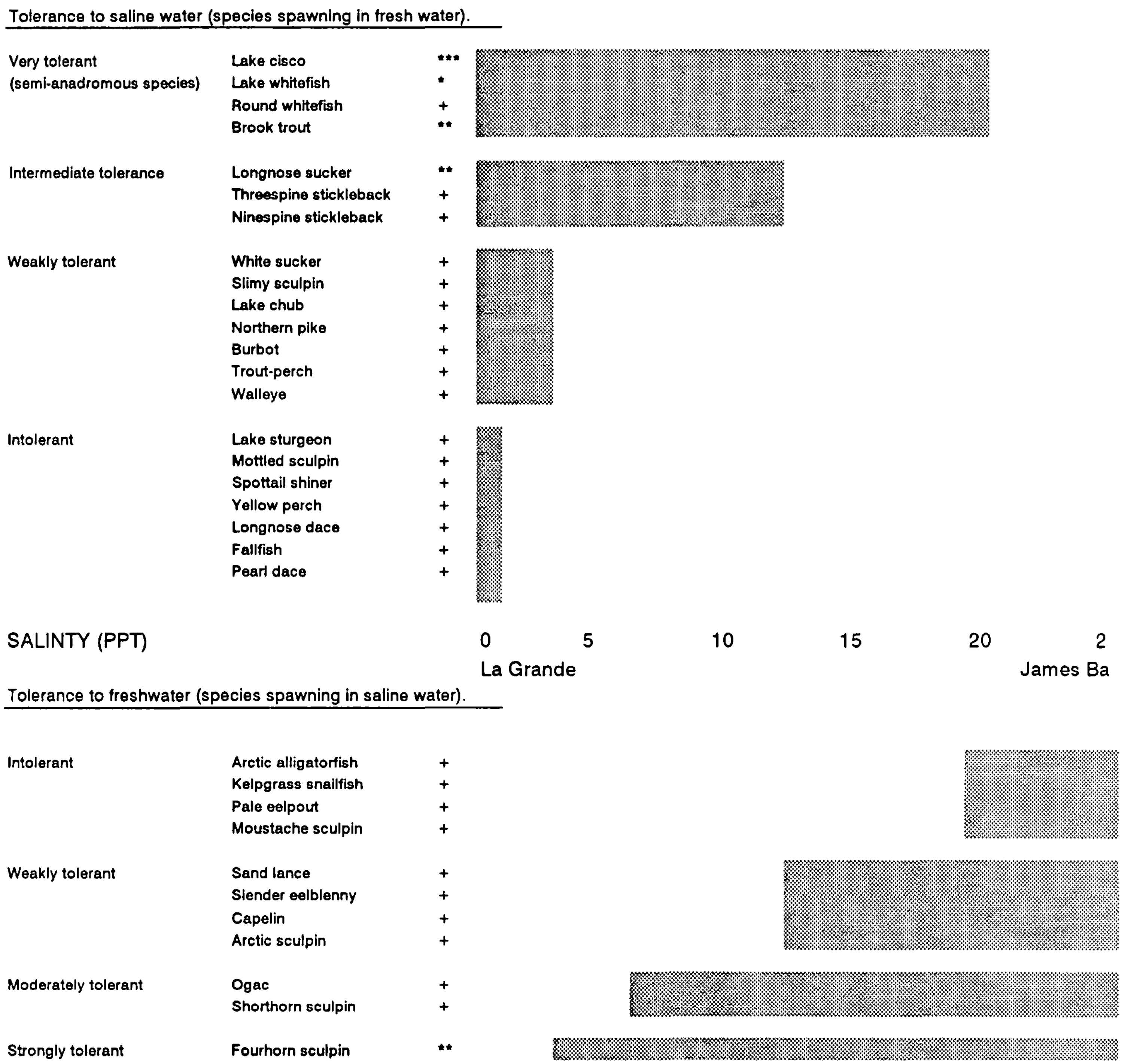


Figure 13. Relative importance and salinity tolerance of fish caught in James Bay (after Messier 1985). Relative abundance indicated as follows: >30% ***; 10-30% **; 5-10% *; present +.

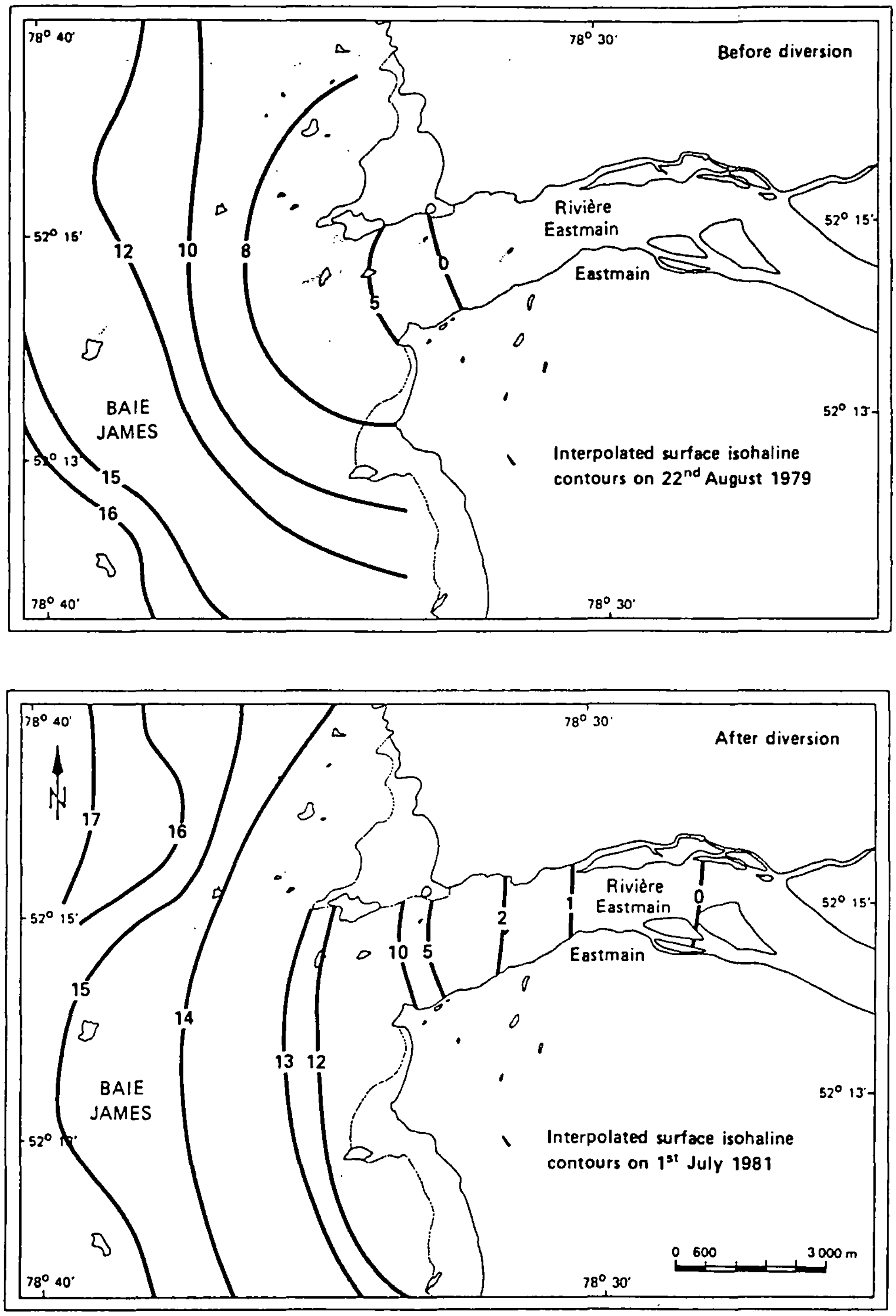


Figure 14. The Eastmain estuary showing salinity before and after diversion (Messier et al. 1986).

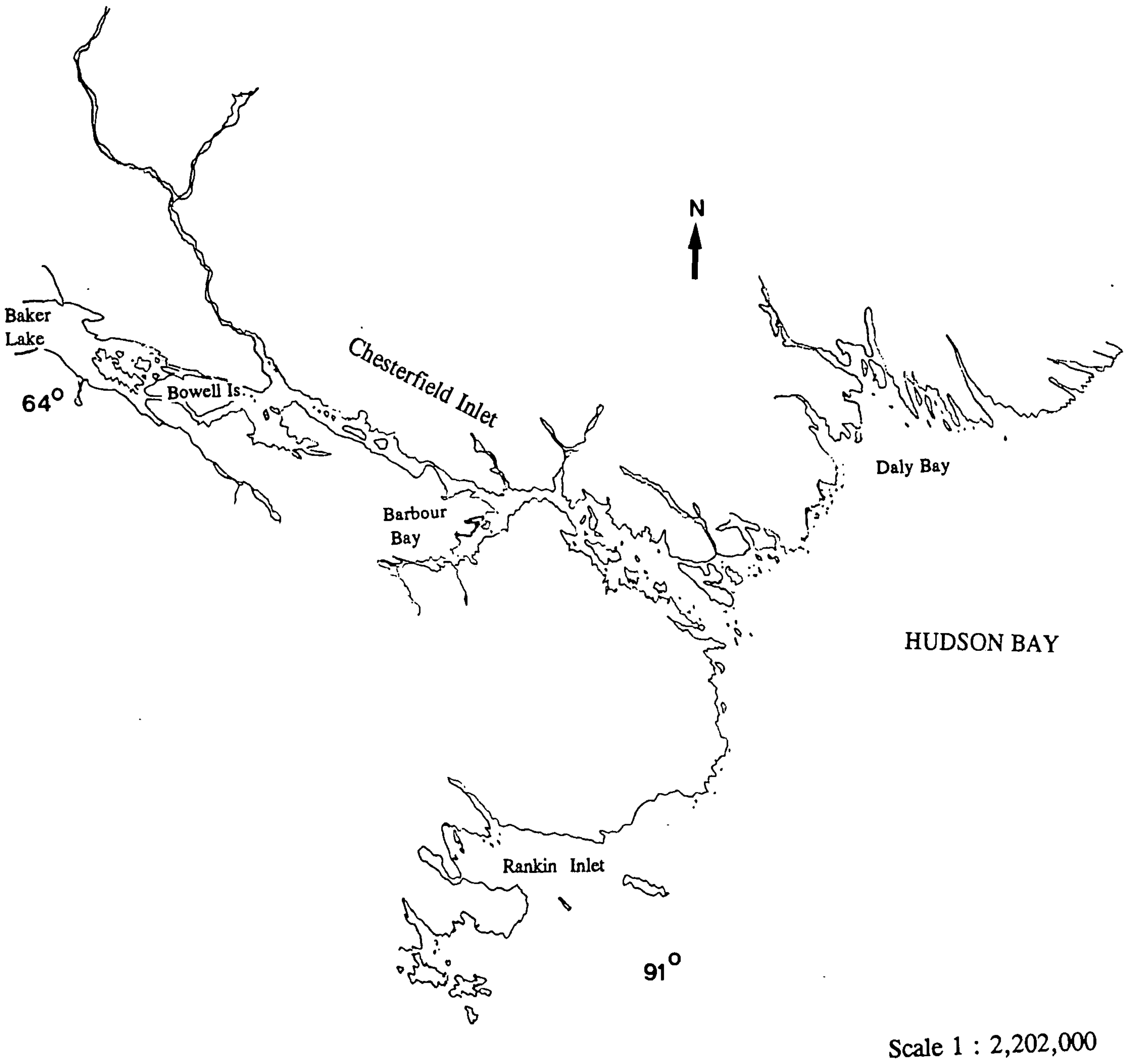


Figure 15. Map of Chesterfield Inlet between Baker Lake and Hudson Bay.

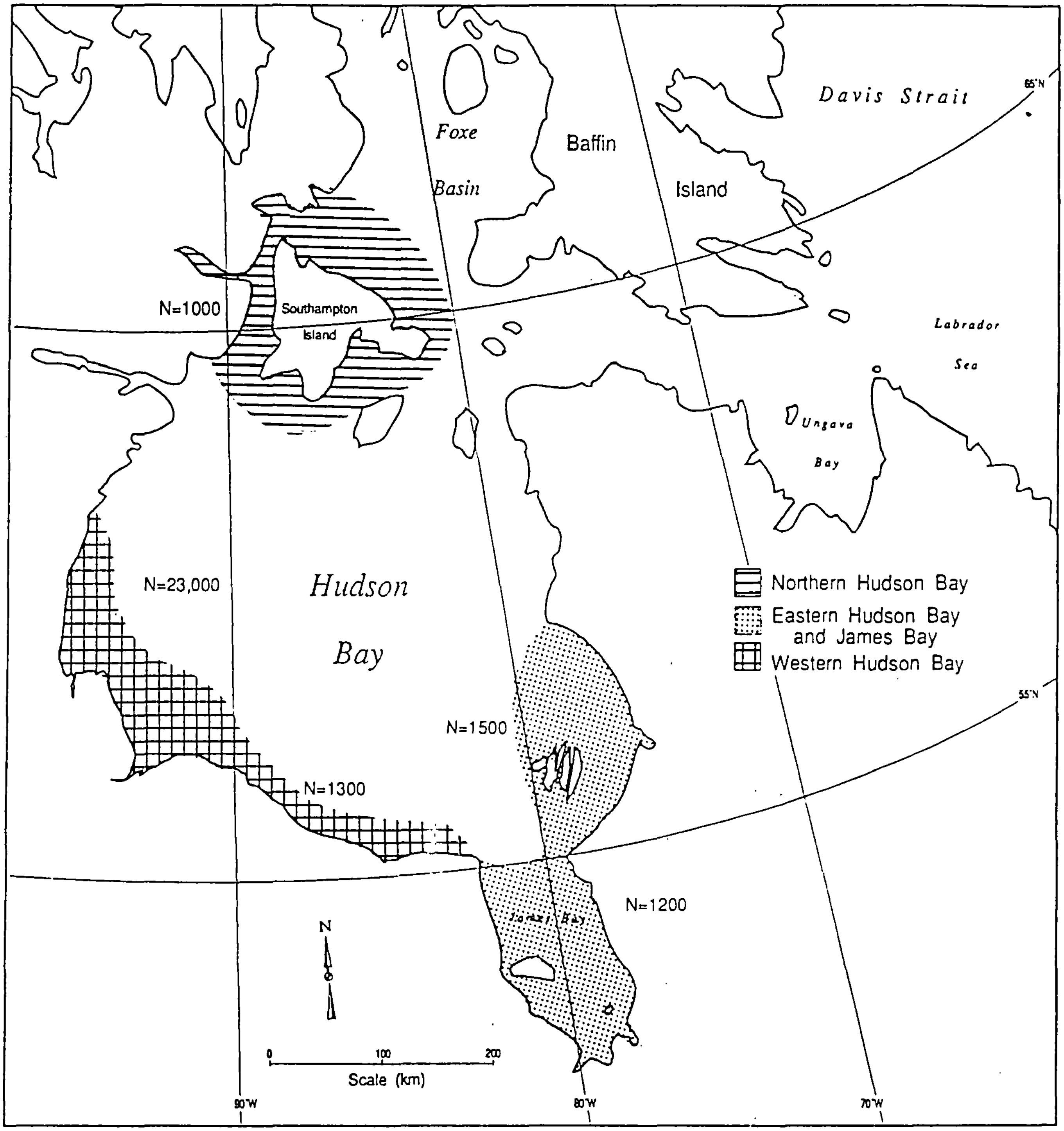


Figure 16. Beluga stocks in the Hudson Bay region during the summer (Baker et al. 1992).

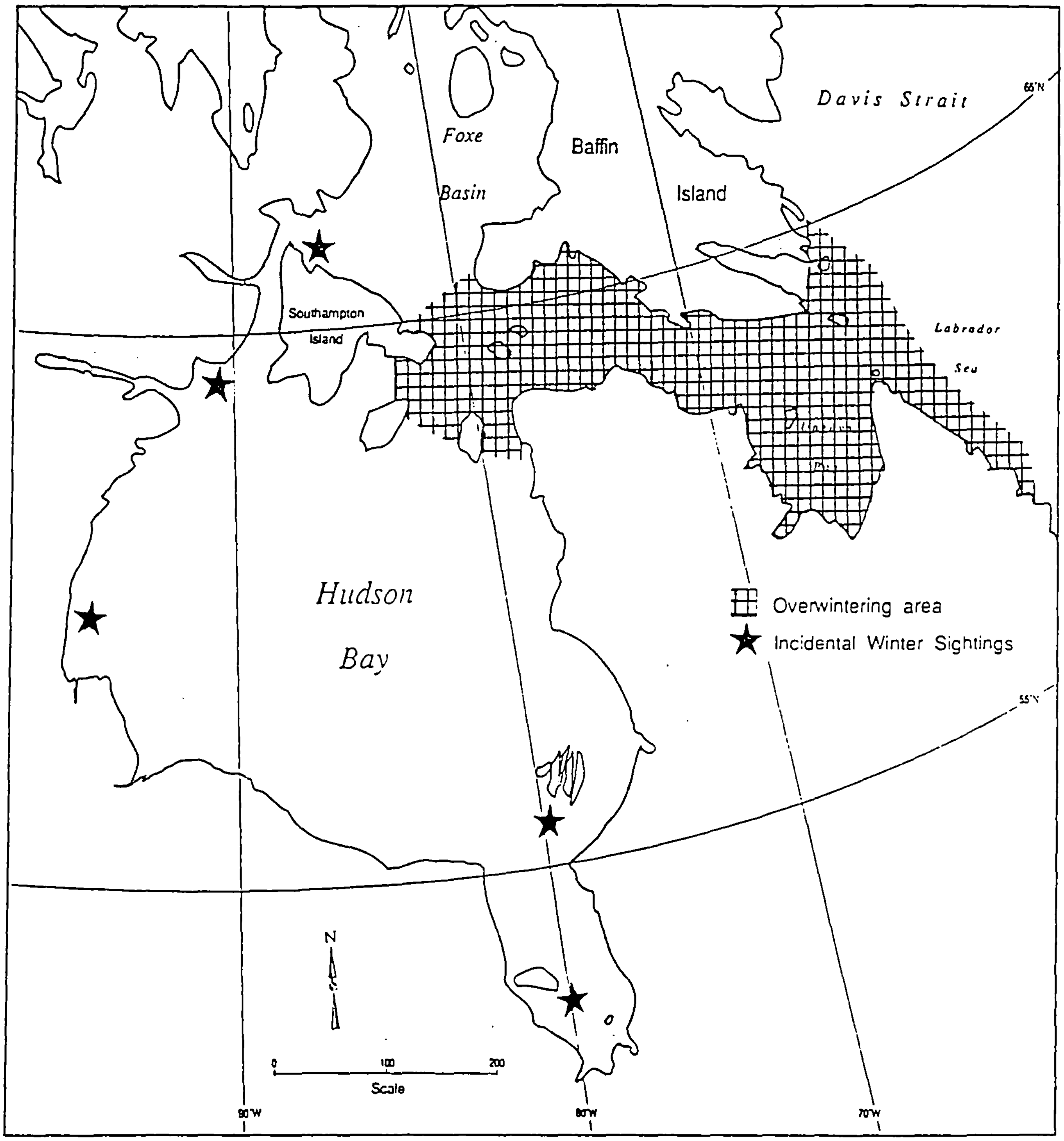


Figure 17. Beluga stocks in the Hudson Bay region during the winter (Baker et al. 1992).